Vol. No. 8 : March 2014

ISSN : 0976-4070

Visfotak®

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

1860s

A North American Company, the "Nitroglycerine Company of New York" adapted a rather gruesome trade mark to warn their clients of the necessity of manipulating their products with care. During the years 1865-1870, nitroglycerine was used as such, being directly poured into bore holes. When frozen, it was thawed by placing its container in hot water. Nitroglycerine was transported on land or sea in drums or bottles, preferably in the solid state.

2010s

UN classification and labeling of 'Explosive substances' September, 2007 :

A substance which is capable by chemical reaction in itself of producing gas at such a temperature, pressure and such a speed as could cause damage to surroundings or which is designed to produce an effect by heat, light, sound, gas or smoke or a combination of these as a result of non-detonative self-sustaining exothermic chemical reaction.

Cover Feature : History of Accidents with Industrial Explosives and the Technology-Safety Conundrum (1880-2010)

The two labels above dramatically illustrate the long journey of the explosives industry since the advent of Nitroglycerine, from the 'Gruesome' to the 'Mundane', as it were; a fascinating narrative of the growth and sustainability of the industry over the past 150 years or so.

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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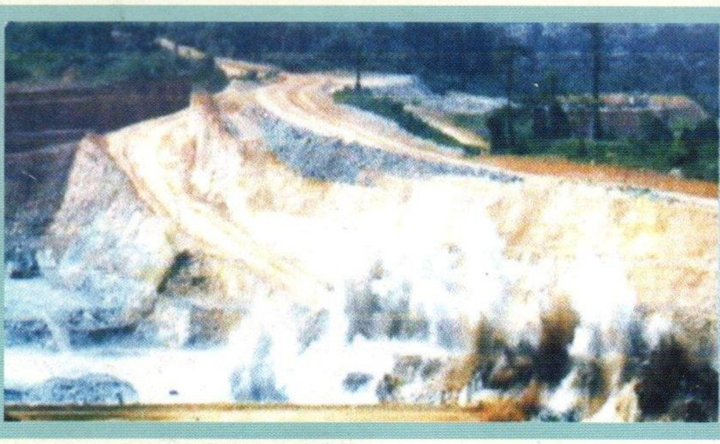

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Editorial...

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

"The basic principle of safety is that there is no unavoidable accident. The accident which we qualify as unforeseeable is only such because of our ignorance or of the limitation of our analytical faculties": quotation from 'History of Accidents with Industrial Explosives', authored by Dr. G.S. Baisutt, which inspired the theme of the cover feature.

And paraphrasing the said principle, there was the time in the 1860s when Nitroglycerine was deemed to be the safest explosive; Nobel himself declared that his explosive oil was an absolutely safe product which could only be detonated by a very hard blow; and then there was the time in the 1920s/1930s when ammonium nitrate was deemed an inert substance until the disaster in Texas city in 1947; and coming to the modern era, not withstanding the unprecedented advances in technology, the conundrum endures?

The thematic burden of the cover feature, therefore, is not so much in terms of the cold statistics of accidents, but in what is not explicated, viz, man's inventive genius to persevere and sustain against grave risks that are uniquely associated with the explosives industry! And there in is the crux?

It is well established that for every serious accident there are many a 'near incident' which are prevented from becoming 'accidents' due to factors of Innovation, Experience and Performance, which collectively lie at the heart of the conundrum. Unfortunately, such near incidents are never brought to the public domain. There is, in fact, a deep seated reluctance amongst the constituents of the industry, to voluntarily share information on such incidents, to mutually learn and innovate safer and more efficient manufacturing practices. Clearly, the industry at large is the loser!

It is suggested, in the interest of promoting ever greater degree of 'Sustainability' of the industry, that an appropriate regulatory mechanism is created by the Department of Explosives, to build a body of knowledge on 'near-incidents', which are then disseminated by advisory circulars duly mandated for compliance.

There is yet another aspect requiring urgent attention, which is that though the industry in recent years, has more or less achieved almost near 'zero-accident' sustainability with high blasting explosives, that goal is still quite distant with regard to the blasting accessories; and more so if the relatively larger number of incidents/accidents with blasting accessories occurring beyond the manufacturing premises, during storage, transportation and handling in use, are factored into the equation. This aspect was discussed in great detail in the 'cover feature' of the 7th edition of the Journal published in March,2013. It was then suggested that a separate regulatory frame work exclusively dedicated to manufacture, storage, transport and handling of blasting accessories, should be devised under the existing statute, for achieving maximum all round safety with blasting accessories.

Ardaman Singh

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COVER FEATURE

History of Accidents with Explosives and the Technology-Safety Conundrum (1880 - 2010)

1.0 Prologue :

The theme of the cover feature is inspired by the book - Histoire des Accidents dans l'Industrie des Explosifs (History of Accidents with Industrial Explosives), authored by Dr.GS Biasutti, edited by Mario Biazzi , with a broad historical sweep from 1769 until 1980, first printed in 1978 and subsequently revised in 1985; perhaps the only such comprehensive manual on the subject, an excerpt from the 'Introduction Chapter' providing its distinctive flavor, is annexed (Annexure-I).

The book only deals with 'Accidents' that occurred during 'Manufacture & Handling' of explosives , both civil and military including pyrotechnics. In the words of the author :-

"In order to limit the very ample field of my survey and to make it more consistent with the objective I have proposed, that is , to increase the safety of manufacture, I have deliberately omitted the description of explosions that occurred during storage, transport, or utilization of explosives, with the exception of a few particularly interesting cases."

"The determination, the classification and the analysis of the causes of explosions would certainly have considerable scientific interest and would be evidently useful judging by the fact that the safety of manufacture and handling would greatly increase if the recurrence of accidents similar to those which have already occurred could be avoided. As a matter of fact, all the development of the means of protection is based on the experience gained from past accidents; Therefore, I believe that it could be beneficial to have the facts issued from explosions gathered in a manual, with the description as far as possible, of their causes ."

Unfortunately, post 1980, there aren't any other known similar 'Follow Up' publications; though, of course, there are many disparate publications which deal with industrial accidents, per se, but none exclusively devoted to industrial explosives. This 'Cover feature' attempts to fill this gap.

1.1 The historical data on accidents relevant to civil industrial explosives from 1860 to 1980, culled from Dr. Biasutti's book, has been supplemented with data covering the post-1980 period until 2010, collated from various reliable sources, notably the 'data base' of Safex International. The entire historical data is put together in Annexure II

Interestingly, the chronology of accidents also provides an interesting insight into the expansion of the high explosives industry globally, over time, to various countries, which is separately illustrated on a world map as part of Annexure II .

1.2 It does not claim to be a complete account of all the incidents and accidents that occurred during the period under reference; but nevertheless, representative enough to provide a very reliable basis to adequately address the theme of the 'cover feature' , viz , the evolutionary history of 'technology-safety conundrum ' uniquely associated with the development and growth of the explosives industry since the advent of Nitroglycerine (NG) in 1864.

2.0 Discussion :

2.1 'Technology-Safety Conundrum : Innovation-Experience-Performance

The history of accidents over the past 150 years or so, is a fascinating narrative, often times contending with unforeseen tragic events, there from learning and evolving and resolutely sustaining the growth of the explosives industry

Clearly, the 'technology-safety conundrum' is about 'Sustainability' to deliver 'Economic Value with Safety' !

2.2 Sustainability

Whilst the focus here is on 'explosives technology', it needs to be emphasized that it is but one amongst many other integral components making up the 'value chain' sustaining the industry at any given juncture. See Box-1.

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

Box-II

Sustainability : Innovation - Experience - Performance

"How can we ensure zero workplace injuries and accidents? How can we achieve zero lives lost? How can we protect those who protect us? How can we achieve zero emissions and zero environmental impact?"

1.0 Micro Perspective : Manufacturing

"The basic principle of safety is that there is no unavoidable accident. The accident which we qualify as unforeseeable is only such because of our ignorance or of the limitation of our analytical faculties. It is perfectly normal for an explosives plant not to have an accident during a 50 years period."

"Every general study on safety can be divided into two parts: a study of the prevention that leads to find the causes of the accidents, and a study of the magnitude of damage, that leads to the investigation of the effects of the accidents and to what can reduce their severity. In other words, supposing that a certain type of accident is possible, the question will be of finding the way of avoiding it; considering further that it is often impossible to entirely preclude the chance of the event, the efforts will be directed toward the minimization of the consequences to personnel and the installation should an accident occur. Personal security partly depends on the mental attitude and the common sense of individuals, not just occasionally but continuously, as an integral part of the daily activity. Foremen are responsible for the safety of the personnel under their supervision. Employees must scrupulously comply with the instructions they have received. The manager must check for correct application of the regulations. Each individual, including the members of the managing staff, is personally responsible for the safety of his subordinates. Each one must promote safety both by persuasion and by authority. Orders must be clear and correct, without any essential omissions. All risks of the operation must be known and understood. The personnel must be acquainted with the nature of his work as well as with the properties or the products they handle," : Dr.GSBiasutti

2.0 Macro Perspective : Sustainability Strategy

2.1 The Americal Institute of Chemical Engineers (AIChE) Institute for Sustainability

a) Sustainability Index :

The Institute through its Advisory Council composed of industry executives, academics and government and NGO leaders, *is* well positioned to establish a baseline definition of what Sustainability entails, as well as to establish a Body of Knowledge (BOK) in the field of sustainability. The body of knowledge at the heart of the new sustainability credential is based on AIChE's Sustainability Index. The Sustainability Index focuses on seven areas critical to a world class sustainability effort : Strategic Commitment, Innovation, Environmental Performance, Safety Performance, Product Stewardship, Social Responsibility and Value Chain Management. AIChE has a programme that offers engineers and other professionals a specialized credentials in 'Sustainability'.

b) In the words of Deborah Grebbe, Member, Advisory Council of the Institute :

"Consider safety, particularly human safety, as the ultimate form of sustainability. If you are seeing sustainability as the protection of the environment, the only reason you would have asked. "Why do we need to have continued innovation? Why do we need to have good stewardship? Why do we need enlightened leadership? It's so the human race can continue to survive, to flourish. And one way to do that is to assure that the human race is as safe and sustainable as possible."

"The more enlightened management teams understand that healthy investments in safety and sustainability projects actually lead to higher returns and better returns, so it's not a necessary evil - it's an investment. A number of years ago, DuPont did a study that found that for every dollar they invested in safety, they received between $2 to $4 in return."

An effective health and safety program reflects the company's sustainability strategy. "If the company is thinking correctly about its overall sustainability strategy, it will see the linkage itself," she explained. "In order to have good sustainability, it's more than just good environmental performance. It's more than just a robust supply chain that has minimal waste. It's more than just innovation. How does one become innovative? How does one have productive employees to do this? They have to have employees who are safe because if employees believe they're not in a safe environment or that management doesn't care, they're not going to be able to do their best work, which means they're not going to be innovative, they're not going to be able to worry about the small things that makes good performance outstanding performance.

"The difference between good and great is the fine tuning that's required. The good companies and the great companies are doing the same activities; the great companies are doing the same activities at a much finer level of detail. And the way you get people to focus on all of that detail, like the Subaru example, is to give the employees the freedom and the ability to address them and support them. That includes making sure that employees are safe and they don't have concerns with being hurt, both emotionally and physically at work,": Deborah Grebbe,Member, Advisory Council of the Institute.

2.2 Safety Culture

(Extract from Health and Safety Briefings, No.07, Dec,2006, Health and Safety Policy Advisory Group. The Institution of Engineering and Technology, UK)

"The immediate causes of accidents are often identified as human error or technical failure but the investigation and analysis of the circumstances surrounding major accidents have revealed issues beyond the immediate causes. These causes relate to wider considerations of the organization as a whole.

"It has become clear that basic faults in organizational structure, climate and procedures may predispose an organization to an accident. This background environment is being increasingly described in terms of safety culture where culture comprises the attitudes, beliefs and behaviors that are generally shared within the organization."

"The term 'Safety Culture' was first introduced by the International Nuclear Safety Advisory Group(INSAG) following the Chernobil accident. Various definitions have been used for safety culture but it perhaps most succinctly expressed by CBI as ***"the way we do things around here"***.

"The safety culture of an oraganisation is the product of the individual and group values, attitudes, competencies and patterns of behavior that determine the commitment to, and the style and proficiency of, an organisation's health and safety programmes. Organisations with a positive safety culture are characterized by communications founded on mutual trust, by shared perceptions of importance of safety, and by confidence in the efficacy of preventative measures'." All organistions should note that a poor safety culture can prove very costly.

2.3 Sustainability Quotient (SQ)

Based on the history of accidents, the statistical measure of 'Sustainability' of a product system or a group of product systems, at any juncture or period of time, is a derivative of the safety performance of the prevailing 'technology - product(s) - demand' regime, expressible as Sustainability Quotient (SQ), vide the following equation :-

$$\text{Sustainability Quotient (SQ)} = \frac{\text{Period, say, 10 yrs}}{\text{No. of accidents}} \times \text{Incremental Index of demand (Base 1880)} \times 100$$

Greater the SQ, more sustainable is the scheme of things under reference.

2.4 Historical SQ Profile of the explosives industry: 1880- 2010

The relevant data developed for the purpose is given in Table 1 which is also graphically illustrated in Figure 1. The data on global demand for high explosives has been largely derived keeping in perspective the growth of the US market as well as the history of materials/resource use in world economy during the period under reference, for which reliable published data is available. Unfortunately, similar demand estimate for blasting accessories couldn't be done for lack of adequate published data.

Table 1 - Historical Profile of the Explosives Industry : Demand, Technology and Safety (1880-2010)

Item	1880	1890	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000	2010
1.0 High Explosives (HEs)	**220**	**220**	**230**	**230**	**280**	**230**	**230**	**400**	**570**	**1140**	**1800**	**2200**	**2600**	**3200**
1.1 US Market														
Quantity ('000t)	50	90	130	150	220	200	200	360	540	1140	1800	2200	2600	3200
Estimated Share of Global Market (%)	90	90	80	75	75	75	75	70	50	50	50	30	30	30
1.2 Global Market ('000t)	55	70	160	200	290	300	300	520	1100	2500	3600	6700	8700	10300
1.3 Global Market by Technology														
a) NG :														
Share(%)	00	100	100	100	100	100	100	100	80	40	10	3	2	1
Qty. ('000t)	55	70	160	200	290	300	300	520	880	1000	360	200	170	100
b) ANFO														
Share(%)	-	-	-	-	-	-	-	-	20	60	60	55	50	50
Qty. ('000t)	-	-	-	-	-	-	-	-	220	1500	2160	3680	4350	5000
c) AN Based Blasting Agents														
Share(%)	-	-	-	-	-	-	-	-	-	-	30	42	48	49
Qty. ('000t)	-	-	-	-	-	-	-	-	-	-	1080	2800	4200	5000
1.4 Accidents with HEs during Manufacture and Handling (Nos.)	-	**81-90**	**91-00**	**01-10**	**11-20**	**21-30**	**31-40**	**41-50**	**51-60**	**61-70**	**71-80**	**81-90**	**91-00**	**01-10**
NG	-	6	15	44	25	31	28	19	47	46	40	-	1	1
AN		-	-	-	-	2	1	2	3	2	-	-	-	1
ANFO	-	-	-	-	-	-	-	-	1	1	-	-	-	-
Slurry	-	-	-	-	-	-	-	-	-	-	5	1	3	-
Emulsions Including bulk	-	-	-	-	-	-	-	-	-	-	2	7	14	18
Total	-	6	15	44	25	33	29	21	51	49	47	8	18	20
1.5 SQ Profile														
All HEs	-	100	120	70	160	160	180	350	260	612	1060	10400	7130	7920
NG Expl.	-	100	120	70	160	160	180	350	230	350	300	?	3000	2100
2.0 Blasting Accessories (BAs)														
2.1 Accidents during Manufacture and Handling (Nos.)														
Detonators	-	-	-	-	-	3	5	2	3	11	15	18	13	33
PETN	-	-	-	-	-	-	1	-	-	3	3	-	1	1
Det. Fuses		-	-	-	-	-	-	-	-	3	4	5	1	1
Cast Boosters	-	-	-	-	-	-	-	-	1	-	2	2	1	-
Total	-	-	-	-	-	3	6	2	4	17	24	25	16	35
2.2 SQ Profile	The profile could not be assessed for want of reliable global data.													

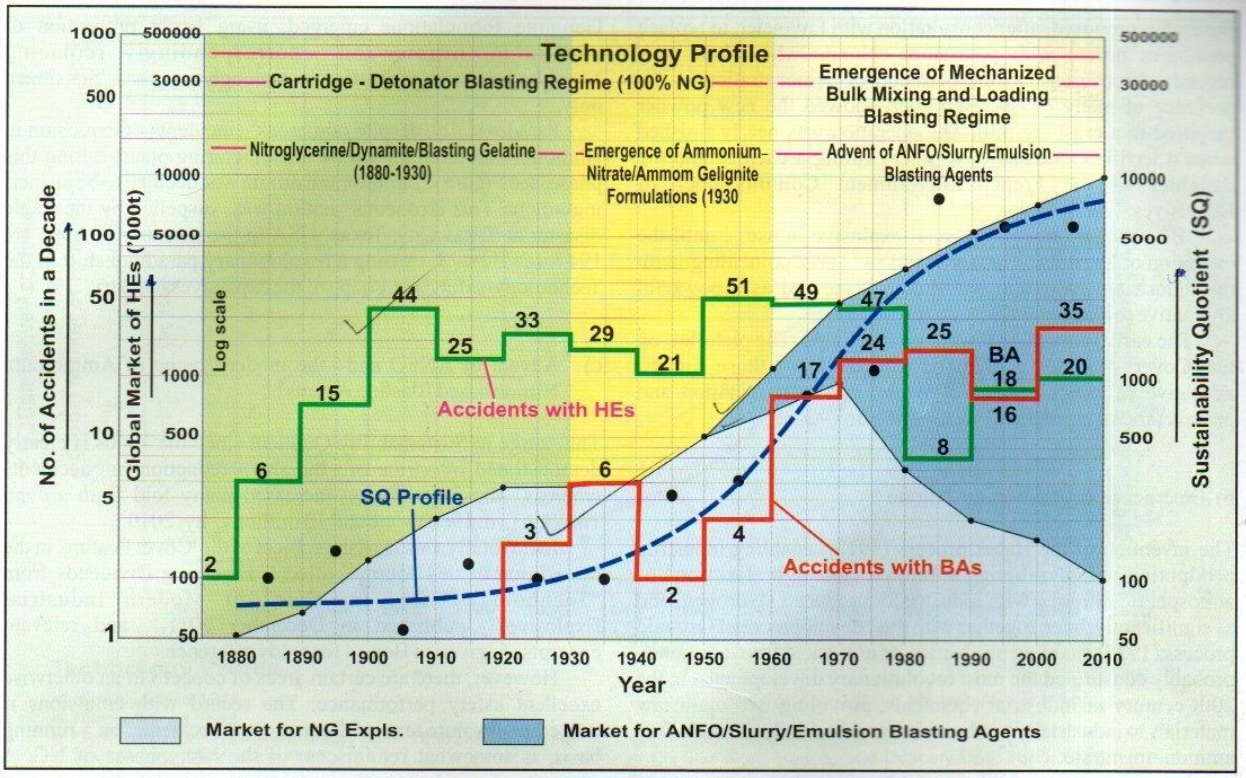


Figure 1 - Graphical Presentation of Data inTable 1

The distinctive evolutionary phases, indicative of the paradigm shifts, each shift exponentially propelling the sustainability quotient are highlighted in Table 2, and briefly discussed in the following paragraph.

Table 2 - Technology vs Sustainability Quotient (SQ)

Sr. No.	Technology Phase/Period	Index of cumulative production of HE	No. of Accidents	SQ
1.	Nitroglycerine/ Dynamite/Blasting Gelatin (1880-1930)	x	123	100
2.	Emergence of Ammonium Nitrate/Ammon Gelignite formulations (1930-1960)	3x	195	450
3.	Advent of ANFO/ Slurry/Emulsion blasting agents (1960-2010)	10x	49	8000

2.4.1 High Explosives (HEs)

The history of accidents with the various product technologies, emerging over time and correspondingly influencing the sustainability of the industry, are separately illustrated in Figure 2.

a) The Nitroglycerine Phase : 1860 - 1980

A brief recap of the recorded history of commercial explosives is in order which goes back to 1650 when the very old black powder (BP) technology of China, used until then for military purposes, was adapted for mining in Hungary and England.

(Interestingly ancient India was the original home of black powder, familiar with pyrotechnic mixtures of metal powders (Kumbhi, Lead, Zinc,etc) and charcoal, used in fire arms. Reference of "Agneya-Astra", and "Cannon" are found in the epics of "Ramayana" and "Mahabharata").

The first recorded serious explosion with BP during manufacture was recorded in Brescia, Italy, in 1769, involving close to 85 tons of powder which exploded for unknown reasons, and its destructive effect was extraordinary - 190 houses were razed to the ground within a radius of 600 ft.

Another incident of an explosion involving newer BP formulations occurred in 1788 when "the renowned chemist

Bertholett proposed, after consultation with Lavoisier, to replace potassium nitrate with potassium chlorate which had been recently discovered. On the occasion of demonstration in the presence of many guests, Bertholett showed the new powder prepared in a crushing mill. The operation was nearly finished when a terrific explosion took place, killing a chemist and the daughter of the French Government Commissioner of Explosives."

BP was the only commercial explosive in use , until the invention of Nitroglycerine (NG) in 1847 ; and coinciding with the industrial revolution, NG quickly emerged as a powerful alternative to black powder.

The early years of NG were no less tragic. The pictorial on the 'Cover' provides a dramatic illustration of those times , evocative of man's inventive genius, grit, determination and perseverance against heavy odds ! See Box - 2 .

b) Emergence of Ammonium Nitrate :

The invention of the Haber process (1913). enabling industrial production of synthetic ammonia through fixation of atmospheric nitrogen with industrially produced Hydrogen, and as significantly, later, together with the development of Ostwald process (1925) enabling production of nitric acid from ammonia, probably constituted the most revolutionary developments in the 20th century in industrial chemicals, providing two main raw materials to industrially produce nitrogenous fertilizers including ammonium nitrate.

Inevitably, with easy availability of ammonium nitrate in commercial scale, it duly found application in Blasting Gelatine formulations and, in due course, a new range of Ammon Gelignite formulations emerged, using larger proportion of ammonium nitrate and correspondingly replacing Nitroglycerine to a proportion just enough to act as a 'Sensitizer' only.

Paradoxically, despite numerous incidents of explosion in ammonia / ammonium nitrate manufacturing plants during this phase, see Figure 2, ammonium nitrate was deemed to be an inert ingradient, This erroneous notion was dispelled by the tragic disaster at Texas City, Texas, USA in the morning of April 16, 1947, see Box - 3, causing a revolutionary paradigm shift in the 'technology-safety' landscape of the explosives industry.

c) Advent of ANFO and the modern range of Ammonium Nitrate based Blasting Agents :

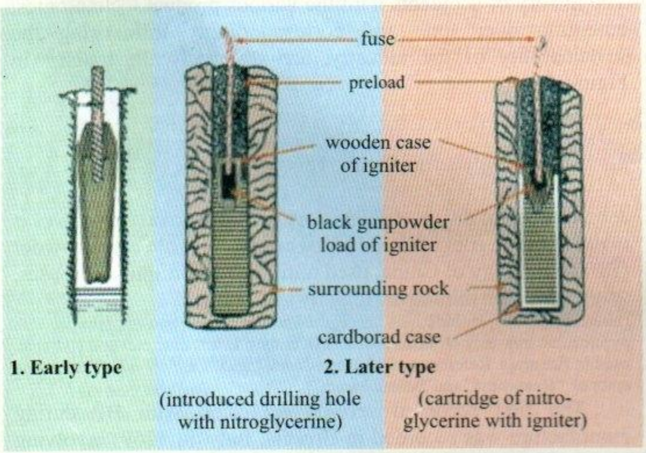
The surge in Sustainability Quotient since the 1960s is clearly demonstrated by virtue of the sharp reduction in accidents whereas the consumption increased many fold from around 1million t, in 1960 to around 10 million t, by 2010.

Incidentally, this was the subject of the 'Cover Feature' in the 6th edition of this Journal, titled :- Emerging Dividends from "Technology-Safety Interface" of Modern Industrial Explosives", published in December 2011, and relevant excerpts are given in Box - 4 for ready reference.

However, there are certain areas of concern in an otherwise excellent safety performance. The record with emulsions if judged in absolute term of frequency of accidents, on a running basis, is somewhat reminiscent of the later phases of NG. A .majority of accidents with emulsions occurred during pumping operations, which, if given appropriate preventive measures, were perhaps avoidable ?

Box-2

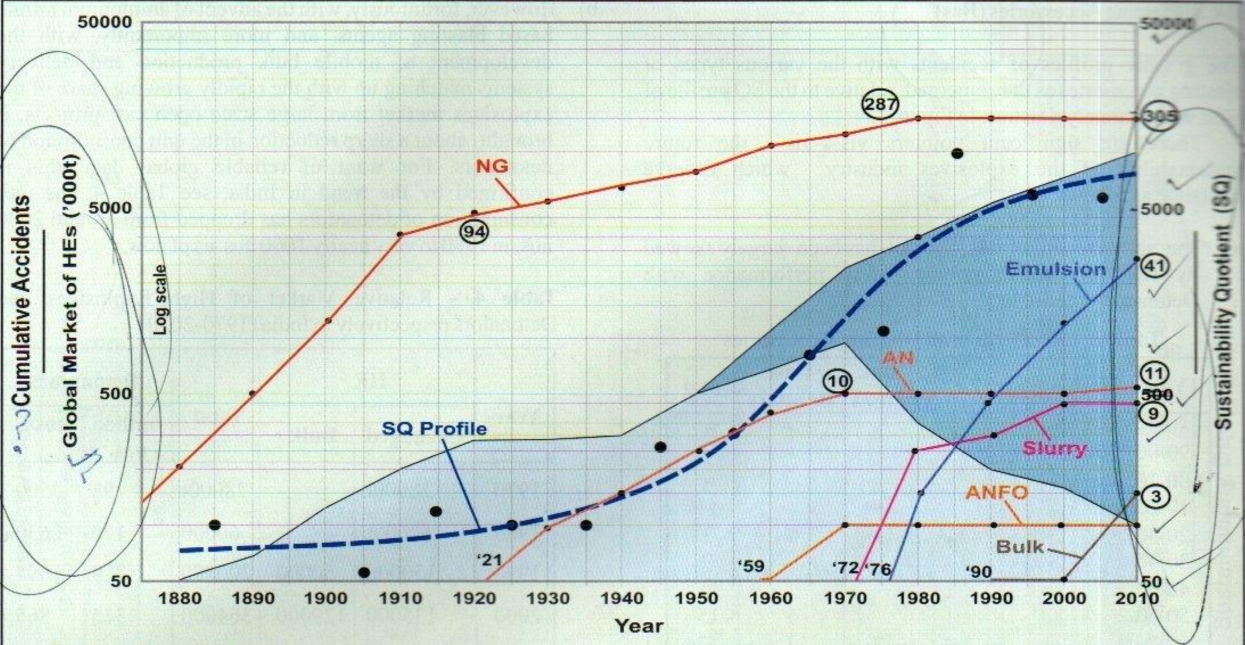
Nitroglycerine and Dynamite



Nitroglycerine is an explosive liquid which was first made by Ascanio Sobrero in 1846 by treating glycerol with a mixture of nitric and sulphuric acid. The reaction which follows is highly exothermic, i.e. it generates heat and will result in an explosion of nitroglycerine, unless the mixture is cooled while the reaction is taking place. Liquid nitroglycerine is colorless if pure. It is soluble in alcohols but insoluble in water. Nitroglycerine is extremely sensitive to shock and in the early days, when impure nitroglycerine was used, it was very difficult to predict under which conditions nitroglycerine would explode. Alfred Nobel studied these problems in detail, and was the first to produce nitroglycerine on an industrial scale. His first major invention was a blasting cap (igniter), a wooden plug filled with black gunpowder, which could be detonated by lighting a fuse. This in turn, caused an explosion of the surrounding nitroglycerine.

Alfred Nobel worked hard to improve nitroglycerine as an explosive that could be used in blasting rock and in mining. He made one of his most important discoveries when he found that by mixing nitroglycerine, an oily fluid, with kieselguhr, the mixture could be turned into a paste. This material could be kneaded and shaped into rods suitable for insertion into drilling holes. He called his paste dynamite and went on to develop a blasting cap which could be used to detonate dynamite under controlled conditions.

The very first recorded accident in connection with the manufacture of Nitroglycerine occurred in Heleneborg, Sweden, 3 Sept.,1864, in which Emil Oscar, Alfred Nobel's brother and four other persons were killed. Following this accident, the manufacture of Nitroglycerine was forbidden in Sweden.



Technology Profile

- Nitroglycerine 1845
- Nitrocellulose 1846
- Dynamite and "Ordinary Blasting Cap" 1860s
- Discovery of Detonation 1881
- Blasting Gelatine 1900s
- Emergence of Ammonium Nitrates 1920s
- Ammon Gelignite Formulations 1930s
- Prilled ANFO : Dawn of Bulk Systems,1955
- TNT/ Aluminised Slurries by Cook and Farnam,1960.
- Plant-Mixed and Site Pumped Slurry System, Ireco, 1963 & Non-Aluminised, Fuel Sensitized Slurries, Ireco, 1963.
- Emulsion Explosives, 1969 & Methyle Amine Nitrate slurries, DuPont. 1969.
- Emulsion - ANFO Blends, 1971.
- On-Site Slurry Mixing and Delivery Unit, Ireco, 1972.
- Shock Tube Non-Electric Detonators, 1974
- Computer Modeling of Blast Design, 1977
- Bulk Emulsion Matrix- AN prills. Blends, 1980
- Electronic Delay Detonators, Late 1980s.
- Laser profiling of benches; GPS hole spotting and automated Drilling and other blast relatedservices, Late1990s
- Digital Age of "Virtual Product Delivery and Blasting"; 2000

Market for NG Expls. | Market for ANFO/Slurry/Emulsion Blasting Agents

Figure 2 - High Explosives (HEs)

Box-3

Texas City, Texas, USA in the Morning of April 16, 1947

At 8.00 a.m. loading of a Liberty ship with ammonium nitrate in paper bags had resumed. Ten minutes later, smoke was detected in the hold of the ship. When the bags were moved around, flames appeared. Fire extinguishers and water hydrants were unsuccessful in extinguishing the fire. At 8.20 a.m. order was given to abandon ship. At 9.12 a.m. a frightful explosion occurred, the ship disintegrated and fire was spread to other boats and to buildings ashore

Fifteen hours later, a second ship loaded with nitrate blew up as well. This dreadful catastophey cost the life of 600 persons and caused damage of 60 million dollars. A large polystyrene plant was razed to the ground. Dead birds fell from the sky. People were thrown to the ground in B. Galveston, 10 miles away. The cause of the accident was apparently a cigarette !"

Another accident , shortly after, occurred in Brest, France, on 28July, 1947, following a fire aboard a ship loads with ammonium nitrate fertilizer. 20 people were killed and 250 injured.

The rest is history, heralding the beginning of the end of NG based explosives, forever changing the technology-safety landscape of the explosives industry.

2.4.2 Blasting Accessories (Bas)

The graphic profiles of accidents with the various types of blasting accessories as they emerged, relative to the SQ profile of HEs, are separately illustrate in Figure 3.

There are significant pointers vis-à-vis the future sustainability of the explosives industry which deserve attention, as follows :-

a) The safety record of BAs, over all, has been largely skewed by relatively much poorer safety performance with Detonators, see Table 3.

Table 3 - Accidents with Blasting Accessories

Year	Detonators	PETN	Det. Fuses	Cast Boosters	Total
80-90	-	-	-	-	-
90-00	-	-	-	-	-
00-10	-	-	-	-	-
10-20	-	-	-	-	-
20-30	3	-	-	-	3
30-40	8	1	-	-	9
40-50	10	1	-	-	11
50-60	13	1	-	1	15
60-70	24	4	3	1	32
70-80	39	7	7	3	56
80-90	57	7	12	5	25 81
90-2000	70	8	13	6	16 97
2000-10	103	9	14	6	132 132

b) However, fortuitously, with the advent of ammonium nitrate based blasting agents, and more importantly, with the development of mobile bulk production and delivery systems matching up with the rapidly growing share of the explosives market from large scale open cast projects, it brought about a sharp reduction in the unit consumption of detonators. For want of reliable global data, this is confirmed by the trend in India, see Table 4; the unit consumption of detonators has dropped from around 2600 nos, in 1980 to very nearly 1000 nos. as of now.

Table 4 - Relative Market of High Explosives and Detonators respectively in India (1970-2010)

Year	HE		Total	Detonators	
	Packaged	Bulk		million nos.	nos/t
1970	28000t	-	28000t	98	3500
1980	60000t	-	60000	170	2630
1990	150000	50000	200000	219	1095
2000	135000	129000	364000	315	865
2010	180000	360000	540000	724	1300

Box-4

Excerpts from the Cover Feature Emerging Dividends from "Technology-Safety Interface of Modern Industrial Explosives"

The modern genre of blasting agents represents revolutionary advances in explosives technology and manufacturing from the stand point of the most important aspects of speed of manufacture, safety and economy, as follows :-

4.1 Simplicity and Inherent safety of manufacture, handling and use on account of absence of molecular chemical explosive sensitizing ingredient(s) in the formulations.

4.2 Further, the unique Rheology of these formulations, viz, the flow characteristics of solid and fluid ingredients under applied stresses or strains, has enabled modular designs for bulk production processes and systems in a continuous flow at high speeds, easily adaptable for automation and digital control systems for optimization of processes with complete safety ,including capability to modify formulations; on-line; to match specific requirements. Further, unlike the traditional batch processes, the In-Proces volume of active formulation can be minimized and fully contained, thereby, significantly reducing the extent and severity of collateral damage to life and properties, in the event of an accident during operations.

4.3 Transition to Mobile Production and Delivery Units (MPDUs).

Typically, a MPDU is truck mounted modular configuration of storage and processing equipments, powered through a power-take off mechanism, of capacities ranging from 5-15,carrying ingredients from a base plant close by, and mixing the ingredients including additives such as sensitizers, gassing agents, etc, at site, as per requirements, with The design ensures safety of operation; and the final product(s) is dispensed directly into the blast holes.

The MPDUs, first introduced with ANFO in the 1950s, have lent the following path breaking, dividends :-

Firstly, from the stand point of public safety, by eliminating in one stroke, all the risks and hazards associated with handling, storage and transportation of packaged explosive product from fixed plant sites to various distant destinations by road or otherwise; Secondly, and as significantly, the explosive business is forever unshackled and transformed into an open ended, consumer driven, business model which provides a set of marketable options of Product Systems & Services (PSS) tailored to provide Quality solutions that the Customer Wants (QCW) and Thirdly, the new market dispensation duly led to the development of blast related, 'Value Adding' technologies and systems to further augment the scope of Bulk System.

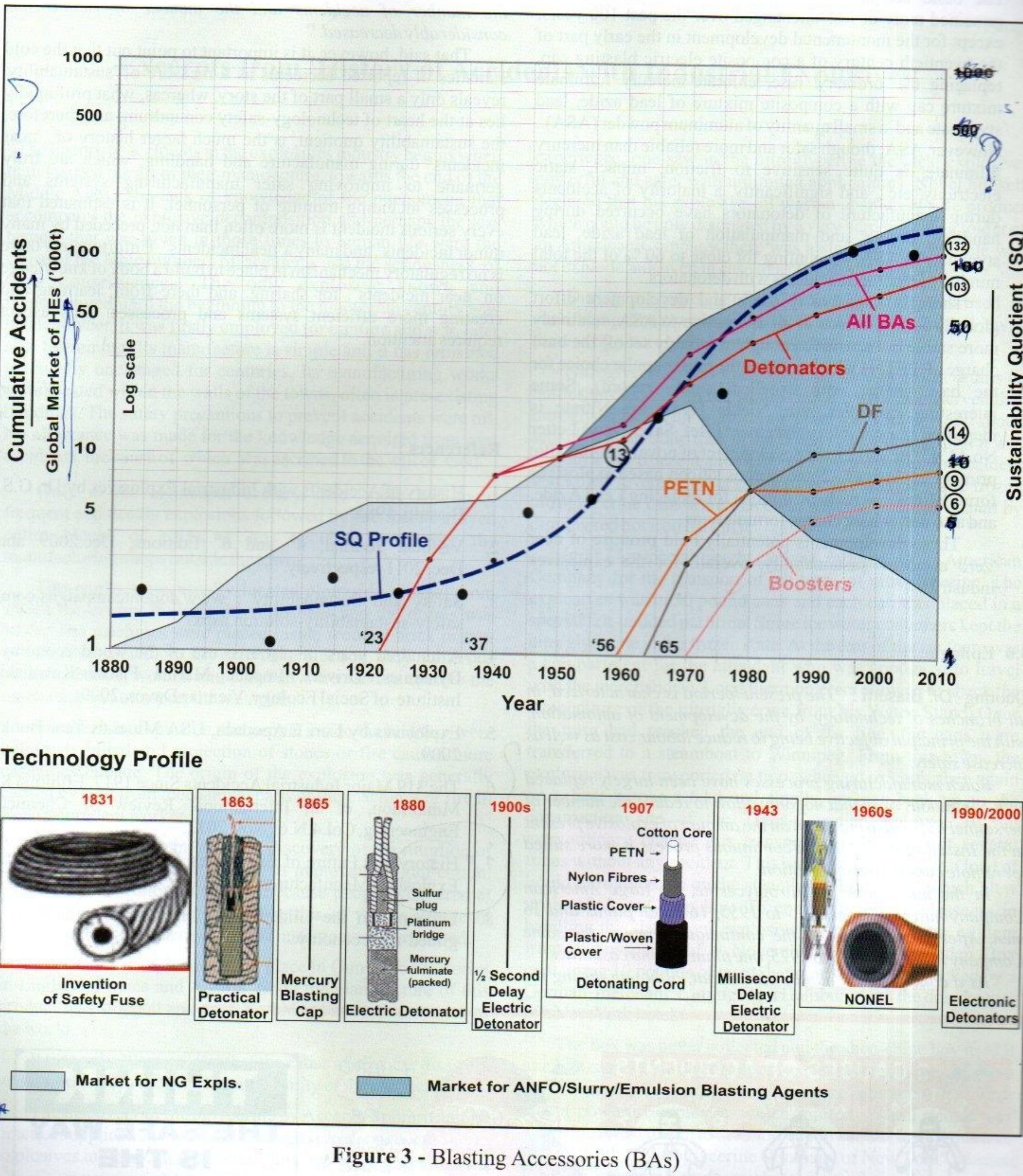


Figure 3 - Blasting Accessories (BAs)

c) The basic design and construction of detonators, have remained more or less unchanged over the past 100 years, except for the monumental development in the early part of the twentieth century of a composite electric blasting cap, replacing the 'ordinary' fuse, chlorate-mercury fulminate mixture cap with a composite mixture of lead azide, lead styphnate and a small quantity of aluminum powder (ASA).. However, ASA, though safer and more reliable than mercury fulminate, is quite sensitive to friction, impact, static electricity, etc , and significantly, a majority of accidents during manufacture of detonators have occurred during handling, drying, and manipulation of lead azide, lead styphnate or ASA, accounting for close to 60 % of the total number of recorded accidents with detonators..

There is intensive research and development effort globally for the search of an alternative to ASA, relatively more stable but sensitive enough to reliably set off the base charge of PETN (which remains the most popular choice for the base charge with excellent safety record). Some interesting examples, viz, Nickle Hydrazine Nitrate is identified as a suitable replacement (Ref. Safex News Letter No.43, 4th Qtr, 2012); the development of novel non-metallic primary explosives - Nano-porous silicon based explosives formulations - as realistic options for replacing Lead Azide, and also newer base charge formulations.

These developments potentially hold promise of near 'zero accident' sustainability, overall, for the explosives industry.

3.0 Epilogue :

Quoting Dr. Biasutti : *"The present 'period is characterized, in all branches of technology, by the development of automation, with the principal objective being to reduce labour cost as well as increase safety.*

Batch manufacturing processes have been largely replaced with continuous ones that not only allow to reduce the number of personnel but to also cut down on the amount of explosive present in the Installation. Further, a continuous process is more suited for remote control and automation.

In the manufactur of nitroglycerine, a large American Company had lost, from 1915 to 1955, 16 batch plants and 16 men, After reconversion to the continuous process, the same Company lost, from 1955 to 1975, one plant with no casualties.

As a conclusion, it can be stated that, although during the last 50 years the production of explosives has increased fivefold, the number of accidents and the number of victims has considerably decreased."

That said, however, it is important to point out that the cold statistics of reported accidents as a measure of 'sustainability' reveals only a small part of the story, whereas, what profoundly lies at the heart of technology-safety conundrum, and therefore, the sustainability quotient, is the much larger history of 'near incidents' during manufacture and handling, which are truly germane to improving safer manufacturing systems and processes including training of personnel. It is estimated that every serious incident is more often than not, preceded by many minor incidents , and many a 'near incidents'. Unfortunately there is no regulatory mechanism in place to build a body of knowledge on 'near incidents', for sharing, and there from, learning and creating more efficient systems and processes. This aspect requires attention.

- Editor

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Annexure - I

Excerpts from 'History of Accidents with Industrial Explosives'

"The history of accidents in the explosives industry begins when man learned the art of their manufacture, towards the end of the Middle Ages. The lack of knowledge of the phenomena that accompany the explosive decomposition and perhaps the less respect that was given in those times to human life were the cause of the large numbers of' accidents and the seriousness, of their consequences. The only explosive known and manufactured until the beginning to the nineteenth century was black powder. It was firstly employed for hunting and war, later also for mining. Its manufacture is simple and it has remained practically unchanged for centuries. Its manufacturing works were located within the walls of the towns, often in pre-existing buildings. The safety precautions to prevent accidents were nil. No allowance was made for the knowledge acquired from past accidents. the cause of which was ascribed to the will of God.

Only in the eighteenth century, after more and more frequent and deadly explosions followed by fire that destroyed entire blocks of cities, it was decided to transfer the manufacturing shops outside the town.

The works were usually located alongside a canal from which the energy to drive the millstones and the drums was taken. The machines were placed inside wooden brick or cut-stone buildings without any external protection. Very numerous personnel, men, women and children were used to operate the machinery and transport the materials.

In case of an explosion, the people inside the building were helplessly killed and projection of stones or fire caused more casualties outside. The origin of the explosion was generally caused by heat from mechanical parts of the machines or fire lit by an imprudent worker.

In 1848, Schonbein, after his discovery of the nitration of cellulose, built his firi-it factory to manufacture gun-cotton. Other factories followed rapidly because people wondered at and admired the prodigious properties of this explosive in which the chemical energy could be instantaneously released. However, several explosions took place in Gun cotton factories in England, France and Austria. Soon the manufacture of this product was stopped and even Forbidden in most countries of the world.

It was only 20 years later that the cause of all these disasters was found to be in the insufficient stability of the product.

The discovery of nitroglycerine by Ascanio Sobrero and its practical application by Allred Nobel marked a new era in the explosives industry. In spite of the' first accidents due to lack of experience, one saw in the nitroglycerine the ideal explosive, powerful and safe, with unlimited applications. Nobel himself declared that his explosive oil was an absolutely safe product which could be only detonated by a very hard blow. In a folder of an American Company there was a statement: "dynamite will not explode, not even in case of a railroad crash or a fire".

During the years 1865-1870 nitroglycerine was used as such, being directly pouted into bore holes. When frozen, it was thawed by placing bits containers in hot water.

Nitroglycerine was transported on land or sea in drums or bottles, preferably in the solid state. It had been observed that nitroglycerine, with a freezing point of 13c, Is less shock sensitive in the solid than in the liquid state. For transport it was customary to freeze it and thaw it on the work site. An accident that killed several workers took place in America while frozen nitroglycerine cans were placed in water which was heated by dipping red hot iron bars in it.

In 1877 a special freight car was ordered by an American Company for the transport of ten tons of nitroglycerine. The explosives was in 50 pound cans and each can was placed in a special felt-padded partition. Some ice water containers kept the nitroglycerine in the frozen state. At the rear of the car there was a compartment for the attendant who was appointed to travel with the merchandise. Long thermometers allowed to check the temperature of the nitroglycerine front his Watch Stand. Once the train had reached the end of the line, the cans were transferred to a steamboat to Winnipeg. From this town, the explosive was transported on two- wheeled ox carts, then again on a boat across a lake and finally on man-back up to the construction site of the Trans-Canadian Railway. By an extraordinary chance this transport was carried out several times without any accident. This was not the case with a load of liquid nitroglycerine on the steamboat "European" which blew up in 1865 in Colon Bay. To emphasize the carelessness in handling this dangerous explosive we wish to quote an item from a newspaper of 6 November 1865, "A wooden Box containing 10 pounds of nitroglycerine had been checked by a German merchant coming from Hamburg with the door keeper of a New York hotel.

The box was never collected and the shoe-shine boy used it as a loot-stand. One day the door-keeper saw red fumes pour out of the box and dragged it out on the street. A moment later there was a powerful explosion which injured several people and caused severe damage to the shop windows." A North American Company, the "Nitroglycerine Company of New York" adapted a rather gruesome trade mark to warn their clients of the necessity of manipulating their products with care (Figure 1).

The years 1870-1880 were the age of glory for nitroglycerine, but also those where the accidents were the most frequent and deadly. Finally one had to bow to the facts that handling nitroglycerine was dangerous; gradually, protective measures were taken.

As a first step, the various stages of manufacture were distributed in separate buildings protected with sand bags or earth mounds provided with lightning rods.

At the end of the nineteenth century a new category of explosives appeared on the scene. Picric acid first and TNT later were employed, on account of their great shattering strength, as a charge for bombs and projectiles.

These products being essentially military explosives, their manufacture was important mostly in war time. During such periods the greatest concern was high production and the manufacture was often carried out in improvised installations with un-experienced personnel who worked under hazardous and uncomfortable conditions.

It is not surprising to learn that, in spite of the lesser sensitivity of TNT compared with nitroglycerine, a great number of catastrophic 'explosions took place during war periods.

Statistics on explosions which occurred in Great Britain during the years of World War 1 is rather convincing on this subject:

Year	Number of casualties in explosions of explosive factories
1915	21
1916	195
1917	54
1918	44

Using the same country as an example, and with the application of the principle of better safety design in plant layout, there are found for the period 1939 through 1945 only 61 casualties caused by accidental explosions in the military explosive manufacturing industry and that with a total production many times greater than in the earlier war.

The present period is characterized, in all branches of technology, by the development of automation, with the principal objective being to reduce labour cost as well as increase safety.

Batch manufacturing processes have been largely replaced with continuous ones that not only allow to reduce the number of personnel but to also cut down on the amount of explosive present in the Installation. Further, a continuous process is more suited for remote control and automation.

In the manufacture of nitroglycerine, a large American Company had lost, from 1915 to 1955, 16 batch plants and 16 men, Alter reconversion to the continuous process, the same Company lost, from 1955 to 1975, one plant with no casualties.

As a conclusion, it can be stated that, although during the last 50 years the production of explosives has increased fivefold, the number of accidents and the number of victims has considerably decreased. The accident which we qualify as unforeseeable is only such because of our ignorance or of the limitations of our analytical faculties. It is perfectly normal for an explosives plant not to have a single accident during a 50 years period.

Every general study on safety can be divided into two parts: a study of the prevention that leads to find the causes of the accidents i.e. study of the magnitude of damage, that leads to the investigation of the effects of the accidents and to what can reduce then severity. In other words, supposing that a certain type of accident is possible, the question will be of finding the way of avoiding it; considering further that it is often impossible to entirely preclude the chance of the event, the efforts will be directed toward the minimization of the consequences to personnel and the installation should an accident occur.

Personal security partly depends on the mental attitude and the common sense of individuals, not just occasionally but continuously, as an integral part of the daily activity.

Foremen are responsible for the safety of the personnel under their supervision. Employees must scrupulously comply with the instructions they have received. The manager must check for correct application of the regulations. Each individual, including the members of the managing staff, is personally responsible for the safety of his subordinates. Each one must promote safety both by persuasion and by authority. Orders must be cleat and correct, without any essential omissions. All risks of the operation must be known and understood. The personnel must be acquainted with the nature of his work as well as with the properties or the products they handle.

I sincerely hope that the lecture of this book will contribute to the increase of safety in the manufacture of explosives and thereby saving of lives".

Annexure - II

History of Accidents (1847-2010)

1) High Explosives (HEs)

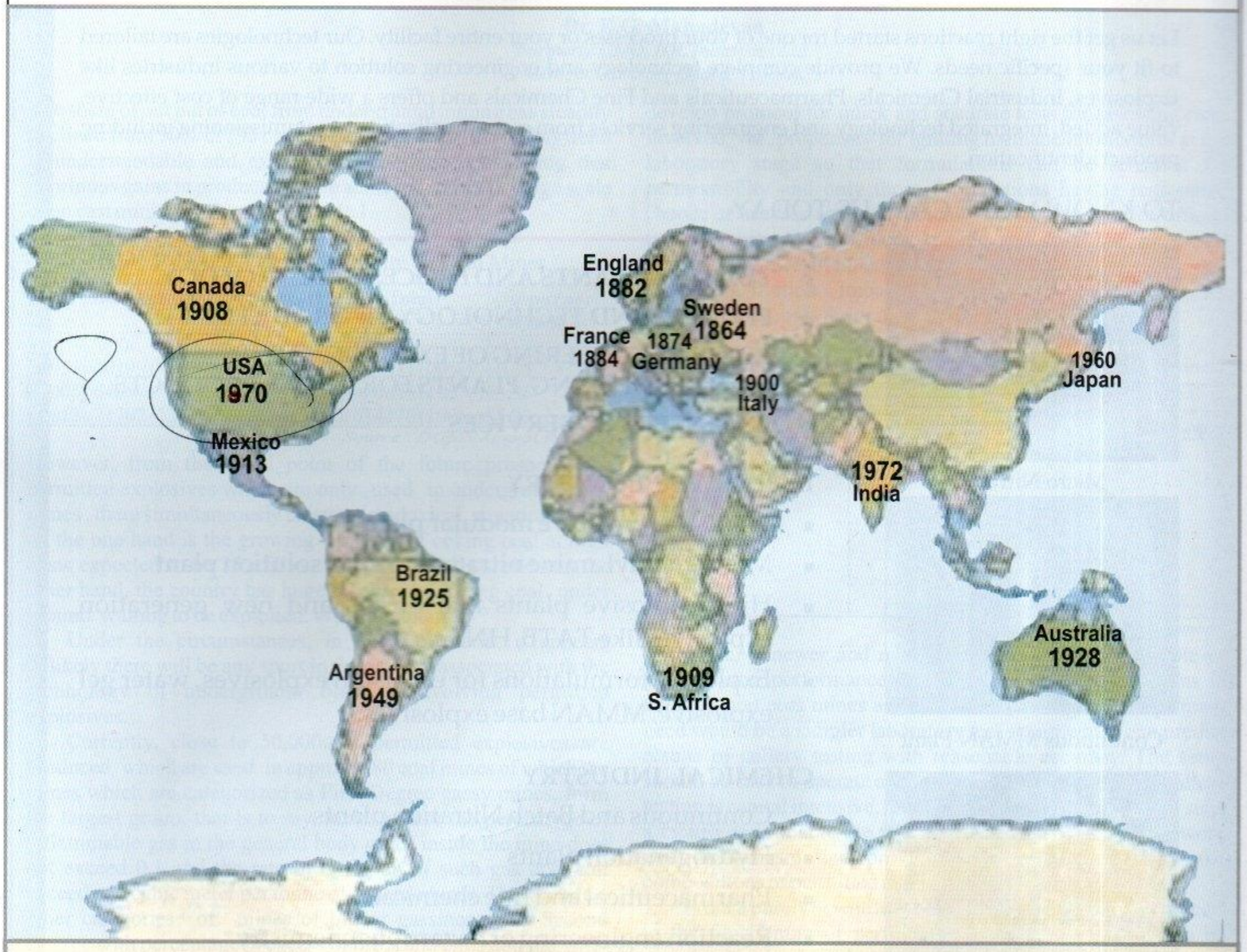
YEAR	Cumulative Number of Accidents with HEs							Remarks (Chronology of Accidents Indicative of the Technology Profile)
	NG	Ammonium Nitrate (AN)	ANFO	Slurry	Emulsion	Bulk	Total	
1860	0	0	0	0	0	0	0	**1847** – First explosion with NC, England **1864** – First Accident with NG, Sweden
1870	2	0	0	0	0	0	2	**1879** – Dynamite, USA
1880	4	0	0	0	0	0	4	**1887** – Picric acid, England
1890	10	0	0	0	0	0	10	
1900	25	0	0	0	0	0	25	**1901** – Hall Packaging Machine, Dynamite, USA **1902** – Gelatin expls. England **1907** – Gelatinization, USA
1910	69	0	0	0	0	0	69	**1911** – Ardeer Mixer, Canada
1920	94	0	0	0	0	0	94	**1921** – Ammonia Plant, Germany **1921** – TNT, Germany **1924** – Amatol, USA
1930	125	2	0	0	0	0	127	**1933** – First accident in continuous NG plant, Schemid Process, Sweden
1940	153	3	0	0	0	0	156	**1940** – Large diameter packing house, USA **1940** – Continuous NG plant, Schemid process, England **1941** – Ammon – Gelignite, S. Africa **1947** – Ammonium Nitrate explosion, Texas City, USA **1947** – Ammonuim Nitrate explosion, Brest, France
1950	172	5	0	0	0	0	177	**1951** – Biazzi Continuous plant, Switzerland **1953** – Continuous Schemid – Meissner NG plant, Sweden **1954** - Continuous Schemid – Meissner NG plant, Sweden **1956** – Automatic cartridging machine, France **1957** – Semi-automatic extruder, wales, England **1957** – Tally Mixer, USA **1959** – An prills + 4% oil + 5% ground out shell, along with 2t dynamite – explosion due to fire USA **1959** – Niepmann automatic cartridging machine, gelatinous explosive, Belgium **1960** – Meisnner continuous plant, Scotland
1960	219	8	1	0	0	0	228	**1961** – ANFO plant, USA **1963** – AN manufacturing plant, Finland **1963** – Biazzi NG plant, Mexico **1965** – DuPont cartridging machine, India **1967** – Drais Gelatin Mixer, Aweden **1967** – Schemid – Meissner Nitration Plant, Sweden **1967** – Meisnner continuous plant, Brazil **1968** – Milling AN, Spain
1970	265	10	2	0	0	0	277	**1972** – Nitric acid sensitized Slurry, India **1973** – Tally mixer, India **1974** – Slurry, Screw Extruder, Norway **1975** – Biazzi NG plant, Romania **1975** – Ethylene Glycol Mono-Nitrate sensitized slurry, Canada **1976** – Slurry (MMAN based), USA
1980	303	10	2	5	2	0	322	**1988** – Emulsion Matrix, China **1990** – Packaging emulsion by Cavity Pump, S. Africa **1990** – Transferring emulsion from one truck to another, Canada
1990	303	10	2	6	9	1	331	**1992** – Emulsion, Mono pump used in reverse, Australia **1998** – Bulk pumping of emulsion, Costa Ricas
2000	304	10	2	9	23	1	349	**2003** – Packaged emulsion building, Brazil **2009** – Bulk Emulsion Plant, India
2010	305	11	2	9	41	3	371	

Annexure - II

2) Initiating Explosives

Year	Cumulative Number of Accidents with HEs				Total	Remarks (Chronology of Accidents Indicative of the Technology Profile)
	PETN	Detonators	Cast Boosters	Detonating Fuses (DF)		
1860	-	-	-	-	0	-
1870	0	0	0	0	0	-
1880					0	-
1890	0	0	0	0	0	-
1900	0	0	0	0	0	-
1910	0	0	0	0	0	-
1920	0	0	0	0	0	**1923** – Mercury Fulminate drying unit, S. Africa **1927** – Drying Lead Trinitroresorcinate, England **1930** – Safety Fuse Factory, Czechoslovakia
1930	0	3	0	0	3	**1935** – Detonator plant, Italy **1936** – Filling blasting caps, England **1937** – PETN plant, Germany
1940	1	8	0	0	9	-
1950	1	10	0	0	11	**1958** – Pentolite, England **1958** – Lead Styphnate, Belgium
1960	1	13	1	0	15	**1962** – ASA batch, England **1964** – PETN drying, France **1964** – Detonator Fuse Plant – PETN feeding, USA **1966** – Lead Azide, Sweden
1970	4	24	1	3	32	**1971** – ASA mixture explosion, India **1975** – Lead Azide loading machine, Ardeer, England **1975** – Detonator fuse spinning, USA **1979** – PETN Continuous Plant, India
1980	7	39	3	7	56	**1981** – Remote Control Weighing of Lead Styphnate **1982** – Inserting Delay Elements by pneumatic pressure, S. Africa **1986** – Automatic Press for detonators, Brazil
1990	7	57	5	12	81	-
2000	8	70	6	13	97	**2002** – Remote controlled Detonators Plant, Japan **2006** – Electronic Det. Plant, S. Africa
2010	9	103	6	14	132	-

Annexure - II



Globalization of High Explosives Industry
(Based on the Year of First Accident with High Explosive during Manufacture and Handling)

(Note: the year under USA was wrongly typed as 1970 in the printed version which is regretted. Edit)

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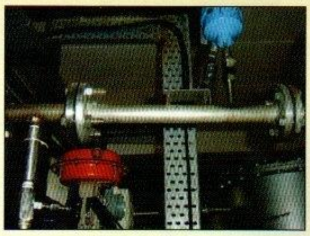
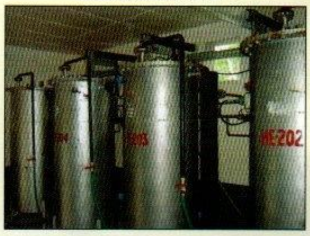
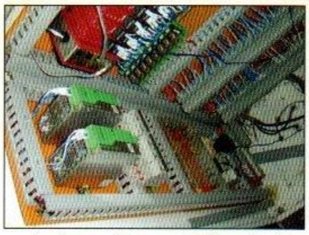


Micro Nitrator



Continuous MMAN Plant

Hydrogenation Module



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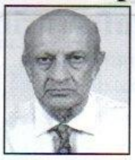
Status of Permitted Explosives in India



Dr. E.G. Mahadevan
Formerly CMD, IDL Industries Ltd.
Member, Advisory Board, Visfotak.

The share of out put of coal from underground mining has steadily declined from 90% in 1951 to close to 10% in 2010-11. This trend is understandable and expected to continue considering that enormous gains in productivity are achieved through large scale open cast mining projects . See Table 1.

Table 1 - Output and Productivity in Coal Mines

Year	Belowground	Opencast	Total	Output per Man shift
	'000t	'000t	'000t	t
1951	30199 (86%)	4784 (14%)	34983 (100%)	0.35
2005	64087 (15%)	356758 (85%)	420845 (100%)	3.35
2011	71702 (12%)	542474 (88%)	614176 (100%)	5.23

Source : DGMS Annual Report

However, from the stand point of the future prospects for permitted explosives which are only used in underground coal mines , there simultaneously exists a paradoxical situation where on the one hand is the growing imports of coking coal at high costs expected to be 35 million tonnes in 2013-14, and on the other hand, the country has huge reserves of coking coal under ground waiting to be exploited. Why this anomaly ?

Under the circumstances, in the short term, it appears unlikely there will be any spurt in the activity associated with the technology of underground blasting involving permitted explosives.

Currently, close to 50,000t of permitted explosives are produced which are used in approx. 380 coal mines of which the mines which are categorized as First Degree gassy mines, form the largest group, that is to say, mines where the percentage of inflammable gas in the general body of air inside the mine does not exceed 0.1 and the rate of emission of such gas does not exceed one cubic meter per tonne of coal produces. There are two other categories of mines of higher gassiness, viz, Second Degree with percentage in excess of 0.1% and emission rate of 1-10 cubic meter, and Third Degree with rate of emission in excess of 10 cubic meter per tonne of coal produced, respectively. The distribution of mines under these categories is shown in Table 2.

There may well exist scope for designing stronger but safer permissible explosives for First Degree mines. However, establishing stronger and yet safer permitted explosives needs extensive product development and frequent testing. Both involve considerable financial expenditure and in turn has to be justifiable and sustainable by market economics. Even assuming the latter is favorable and the market is ready to absorb newer and better blasting systems for underground mining, the requisite research and development may be greatly hampered by the present extremely cumbersome, costly and time consuming official test procedures. There is therefore, the need, firstly to develop protocol for quick and accurate tests for assessing risks involved, viz , propensity for igniting methane/air mixtures at the laboratory stage so that formulations can be screened for permissibility and only those formulations having reasonable chance of success and economically viable, are sent for official tests. In this way considerable time and costs can be saved. Merely the measurement of strength, VOD, COD, air gap sensitivity, friction / impact sensitivity, prior to submission for gallery testing, as is the practice now, will not suffice.

Table 2-Number of Underground Mines and Degree of Gassiness

Degree of gassiness	Number of mines	
	2005	2011 estimated and provisional
I only	270	275
II only	102	80
III only	14	7
I & II	7	12
I & III	-	-
II &III	3	2
I, II &III	-	-

Source : DGMS Annual Report

Therefore, if newer and more effective explosives capable of giving better performance without reducing safety margins in underground coal mines are to be discovered, then the primary need would be a simpler laboratory test set up which can predict results of gallery testing with reasonable accuracy. The setup should be easy to operate and less time consuming.(Field gallery testing is capital intensive, requires large free space). Only if such a facility is available the formulation chemists can get to work with enthusiasm and provide many more options in the compositions of permitted explosives.

From a purely scientific point of view there are many aspects in the functioning of permitted explosives which need to be examined in depth for better understanding of the phenomena of ignition of methane/air mixtures by detonating explosives. Role of water, coolants needs to be understood in order to elucidate theory and mechanism of the ability of certain compounds to promote permissibility.

The interest at the current level in the coal mining industry for underground mining is not sufficient to induce vigorous research and development. Unless a clear signal is given from the end user I doubt whether newer types of permitted explosives will find the light of day commercially. In other words the products available in the market are maintaining a degree of safety and performance commensurate with requirements of the end user industry and hence are well entrenched for many years to come although I would like to be proved wrong by the appearance of newer products.

Safety Audit Protocol for Explosives Manufacturing Plants

Rahul Guha
Sr. General Manager (Technical)
Solar Industries India Limited (earlier known as Solar Explosives Ltd.)

1.0 Introduction :

Studies have shown that generally across the industry human error is the cause in nearly 90% of incidents and that 70% of incidents could have been prevented by management action.

A generally accepted principle ,in this respect, is that the primary responsibility for doing something about accidents lies with those who create the risks and those who work with them. Hence there is nothing new in the idea that Safety requires to be managed. It is therefore understood that close attention to management of safety is effective in preventing accidents and that it is compatible with and indeed promotes first rate commercial performance.

Success in managing safety can only be achieved by having a clear corporate commitment, the establishment by positive action of a "safety culture" which percolates through the organisation. It is a matter for leadership, the acceptance of responsibility at the top and exercised through a clear chain of command, seen to be real and felt throughout the organisation.

It is a matter for conviction that high standards are achievable, that set objectives and targets can be met, that hazards can be identified and preventive measures devised ,then audited and reviewed.

2.0 Safety Policy :

As per the Factories Act, every industry has to have a laid down Safety Policy of the company and the management has to put in place arrangements that would target to achieve compliance against the objectives laid down in the policy.

The setting and monitoring of relevant objectives and targets need to be based on satisfactory information systems. Line managers should be held accountable and there should be a systematic evaluation of their performance in this aspect of their job.

3.0 Training :

This is an essential ingredient of any successful safety policy. Lack of training is a major contributory cause if not the main source of human error. Managers need to have knowledge of the health and safety legislation applicable in their area of responsibility, of the general principles of occupational health and safety and of the elements of safety management.

There is a need to learn from past mistakes and accidents and in particular to learn from experience at other places where the same hazard may exist.

4.0 Set Standards :

Having established the nature and extent of the hazards, they should be eliminated, where possible. Where they cannot be eliminated, measures need to be taken and standards set to control them. Standards are the prerequisite for monitoring and review.

A realistic approach is required, one which takes account of the way that people actually work. Procedures must be clear, unambiguous and capable of being understood by everyone concerned. But they should not be overwhelmed by paperwork.

5.0 Monitor :

Monitoring by the organisation is an essential function which covers not only hazards and risks but compliance with procedures, systems of work, the adequacy of information, ,training and supervision.

In the control of high hazard, low probability situations, particular attention should be paid to the identification and analysis of near misses rather than to statistics of accidents. It has been established that in industry generally for every serious injury incident there were 10 minor injury incidents,30 property damage only incidents and 600 near miss accidents.

6.0 Commitment:

It is important to promote commitment by individual responsibility and accountability, by proper recognition of success, by promotion and reward of enthusiasm and good results. This again underlines the need for productive monitoring based on success not failure.

7.0 What are Safety Audits ?

What is a Safety Audit ? What is a Safety Inspection ? Although the words ***audit*** and ***inspection*** are frequently used interchangeably, they are not the same.

Broadly defined, an **audit** is a systematic and, wherever possible, independent examination to determine whether activities and related results conform to planned arrangements and whether these arrangements are implemented effectively and are suitable to achieve the organisation's policy and objectives.

To spell out clearly, safety audits

- Verify compliance with established standards(regulations, internal policies & industry wise standards of practice)
- Identify deviations from designed & planned maintenance procedures and standards
- Identify conditions and operating procedures that could lead to an accident and significant losses to life or property.

Inspection, on the otherhand, is defined as that monitoring function conducted in an organisation to locate and report existing and potential hazards that could cause accidents in the workplace. One should take corrective action as soon as possible to eliminate all hazards found during an inspection. If the hazard presents an imminent danger to employees, corrective action should be immediately taken. If there is a delay in taking corrective action for nonimminent hazards ,the reason for delay should be documented along with the estimated date of correction. When corrective action has been taken, this should be documented.

8.0 Types of Safety Audit :

Broadly the type of Safety Auditing system presently being followed in India may be classified into two categories

- Internal Audits
- External Audits

Internal Audit :

This type of audit could be of two types :-

I. Walking tour This is an audit which is generally carried out by very senior officials of a manufacturing unit who may not be fully conversant with the finer details of a manufacturing process, but have a fairly good idea of how a product is manufactured. The concerned official should carry a copy of the Walking tour checklist (Appendix I) and note down his observations in it.

2. Compliance audit against various sections of Explosives Rules 2008 :

   The Explosives Rules 2008 defines a host of guidelines which are mandatory and have to be followed by each and every Explosives and accessories manufacturing unit. Most of these rules would also be applicable to Bulk explosives manufacturing as well as to the transfer plants which have no manufacturing facility, but only have silos to store the non explosive bulk emulsion matrix.

   Some important points against the Explosives Rules are listed in Appendix II.

3. Process safety audit :

   This audit should be carried out by a multidisciplinary team of technical personnel who would audit the operations. The main concerns in the explosive industry revolves around "Fire & Explosion" and the primary causes which lead to these are from :-

- Friction
- Impact
- Discharge of Static electricity
- Direct Heat
- Thermal decomposition
- Electric discharge
- Incendive spark
- Adiabatic compression

Each manufacturing unit should prepare a audit checklist which should include the controls that have been put in place to guard against each of the above primary causes for an ignition in an explosive manufacturing operation e.g. in case of thermal decomposition in an emulsion plant whether on the matrix pump the following have been provided or not-

- Low pressure switch
- High pressure switch
- Low flow sensor
- Protection against dry running
- Protection against high temperature
- Bursting disc

Also if the above safety devices have been provided, whether a preventive maintenance schedule has been put in place & is being followed, should be audited.

Another area of concern, in respect of safety, is in the manufacture of Lead Azide & Lead Styphnate used in the manufacture of detonators. A number of incidents have taken place around the world either during the preparation or handling of these chemicals, and some have resulted in fatal injuries.

The focus areas in this case, therefore should be to guard against

- ❖ Friction
- ❖ Impact
- ❖ Static
- ❖ Heat

An audit checklist should be prepared paying attention to all possible scenarios which can emerge in triggering an event involving any of the above situations. A Risk Assessment could be carried out for each individual manufacturing process & this would be helpful in designing the audit checklist

Some examples of typical controls to avoid sources of ignition are

- Maintenance of equipment
- Isolation of the hazard- external motors, lights
- Materials of construction conductive ,soft surfaces tools
- Choice of clothing-antistatic, no pockets, no metal fastners
- Trips/alarms
- Permitted article list
- Earthing (grounding)
- Operating Instructions
- Metal detector, screens
- Bonding/securing of nuts/bolts
- Housekeeping
- Training

All these points should be included in the audit checklist for any process plant.

As distinct from the above mentioned in company teams, many companies are now getting independent, third party external audits done by experts in the field.

Relative merits and demerits of Internal & External audit systems:

External Audits :

The main benefit of such an audit is that they are third party and therefore relatively free from bias and give an independant professional evaluation to the top management of the safety status of the plant. Further, when such an audit is carried out by a government ,semi-government or professional public sector consultancies these agencies have a wide range of experience of auditing across different companies. They also have better knowledge of statutory provisions & prevalent good practices being followed in the industry.

Some limitations however arise from the fact that their recommendations may be more general and may not deal with constraints of implementation. Further their knowledge about what is going on in a particular plant will be limited to the information provided by the management which may not be complete for a variety of reasons. Such constraints are less experienced by in company auditors.

Hence, if an audit has to be done by an external agency, especially in an explosives manufacturing unit, a competent person who has the experience of auditing explosives plants ,should be contracted and a confidentiality agreement signed with him before any audit is carried out by him.

Internal Audits :

In company audit teams have greater familiarity with the specific technology in use, company practices and work culture particularly in relation to the company's safety standards and programme. Their long years of experience and detailed knowledge of their company's operations helps them to probe much better than external auditors, particularly in relation to accidents/hazards that may have occurred at other locations within the company. Further by virtue of their specific experience in the company, they may be able to give greater details in their recommendations which would facilitate implementation.

9.0 Conclusion :

Auditing is essential if we want to keep our finger on the pulse of the safety management arrangements. No one can manage without hard facts. Good auditing gives just that.

Appendix I

Walking Tour

Plant Audited : **Date of Audit :**
Audited By :

1.0 SAFETY SYSTEMS AND PROCEDURES		Comments
a) Working Regulations, Operating Instructions & Use List		
• Availability	Yes / No / NA	
• Condition	Yes / No / NA	
• Displayed	Yes / No / NA	
• Kept upto date	Yes / No / NA	
b) Work Permits and Clearance Procedures		
• MRO / Clearance certificates for different jobs available.	Yes / No/ NA	
• Compliance against audit Of Clearance certificates	Yes / No/ NA	
• Provision & testing of Safety showers & Eye wash	Yes / No/ NA	
2.0 PREMISES AND HOUSEKEEPING		
a) Buildings , Floor & work areas :		
• Cleanliness , Maintenance	Yes / No/ NA	
• Condition of flooring	Yes / No/ NA	
• Explosive Spillage	Yes / No/ NA	
b) Lighting :		
• Quality, adequacy	Yes / No/ NA	
• Emergency lighting	Yes / No/ NA	
c) Ventilation for fumes,dust		
• Gases, vapours	Yes / No/ NA	
d) Explosion protection		
• Mounding	Yes / No / NA	
• Licence limits	Yes / No/ NA	
e) Inter Plant Transportation of explosives		
• Cleanliness of trolleys	Yes / No/ NA	
• Proper use	Yes / No / NA	
f) Stacking & storage practices		
• Safe height of stacks, clearance to Lights, switches etc.	Yes / No/ NA	
• Materials stored safely	Yes / No/ NA	
• Aisles kept obstruction free	Yes / No/ NA	
g) Yard area / Surroundings		
• Condition of roads, walkways Drains, storage area	Yes / No/ NA	
• Adequate storage facilities	Yes / No/ NA	
• Cleanliness, tidiness	Yes / No/ NA	
• Condition of nonexplosive waste bin	Yes / No/ NA	
h) Plant maintenance shed / spares store		
• Neatness	Yes / No/ NA	
• Spares labeling / control	Yes / No/ NA	
• Redundant materials / unrepaired spares	Yes / No/ NA	
• Tools condition / storage	Yes / No/ NA	
3.0 IN PROCESS QUALITY CHECKS		
• Check sheets filled up	Yes / No/ NA	
• Relevant records maintained	Yes / No/ NA	

4.0 MECHANICAL, ELECTRICAL, INSTRUMENT & PERSONAL SAFEGUARDING		Comments
\a) Machine safeguarding		
• Guards, adequacy, quality, effectiveness	Yes / No/ NA	
• Provision of emergency stop button	Yes / No/ NA	
• Record of inspections	Yes / No/ NA	
b) Labelling (vessels, switches, instruments)		
• Switches, isolators, fuses labeled	Yes / No/ NA	
• Vessels/equipment labeled	Yes / No/ NA	
• Pipelines identified	Yes / No/ NA	
• Instruments on site & on control panels labeled	Yes / No/ NA	
c) Pressure Vessels		
• Regular inspection/test certificate	Yes / No/ NA	
d) Electrical Installations		
• Condition of switches, wirings & Flame-proof equipments	Yes / No/ NA	
• Checking of earthing strips	Yes / No/ NA	
• Electrical panels locked	Yes / No/ NA	
e) Chemicals Handling & Storage		
• Register of chemicals	Yes / No/ NA	
• MSDS availability	Yes / No/ NA	
• Adequate storage facilities	Yes / No/ NA	
• Adequate packaging, labeling	Yes / No/ NA	
f) Personal safeguarding methods & materials		
• Areas, jobs where required clearly defined	Yes / No/ NA	
• Regular checks for condition of PPE's	Yes / No /NA	
• Adequate stock maintained	Yes / No/ NA	
• Correct location/storage in plant	Yes / No/ NA	
g) Notices & Signs		
• Positioning / condition	Yes / No/ NA	
• Adequately maintained	Yes / No/ NA	
• Missing signs	Yes / No/ NA	
• Redundant signs	Yes / No/NA	
5.0 FIRE PROTECTION & PREVENTION		
• Availability & condition of Fire extinguishers	Yes / No/ NA	
• Proper location	Yes / No/ NA	
• Regular inspection	Yes / No/ NA	
• Training of personnel	Yes / No/ NA	
• Availability of water for emergency fire fighting.	Yes / No/NA	

Appendix II

Important Provisions of the Explosives Rules 2008

Sr.No.	Clauses underExplosives Rules 2008	Remarks Available / Not Available
1.	Original licences with approved drawings	
2.	List of Authorised Explosives (Rule 6)	
3.	Process of manufacture stating safe operating procedures and precautions	
4.	Employment of Competent persons (Rule 11/7) Name Qualification Experience (min. 5years)	
5.	Lightning conductor (Rule 12) • Test certificate • Display of test results	
6.	Provision of mounds (Rule 20)	
7.	Record of accidents (Rule 25)	
8.	Safety Management Plan (Rule 26)	
9.	Exhibition of particulars on process buildings (Rule 32)	
10	Training (Rule 35) ➢ periodicity ➢ records	
11.	Record of maintenance & servicing plant & equipments (Rule 37)	
12.	Disposal of waste explosives (Rule 42) ➢ collection procedure ➢ periodicity ➢ place approved by CCE	
13.	Destruction List of shot firers permit holders	
14.	Onsite Emergency Plan	
15.	Offsite Emergency plan	

Traceability of Explosives and Accessories - A National Concern for Safety and Security

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Abstract

India ranks amongst the major producers of industrial explosives in the world, with an impressive growth trajectory from a small demand base of 2500 tonnes in 1950 to the current level of 900,000 tonnes for construction and mining industry. The global threat and challenge of pilferage of explosives and accessories necessitates identification and traceability of explosives and accessories. Many countries have outlined new regulations to enable identification and traceability of explosives at every point in the supply chain management. Radio Frequency Identification (RFID) technology has a great potential in tracking and tracing the explosives and detonators. RFID tags have technical potential of automatic identification and data capture using devices having the capacity of safe, fast, and robust reading/writing, storage, and remote retrieval of data via radio waves.

1.0 Introduction :

India is one of the largest consumers of the industrial explosives in the world and the consumption of the industrial explosives is witnessing a whopping growth to meet the mineral demand of the country for achieving the economic and societal developments. There is a global threat and challenge to humanity as posed by terrorists arising out of pilferage of explosives and access Ories. It is of paramount importance to trace and identify the explosives and accessories with defined accountability and ownership. In order to ensure accountability and traceability, the European Union (EU) established regulations requiring all 27 EU countries to possess commercial explosives accountability and tracking at a unit level from April 2012. The Brazilian government also has outlined new regulations in this regard while many other countries are framing country specific regulations in this direction. Geofencing and use of radio frequency identification (RFID) technology can play a pivotal role for tracking and tracing the explosives and accessories. Through the concept of traceability applied to an explosives or accessories item with exclusive identification, it is possible to trace an item from its fabrication to its final destination. Through the ownership criteria, when the manufacturer/seller sells a product, a statutory document as approved by regulatory body is issued, transferring the ownership of the explosives or accessories product from the manufacturer or the seller to the end user. The transference of ownership requires information to the governmental agencies in electronic form or online or in hard copy depending on the legislation prevailing in the country for seeking and ensuring confirmation of transference of ownership to the buyers. In case of non-compliance of the statutory requirements, the governmental agency may make a formal investigation or approve deviations from observance of any statutory compliance.

2.0 Traceability Of Explosives And Accessories :

The traceability pertains to identification process for effective handling and movements of the explosives and accessories products and fulfill the need of operation control i.e. production and logistics. For the traceability of controlled products, the following requirements are necessary (Neto, 2007):

- The controlled product must have a single and standard pattern of identification;
- Information exchange among the various links of the supply chain (Industry-Dealers-Resellers- End Users);
- Responsibility of each link of the supply chain to manage what it has received from its suppliers and what it is delivering to the clients;
- Standardization among the products and their transport and warehousing units;
- Precision and velocity to record and recover data in the traceability system.

Traceability is based on three basic concepts: Collaborative Environment (information exchange among the links in the supply chain); Ownership Control; and Single Identification (ID) for the product.

The rational behind requirement for tracking and traceability of explosives and accessories may be enumerated as follows:

- detecting the pilferage of explosives and accessories.
- detecting the point of pilferage.
- the pilferage of explosives and accessories is not only monetary loss but is a serious matter of concern as it may land in hands of miscreants, antisocial and anti-national elements.
- detecting the misfires in blasting rounds.
- detecting pilferage and spillage during transit.
- effective and efficient control and monitoring of explosive movement, storage and use for decision making.
- detecting expiry of explosives

2.1 Collaborative Environment

Collaborative environment is the information exchange process that allows for tracing and integration among suppliers, clients, distributors, industries, retailers, transporters by optimizing the management of the supply chain through computing systems as shown in Figure 1.

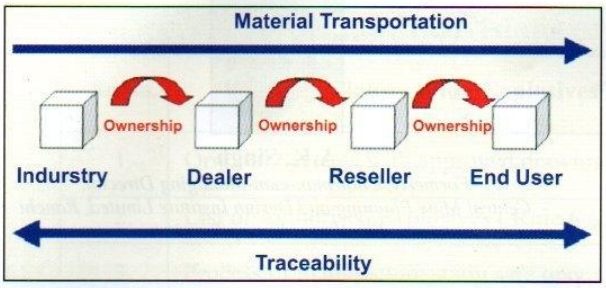

Figure 1 - Supply Chain Management for Effective Traceability

2.2 Ownership

Ownership is the certification of property. Through the ownership criteria, when the manufacturer sells a product, a document is issued, transferring the ownership of the product. Each controlled product has a unique identification and traced by the concept of ownership that exists in each link of the supply chain. During the ownership transference process, the link of the supply chain (eg. seller) checks and informs the operation to the inspection organ. The other link (eg. buyer) will in the same manner register with the inspection organ its ownership of the acquired product (within a pre-established time). In this way, one's responsibility is appointed at each and every stage of the supply chain management. It is in the interest of the link possessing the ownership of the product, to immediately communicate the inspection organ about the operation, at the time of the physical transference of the product, so that in case of deviation, the responsibility is attributed to the link detaining the product ownership. The control of ownership allows for the attribution of sole responsibility in every link of the supply chain.

2.3 Sole Identification (ID)

Sole Identification (ID) is the identification of the unit (smallest part of a product) of an item. Every product in its unit has a sole and exclusive identification, which is the product ID and will follow it throughout its existence. For an effective traceability process, it is necessary for adoption of a code pattern, applied individually to each product. The acquired data by the traceability process must be stored for a certain period as specified by the country. The Brazilian Regulated Traceability Law i.e. Diretoria de Fiscalização de Produtos Controlados (DFPC) requires statutorily to preserve the data for a minimum period of ten years by the respective manufacturers, allowing "On Line" access by the DFPC agency for consultation concerning product logistics and respective ownerships. The inspection architecture followed by Brazilian Regulated Traceability Law is shown in Figure 2.

The Commission of the European Communities has proposed the unique identification methodology as mentioned below:

1. A human readable part of the identification containing the following:
   - (a) The name of the manufacturer
   - (b) an alphanumerical code containing
     - (i) 2 letters identifying the Member State (place of production or import onto the Community market, e.g. AT = Austria).
     - (ii) 3 digits identifying the name of the manufacturing site (attributed by the national authorities).
     - (iii) the unique product code and logistical information designed by the manufacturer.

2. An electronic readable identification in barcode and/or matrix code format that relates directly to the alphanumerical identification code.

Example:

Alfa Explosives Limited
AT 023 100806 B 34512 345101
AT 023 100806 B 34512 345101

3. For articles too small to affix the unique product code and logistical information designed by the manufacturer, the information under 1 (b) (i), 1 (b) (ii) and 2 shall be considered sufficient.

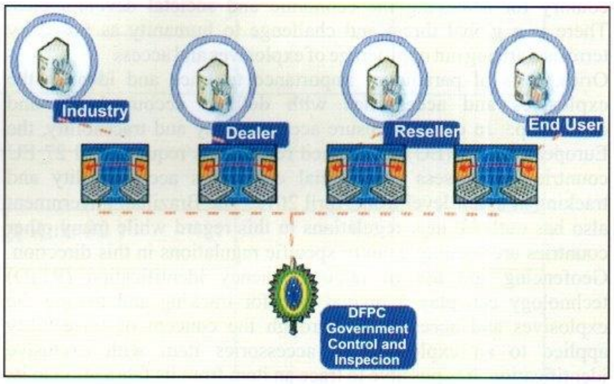

Figure 2 - DFPC's Inspection Architecture

For an effective traceability of products, each unit must have the exclusive markings. The exclusive marking in respect of detonating cords may comprise marking per meter, identifying manufacturer, manufacture date, emergency phone number, identifying no. (ID). The exclusive marking in respect of permitted and non-permitted cartridge explosives may comprise the name of manufacturer, manufacturing date, emergency phone number and ID. The exclusive markings in respect of electrical, non-electrical detonators, electronic detonators and boosters may comprise the name of manufacturer, manufacturing date, emergency phone number & ID. RFID technology is suitable for real time tracking and monitoring of explosives before and after blasts from remote locations and to locate the misfires, if any. The status of global research for tracking and monitoring the explosives and accessories is presented below:

i) RFID tags attached with explosives and accessories and read by mobile reader.
ii) RFID tags attached to explosives and accessories and read by stationary readers.
iii) Finding detonators after blasting in case of misfire.
iv) Inventory control.
v) Online submission of the status of the explosives and accessories to the regulating agencies.

The RFID technology can be broadly categorized as follows and is enumerated below. (Mishra et al., 2012):

i) Passive RFID technology
   - Dual frequency RFID technology
   - Near field VHF/RFID technology
ii) Active RFID technology
   - Zigbee compliant RFID technology
iii) Hybrid RFID technology
   - Rubee technology
   - Dual active RFID
   - Dual active micro wireless sensor chip

3.0 RFID Tracking System An Australian Case Study :

One RFID tracking system has been developed and patented by Global Tracking Solutions Pvt Ltd, Australia. Various products (PREtrack, DETrack, IEtracker, MAGsafe and ETC bank) of this company facilitate RFID based tracking of explosives and accessories for safety and inventory management. PREtrack, as shown in Figure 3, is the application of RFID technology in the explosives manufacturing system to allow the tagging and tracking of explosives throughout the manufacturing process. The PREtrack process is set up to record the quality data along with the operational inputs and to supply the information to the PREtrack server. RFID tag information includes the product name, date of manufacture, net explosive quantity, materials used and operational information is automatically enter within the RFID-ETC tag. PREtrack has finished proof of concept testing with Johnex Explosives in Kalgoorlie, Western Australia using RFID tagging at a box level. This allowed Johnex to have tracking and traceability of these boxes to sites anywhere in Australia.

DETrack, as shown in Figure 4, is the primary product for the tagging of detonators with their own individual ID number through an RFID chip. Detonators are embedded with a security tracking device in such a way that the removal of the internal tags would create the detonators nonoperational. Faster and precise data recording will eliminate record keeping and allow secure data transfer within a controlled structure. This, combined with a second identical RFID tag within the unit is the only detonator product that contains a built-in redundancy system to facilitate tracking each detonator throughout its life and possibly beyond.

IEtracker is a computer based system and hardware that allows to design blast patterns on their current software and then download the information onto a PDA (IEtracker). This patented software and system allows true identification of blast holes via the PDA technology. Where individual explosives units have an RFID tag the IEtracker will log each unit to a given hole when loaded. At the end of loading an electronic download allows for a fast interface against planned versus actual blast design allowing remedial action to be taken, when necessary.

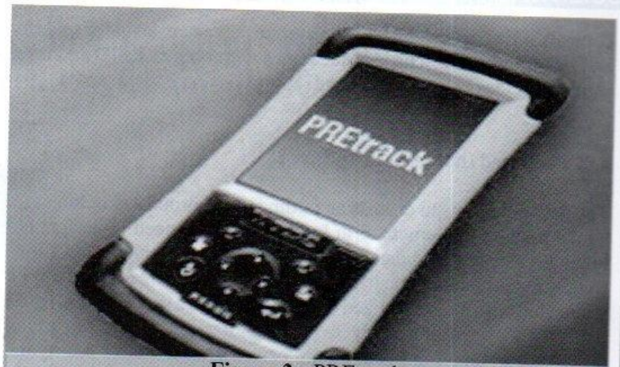

Figure 3 - PREtrack

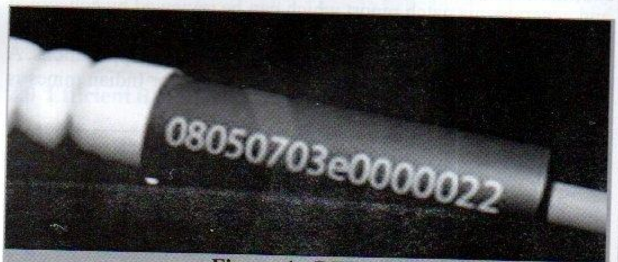

Figure 4 - DETrack

ETC Bank, as shown in Figure 5, is a central data collection and management point for RFID-ETC users around the world. This information is secure and can only be accessed only by authorised personnel. It collects data from RFID-ETC tag suppliers, explosives manufacturers, MAGsafe, IEtracker and the transport industry along with other approved operations. To provide a real time access point to identify the location of an RFID-ETC explosive tag and/or who was the last approved person to handle this particular explosive anywhere in the world.

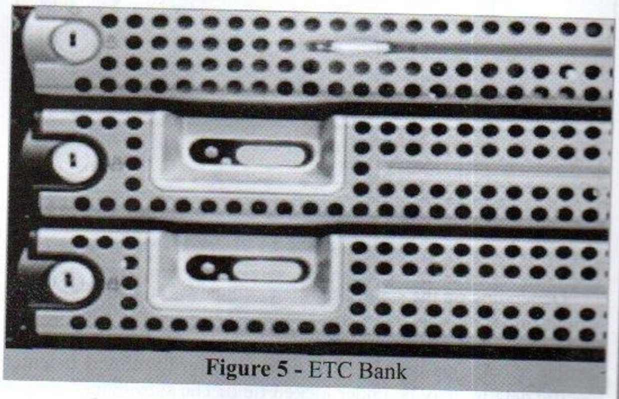
Figure 5 - ETC Bank

MAGsafe is a computerized cabinet designed to record explosive movements into and out of explosives magazines by approved personnel via RFID. The cabinet contains both its own tracking and record software which links to explosives management control and processing software and is integrated into a high level access security program. Combining this with Bio Reader access controls and a 5x5 risk matrix, the system sets a new level for security and risk monitoring. The cabinet comes with both as RFID and laser printers for the printing of tags and reports.

4.0 Proposed Indian Architecture :

The paper attempts to discuss an outline of the proposed architecture which may be implemented in India. There is a need to design and maintain a centralized database by the regulatory authority in India. Every manufacturer, distributer and user organizations will be connected with the centralized database through a secured link. RFID data would be captured by every organization during incoming process or outgoing process of explosives or accessories during the supply chain from their warehouses. The centralized server will tally and generate mismatch report which can be reviewed by concerned organizations for rectifications, observances and compliance. Various types of RFID tags are to be used for varied applications. A schematic diagram of the proposed architecture for Indian mines is shown in Figure 6.

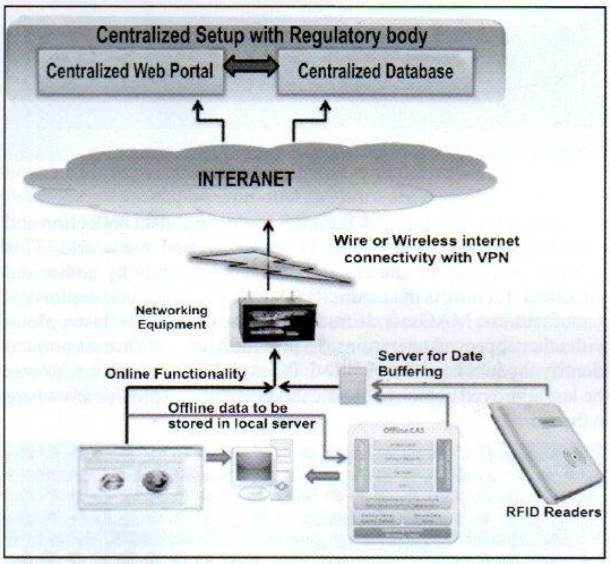

Figure 6 - Schematic Diagram of the Proposed Architecture

Locked Field	Locked Field	Open Field	Open Field
Manufacturer Specific	Indentor Specific	Subsidiary/Area/Magazine Specific	Mine/User/Specific

Depending on the supply chain of explosives and accessories to various mines in India, the hybrid coding methodology using locked field and open field may be practised. The manufacturer specific details viz. batch no./case no., date of manufacturing etc and indenter specific details may be under locked field. The subsidiary / area or magazine where the consignment may be unloaded as well as the name of mine which will consume the consignment may be kept under open field. mine which will consume the consignment may be kept under open field.

Tags may have a variable length unique identification number assigned by their manufacturers which may comprise 96 bits to 512 bits. Optional user information may be written in writable tags, write operations may be done multiple times (typically 10,000 times to 100,000 times). Passive tags should be used for safe application. Tags may be read/ written from distance. Typically a passive tag may be read from as far as 10 m depending on the type of reader being used. Tags may be read/written during motion without any interruption. Tags may be in various shapes, sizes and enclosures for different purposes. The disposable or reusable tags may be used in actual operations. As all the RFID tags are to be imported and hence costly, concerted research is needed to develop the low cost RFID tags indigenously.

5.0 Geofencing For Ensuring Safety :

Geofencing is a software program that uses the global positioning system (GPS) or radio frequency identification (RFID) to define geographical boundaries. Geofence programs allow an administrator to set up triggers. So, when a device crosses a geofence and enters (or exits) the boundaries defined by the administrator, an SMS or email alert is sent.

Many geofencing applications incorporate Google Earth, allowing administrators to define boundaries on top of a satellite view of a specific geographical area. Other applications define boundaries by longitude and latitude or through user-created and Web-based maps. Geofencing can even deactivate the detonator if it crosses predefined borders which may be a magazine or a mine or any other customer defined area. It is a virtual perimeter for a real world geographic area and could also be dynamically generated.

6.0 Conclusions :

Radio Frequency Identification (RFID) technology has a great potential in tracking and tracing the explosives and detonators used in mining and construction industry. There is a requirement for an updated RFID technology for its possible application in the mining industry. Besides tracking pilferage of explosive products, the RFID technology will help in locating the misfires, if any, in blasting operations so that the misfires can be handled properly. With the help of this technology, it is possible to detect the expiry date of explosives. Further, this technology will help in maintaining the online inventory of the explosives and accessories on a suitable software/platform. Considering the advantages of the RFID technology, it is necessary to evaluate the available technology for its possible implementation in the Indian conditions. As the price of RFID tags are significantly high, concerted research may be undertaken to develop the tags indigenously so that the cost will not be prohibitive for application of RFID technology.

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Technology Initiatives for Efficient Blasting Operations and Improved Environmental Control

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1.0 Introduction :

Blasting is one operation which impinges on efficiency of entire operation and results in poor image due to environmental impacts. Adverse environmental effects of blasting ranging from ground vibration, air blast overpressure, dust, fumes, fines and the potential for fly rock may make entire operation as harmful to environment and society. It is important to control all these effects while carrying out blasting operations as increasingly projects are being subjected to scrutiny and at times closure Conventional blasting practices and techniques in mining and infrastructure construction industry are unable to improve efficiency and mitigate environmental hazards. Poor blasting design and execution not only has negative economic consequences, but is also a safety and environmental hazard. Efficient blasting with reduced environmental effects requires suitable planning, good blast design, accurate drilling, the correct choice of explosives and initiation system, blast execution, adequate supervision and considerable attention to details. With the development of new explosives systems and initiation devices, blast design and execution software tools, the blasting process has now become more efficient and safer. Blasting operations are utilizing technology systems that underpin rock blasting in open pit and underground mine operations, such as predictive modelling, blast design, radio-controlled detonation, real-time monitoring of drilling, charging and post-blast data analysis. Across the blast lifecycle, Information Technology (IT) systems are being used to record, manage and analyse data being generated.

Basic considerations such as choice of explosives, maintaining intended hole spacing in drill patterns, and selection of correct delay timing are good starting points for blast-improvement efforts. Another economical approach is to employ blast design and analysis software currently available, including those that allow pre-blast bench face profiling and post-blast analysis of fragment size distribution. Most are frequently updated to accommodate new technology and data-collection capabilities. It is worthwhile to look at some technologies which are being adopted in the mining industry to make blasting operations efficient and reduce the environmental impact.

2.0 Efficient Blasting and Environmental Control Strategies:

Essentially, the energy released by the explosives is useful for fragmentation, displacement and movement of broken rock whereas wasteful part of energy causes adverse impacts such as ground vibration, airblast, flyrock, dust and fumes. Operators need to adopt strategies to control the adverse environmental impact of blasting operations (Figure 1).

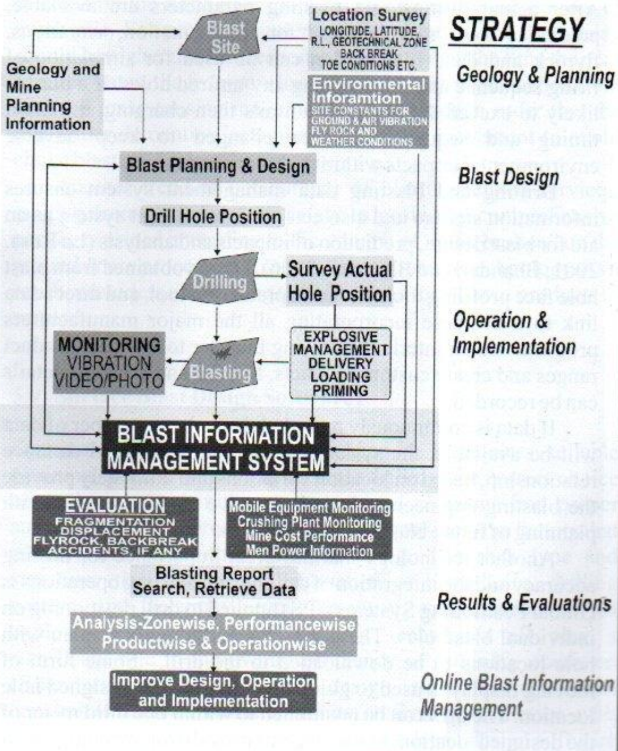


Figure 1 - Strategy for Optimum Blasting Operations

The diagram explains a systematic manner which considers geology and mine planning information, blast block location and environmental information for design of blasts. Based on the blast design, drilling operations take place and measurement of actual drill hole position is recorded. Accordingly, explosives management is carried out which involves delivery, loading and priming. Based on this information environmental impacts can be predicted, which allows explosive and initiation can be changed at the execution level. Several monitoring tools can be used to evaluate blasting results and analyse outcomes to improve overall operations and control subsequent blasting. Key performance indices (KPI) can be determined and continuously monitored by management at different levels.

All the information about blast needs to be recorded in an appropriate manner to plan subsequent steps.

3.0 Information Technology Applications in Blasting :

Information technology can be used in every step of drilling and blasting operations. Based on customized blast design tools for any operation blast design, charging and execution can be planned. The design can incorporate environmental restrictions and result goals. After holes are drilled, measurements regarding burden, spacing, hole depth need to be made either by using GPS or manually. There would always be difference between designed hole location and inclination and actual holes drilled. After actual drilling and blasting parameters are available, predictive tools may be used for fragmentation, vibrations, flyrock and dust. Information can be used for simulation of firing sequence and for checking any unfired holes. If a blast is likely to exceed the respective limits then charging, initiation timing and sequence can be changed to keep adverse environmental impacts within the prescribed limits.

Drilling and blasting data management system ensures information storage and also acts as an intelligent system as an aid for blast design, prediction of impacts and analysis (La Rosa, 2001; Bhandari and Bhandari, 2006). Data is obtained from blast hole face profiling tool, vibration prediction tool, and direct data link to a database incorporating all the major manufacturers products and an interface allowing the user to add new product ranges and create custom products. Misfire and accident details can be recorded.

If data is continuously recorded then a large number of data will be available, the system can up-date the scaled distance relationship, based on location variations and ultimately provide the blasting engineer with an interactive means to assist with planning of future blasts.

Another technology that has great importance for drilling accuracy and the integration of drilling and blasting operations is Global Positioning System (GPS) applied to drill positioning on individual blastholes. These systems allow the blast plan with hole locations to be downloaded to the drill. Some form of moving display is used to guide the drill onto the designed hole location. The drill can be positioned to within one third meter of the designed location. Some systems provide for azimuth as well as coordinates in order that the drill can be accurately located on angled holes. If the elevation coordinate is provided for, hole depths can be adjusted for variations in bench topography.

Use of a drilling machine with a GPS guided system can accurately locate the planned location and can determine the exact collar elevation at each drill location. Normally, the drill pattern file containing the designed hole numbers, northing and easting coordinates for each hole and the defined horizon to which all holes should be drilled is sent to the drill via a radio network from the planning office. The drill monitoring system precisely calculates the depth of the drill hole and it significantly reduces over and under-drilling (Rodgers, 1999). After drilling the data of actual drill hole positions and length can be uploaded from the drill to mine planning office via the radio network. The knowledge of actual locations and spacing between holes facilitates comparison between actual and planned blast design.

Equally important, the system records exactly where the hole is drilled. This is essential for data transfer to blasthole loading operations, because it provides the way to access hole depth and rock strength profile information in the monitoring database (Figure 2). If the elevation coordinate is provided for, hole depths can be adjusted for variations in bench topography. Thus, GPS technology is the key to integrating drilling and blasting operations, and to the possibility of providing for effective quantitative feedback. New technology is helpful in generating good blast designs for transfer to field operations. For example, target less laser survey equipment provides a means to accurately determine the bench faces profile. The laser profiling system provides full-face information including undercutting, back-break irregularities and the nature of toe conditions. This system provides considerably more detailed information than the traditional crest and toe surveys.

UNIT OPERATION	TECHNOLOGY
Drilling	Drill Performance Monitoring GPS for Drill Positioning
Blasting	Blast Design Software Target less Laser Survey Systems on-bord Computing on Bulk Truck GPS on a Bulk Truck Fragmentation Prediction and Analysis Vibration Instrument with GPS
Excavator	Shovel performance monitoring systems GPS for shovel location
Haulage	Dynamic dispatching & haulage monitoring systems Fragmentation analysis
Crushing and Grinding	Continuous fragmentation Analysis Energy Consumption

Figure 2 - Monitoring Technology at Different Stages of Rock Excavation

Proper placement and loading of the front row holes is absolutely essential to good blasting. The laser profiler helps the blasting group design effective front row blasthole locations, or to design explosives loading requirements that reflect actual conditions. The laser systems can also be used to survey the muckpile after blasting. The volume of rock broken by shot can be obtained. The swell of the blasted material can be determined. Swell is a measure of the looseness and therefore, diggability of the blast. Swell can be correlated to excavator productivity and this information can be fed back to blast design for use in designing subsequent blasts in the same area.

Ideally, the blast will be designed with computer assistance using information from laser surveys, geotechnical and other data. The hole locations are placed on blast plans. The final design is downloaded to the drill equipped with GPS capability. The drill machine can then drill the blastholes accurately on the designed locations.

Explosives bulk trucks equipped with on-board computers and suitable communication make it possible to download blast design data. The trucks can then use this information and data from the drill to properly load the individual blastholes.

The overall success of a blast is usually assesses by the speed and efficiency of subsequent digging operations. Thus the fragmentation, position, shape and looseness of the rock pile must be suited to the equipment available. These parameters and equipment productivity can be measured by various techniques, to make a more objective overall assessment of blast performance. Image analysis is now usually used to assess the size of fragmentation.

Mine to Mill concept quantifies and models blast fragmentation and applies this knowledge to optimize the combined performance of mine and comminution circuit. Online image analysis system provides measurement of the size distribution of the ore. Fragmentation and comminution models allow management of optimization and control to increase productivity. Modelling of blast fragmentation and comminution together use ore characterization, blast simulation and mill simulation of mill has been demonstrated by number of case studies. Substantial benefits in improved performance and reduced costs have been achieved

4.0 Explosives and Accessories :

If the mine is new, selection will have to be made between cartridge and bulk explosives depending on the proposed volume of excavation per month. Once this is made, the choice can be exercised amongst ANFO, HANFO, slurry and emulsion depending on the characteristics of rock vis-à-vis its response under dynamic loading during blasting.

The most significant changes in the blast technology have taken place in product-delivery systems. One factor is the continuing trend away from the use of cartridged products in favor of bulk products for both surface and underground operations: new surface and underground delivery-vehicle technologies that boost blast accuracy and safety: high-precision pumps and blending and measurement devices, robotic arms that place the product in the hole, and remote controls. The blasting agent throughout the industry would continue to be ammonium nitrate fuel oil (ANFO) mixture or ammonium nitrate-based emulsions, and this basic explosive chemistry is unlikely to change in the coming decade. When considering blasting technologies, operating companies tend to be highly cost conscious, which mitigates opportunities to develop value-added or innovative products.

Electronic detonators are now commercially available (Cunningham, 2004). Advantages include precise delay timing (resulting in increased blast efficiency and control) and greater compatibility with remote-controlled loading of explosives and wireless detonation. However, these initiating systems have higher costs. Whilst most of the efforts by the manufactures are being directed towards enhanced fragmentation, there are undoubtedly areas relating to environmental control that, with more directed research, can bring benefits to operators, regulators and local residents. The successful use of electronic detonators to control ground vibrations from blasting is a classic example of research leading on to commercial deployment for the benefit of all the stakeholders (operators, regulators, consultants and local residents). The trend towards use of electronic detonators has not been to replace other systems as signal tube or shock tube which has its own advantages.

Selection of initiation system and timing need to be made keeping in view the environmental constraints. The site-specific relation between burden and burden response time can determine the delay between different rows. The time delay should be selected on the basis of response time and the desired throw of muck pile. For proper fragmentation and throw, the time delay should be higher than the response time so that by the time the next row detonates, the front row has just started getting detached from the rock mass causing movement to take place in order that the row under detonation gets proper relief for movement to avoid choke blasts and severe back break.

Another trend is outsourcing of blasting-related services, ranging from consulting on safety to providing comprehensive packages priced according to the volume of "rock broken" on the ground or ore processed. Explosives are a mature technology. As a result, providers are shifting their business focus from products to service.

5.0 Surface Blast Design Software :

Optimum blasting just does not happen. It requires suitable planning, good blast design, accurate drilling, the correct choice of explosives and initiation system and sequence and proper supervision. An approach is needed that considers the factors that interact with one other during blasting. The rock type and structure; size, length and inclination of blast holes, drilling pattern and accuracy, type, quantity and distribution of explosives; charging and initiating techniques all play a significant role in the overall efficiency of a mining operation (Bhandari,1997). During the design stage environmental constraints such as vibration limits or flyrock restriction with respect to any structure can be prescribed. Blast design software can be used as a tool to assess the likely impact or effect of a particular design on results in terms of fragmentation, movement and other environmental impacts. This is in conjunction with field observations, experimentation and monitoring. Blasts can be designed while using scaled distance tools so that ground vibrations and airblasts are within the limits. Information Technology can be used to design blasts based on historical data collected over a period for each geotechnical strata and to provide optimized drilling and blasting patterns. There are several blast design software tools. For example Surface Blast Design Software (BLADES) provides design of blasting pattern according to rock conditions, rock structure, and results required for optimized results, considering explosive properties, drilling, environmental restrictions and equipment and subsequent operations. The software helps to calculate and draw blast parameters. The software has the ability to generate a firing pattern for a blast. It allows to vary delay timing and sequence and the pattern drawn can also be saved and blaster can be provided with charging sheet. It also provides the first movement of rock. The software shows the simulation (animation) of ignition sequence. The program provides output, charts and graphs, as well as reports in real-time and allows output of data via customizable printing capabilities. Figure 3 provides a typical blast designed by this software

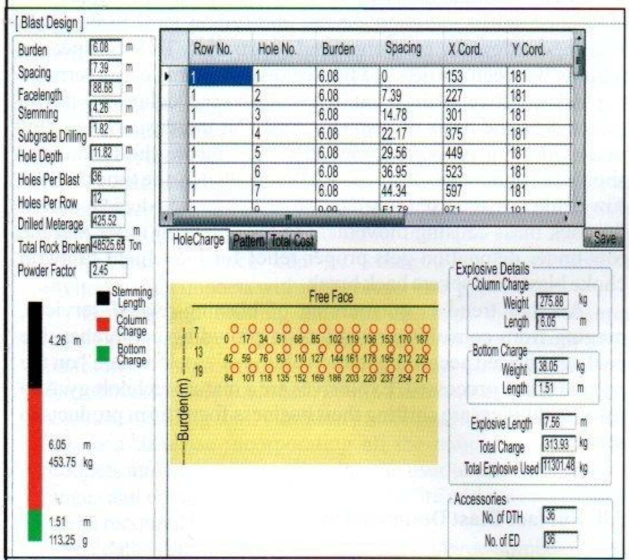


Figure 3 - Surface Blast Designer Software BLADES Provides Design for a Blast Block

BLADES software has modules which predict approximate vibration values, fragment size and approximate danger zone. Initially the software uses empirical constants. However, after historical data have been accumulated, the software can be used to determine specific constants for each pit/bench. Software has drilling and blasting cost analysis capabilities. Software can import/export drill hole data, GPS data, total station records, face profiler records in excel or .csv file. The software can give charging sheet for blaster for loading explosive in each hole and also provides initiator connection. Other blasting software use information to create charge standards to design specific hole by hole explosives loading and create load sheets according to geotechnical zone characteristics and required results. Users can view the animation and subsequently make changes in both the order and firing pattern before the pattern is released. The software provides the ability to calculate the true volume of a blast as planned.

The software allows users to set pattern burden and spacing by rock, allowing greater control over a blast involving different material types. For reporting purposes, each material may have a different specific gravity. The different material can also be assigned different drilling costs per meter, allowing greater accuracy in budgeting for drill and blast and more ability to anticipate areas of higher cost. The software also provides reports as needed for individual operations or as per format of regulatory authorities.

6.0 Blast Information Management System (BIMS) :

Blast Information Management System (BIMS) provides information to meet the strategic and operational needs for planning, controlling and decision-making for optimizing mining operations (Bhandari and Bhandari, 2006, Bhandari,2011). It provides methods to store, manage, document and retrieve drill and blast related information. The system stores blast details, actual blast parameters, blast pattern, face profile, explosive consumption and charging details (Figure 4).

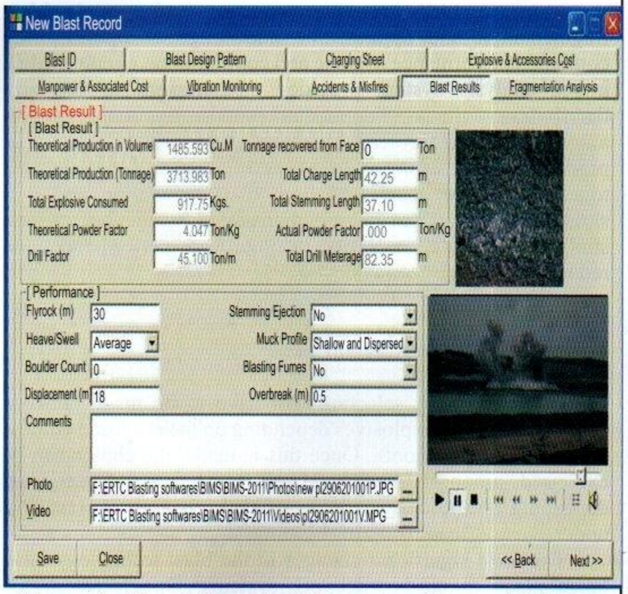


Figure 4 - Blast Information Management System (BIMS)

The stored blast information data can be retrieved quickly and easily. Performance and cost of blasts can be monitored and appropriate blast designs for particular areas or different zones can be identified. The data management and retrieval is easy and simple to use which can be carried out in a few minutes which helps in optimizing various operations. Readily available past data in a logical format and blasting data analysis tools are the key features of the database. The database can be extended to integrate with other systems such as ERP, CMMS etc. If the software is operated in conjunction with a comprehensive monitoring program, it can contribute to the efficient running of an operation and reduce environmental effects to a minimum. Importing data from .csv file, Excel and other mining software makes it is possible to reduce input work. Entered data can be edited through edit parameters functionality. The database can be tailored according products and practices, to customer requirements and can be maintained. This database also has searching options using which the user can look for the records of blasts as per his defined criteria. The software can use several criteria for the search option: between dates, by performance of explosives or initiating system, by vibration limits, by fragmentation size, by location of blasting zone or accident etc.

Protection and regulatory authorities are increasing their expectations for strict accounting of inventory and blast documentation. Using BIMS, presentation of analysis of data, compliance reports suitable for regulatory bodies, archiving and viewing of data at distance location, costs can be developed. Reports suitable for Occupational Health and Safety (i.e. incident reports) can be compiled. Key performance indicators are derived. Thus BIMS provides a way of trapping the experience of drilling and blasting personnel to better control critical parameters such as dilution, vibration, fragmentation, and flyrock and fines generation. Integration with other software such as those used for vibration monitoring and analysis, fragmentation analysis etc is possible to provide simplified management system. The system also provides defensible data that can be provided to regulatory authorities to illustrate the mine operator's compliance with regulations.

7.0 Assessment And Audit Of Existing Blasting Practice :

While planning each blast, accurate assessment of past performances need to be made. An audit of existing blasting practices is suggested to be carried out with video camera, face profiler, borehole location and deviation measurements. Further, assessment should look into the variation between the designed and actual charge distributions. The drill hole deviation alters the planned burden, spacing and depth of holes thus resulting in suboptimum results. After holes are drilled it is important to know their deviations so as to suitably alter the charge distribution in the holes or initiation system. It is considered prudent, if not essential, to regularly monitor and audit blasting performance against design criteria and anticipated results.

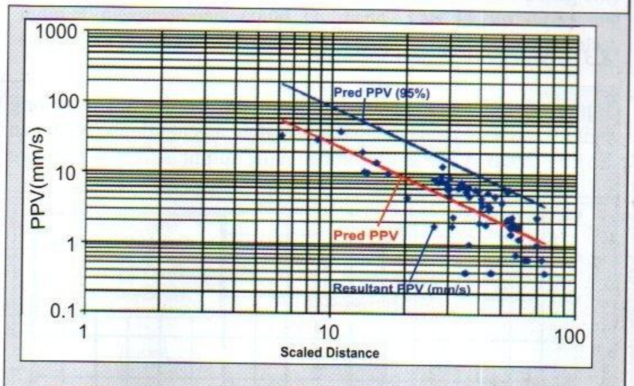
8.0 Prediction And Control Of Environmental Impacts :

There is often difference in designed and actual drilled holes. Actual drilled data need to be checked whether the resulting blast will result in exceeding the set environmental limits by using predictor software. In case the environmental limits for vibration and flyrock imposed by regulatory authorities or by the management exceed then explosive charge quantity, distribution and initiation timing and sequence can be changed so that limits are not exceeded. These software can be used on desktop and are web based are also available. It is also possible to collect blast data through iPad or smart phones and analyse data before and after blasting.

8.1 Blast Vibration Prediction and Compliance

Comprehensive blasting vibration predictor, analysis and reporting software meets the needs of both operators and regulators (Birch et al, 2002). It supports and improves compliance with blasting related planning conditions and contributes to improved blast performance and blast design. Key features include:

Regular updating of predictions using ongoing site data, providing minimum instantaneous charge (MICs) to the operator that ensure compliance with vibration level restrictions by design rather than by accident. The system's advanced analysis also allows blasting on individual benches or areas to be assessed (Figure 5).



Statistics		Site Factors			
No. Data points:	65	A:	1048.03	A(60%):	1219.75
Standard Error:	0.74	B:	-1.60	A (95%):	3528.30
Correction Coeff :	-0.74			A (98%) :	4779.29
				A (99.9%):	10396.69

$$PPV = 1048.0\ (\text{Distance}/\text{sqrt M.I.C})^{-1.60}$$

This site requires: 95% of all blasts to be less than: 6 mm/s

Figure 5 - Determining Scaled Distance

8.2 Wave Reinforcement Predictor

Wave front reinforcement has been found to cause substantial increases in both air and ground vibration from both surface and underground blasting operations (Richards and Moore, 2004). Simple alterations to firing patterns can prevent wave front reinforcement which can be used to control vibration (ground and airblast) levels in many situations. Pattern Analyser is a graphical software program for the design and editing of blast designs. With the help of this software engineers and blasting personnel can optimise the layout and initiation sequence of blasts. Analysis of data imported from other blast design software can also be carried out.

By change of delay timing or sequence, wave reinforcement can be avoided thus lowering of vibration levels as shown in Figure 6.

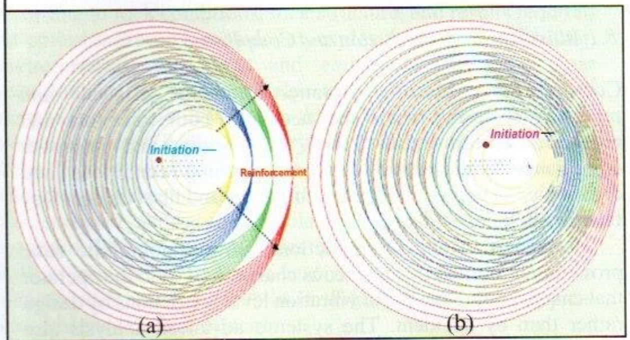


Figure 6 - (a) Wave Reinforcement (b) Non-reinforcement by Change of Delay Timing

8.3 Flyrock Prediction Software

Inputs to the software are charge mass, burden or stemming height, and a site constant that lays within a general range that can be fine-tuned by site calibration and the output is flyrock distance (Richards and Moore, 2004). This 'design your own flyrock' quantification can be used to establish both safe clearance distances, and the critical range of burdens and stemming heights (Figure 7).

The zone of flyrock travel is indicated by this tool. Using safety factors, danger zones for machinery and person are indicated respectively. If it is not possible remove any structure or person, then one can modify the charging of holes.

8.4 Dust Plume Movement

Blasting operations can generate large quantities of fugitive dust. When this dust is released in an uncontrolled manner, it can cause widespread nuisance and potential health concerns for on-site personnel and surrounding communities. Though the blasting dust plume is raised for a few minutes but most of the dust settles in and around mining area and some of it is dispersed before settling down. Depending on meteorological conditions, the dust dispersal can travel to substantial distances endangering health of communities. Generation of fines and dust is influenced by several blasting and rock parameters (Bhandari et al, 2004).

Meteorological conditions such as wind speed and direction, temperature, cloud cover and humidity will affect the dispersion of airborne dust. Atmospheric stability affects dispersion of the emitted plume, determining the extent of the vertical and horizontal, transverse and axial spread of the emitted particulates. Thus, the dispersal of dust plume resulting from blasting is an important area which needs attention. A computer model has been developed to simulate the dispersal of dust (Kumar and Bhandari, 2001, 2002).

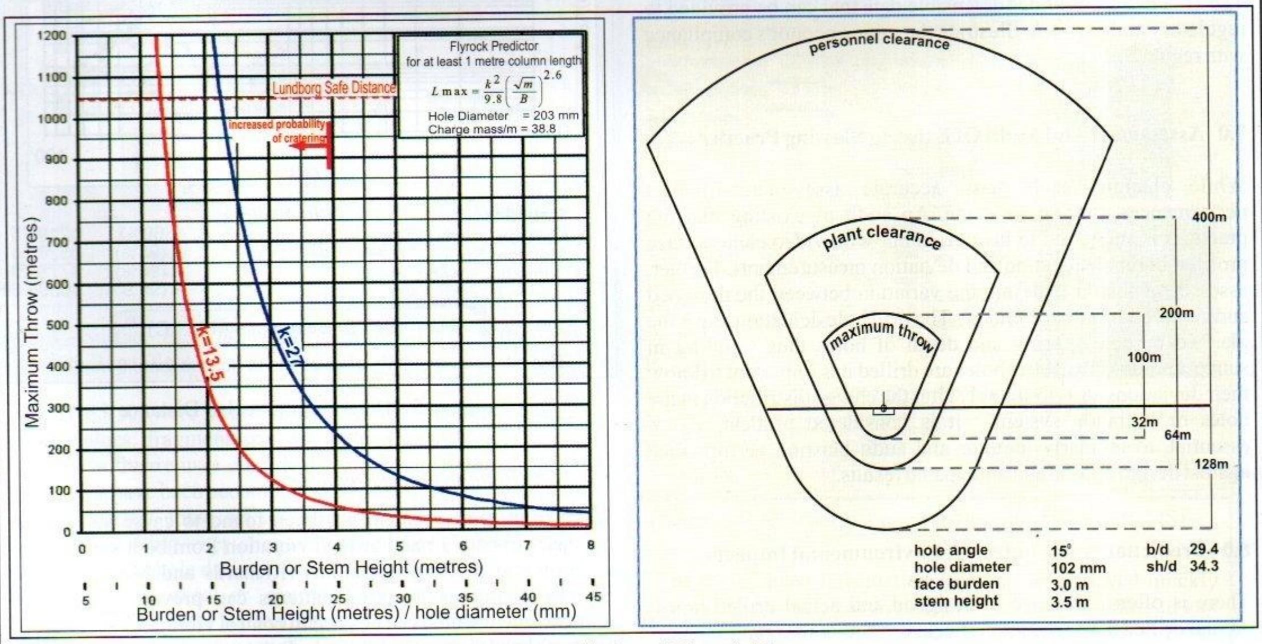


Figure 7 - Prediction of Flyrock Distance

Data input is divided in three parts: blast data, atmospheric data and ground contour data.

Blast Data: Total quantity of dust released, Distance from the blast to the point of observation, Angle of top of column of dust of the blast, Latitude of blast site, Height of blast site (above mean sea level).

a) Atmosphere Data: Surface Pressure, Variation from mean wind speed: Standard variation of speed in meter per second. This is obtained by observation at the blast site in the straight line. Wind speed at 850 hPa, Saturation Mixing Ratio, Mixing condensation level: Surface Wind direction: Height of 850 hPa above MSL.

b) Ground Contour Data: This data is collected by the user before the blast with the help of contour map.

Then the software computes the values of the concentration at different distances in the down wind direction at level (zi) at horizontal interval of ___ m and at lateral distances from the central line on either side at the lateral interval of ____m up to ____m for all (zi) varying from 2m agl (above ground level) to 24 agl in steps of 2m. 3D axis on the point of blast is drawn and converts the x; y coordinates to 3-D coordinates and plots them on the 3-D- coordinate system. Then the movement of plume at different levels is distinctly shown. The software displays 3D movement of plume. A typical display is given in Figure 8.

This prediction allows one to vary delay blasting and/or to avoid blasting during adverse atmospheric conditions.

9.0 Measurement Before, During And After Blast :

Field monitoring and control tools, if properly used, can be valuable in the optimization of blasts. Information must be collected during drilling about the rock strata to decide loading pattern of blast holes. If the field control is poor and implementation of the design is improper, even a very good design will not produce the desired results. Blast should be executed and monitored meticulously. The measurements which can be used to improve blasting execution include:

9.1 Pre-Blast Records

- Geology and rock properties
- Blasthole logging of rock properties
- Blasthole audits (accuracy of drilling)
- Explosive charge verification
- Down hole explosive product densities/pressures

Pre- blast monitoring should also be done cautiously to check deviation in the values of design parameters from the actual ones (Rodgers, 1999). All details like hole position, hole depths, nature and condition of holes, type and quantity of explosives; initiation system, sequence and delay timings are to be recorded. Prior to the introduction of new methods & technologies as working tools in mines, it was not possible to directly measure to inaccessible locations on rock faces. If a person could not occupy the point, only indirect measurements could be made. This led to direct and significant problems with blasting, including fly rock and air blast,

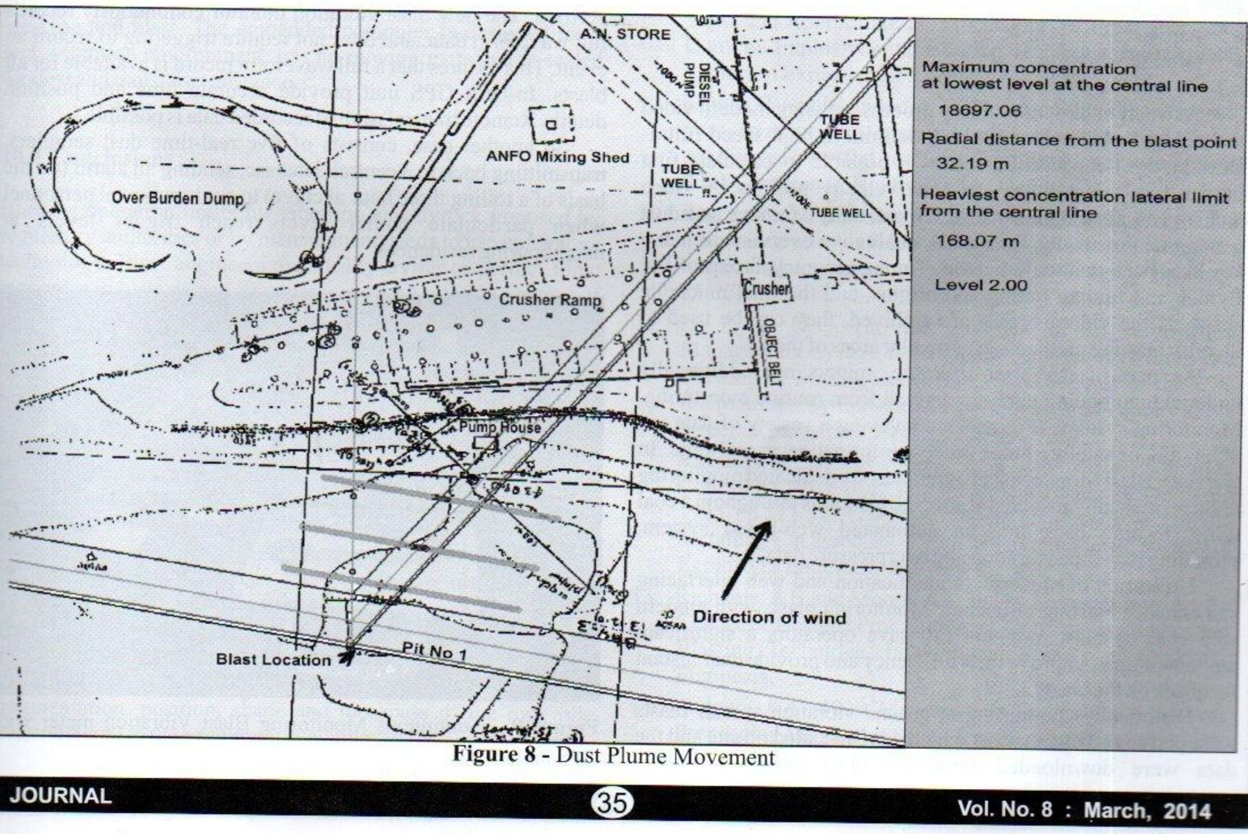


Figure 8 - Dust Plume Movement

excessive vibrations, inadequate fragmentation and tight digging, back break, coal damage (all of which may be caused by excessive front row burdens),. Blast planners have increasing capability—and availability—of simplified photogrammetric/stereo photogram- to profile bench faces and other terrain features of interest. A highly automated workflow that begins with the simple task of photographing, say, a bench face from slightly different angles with a calibrated digital SLR camera, then using sophisticated algorithms in software to process the photos into a 3-D image, and applying the resultant information to fit drill-pattern layout to the actual bench face geometry.

In cases where larger areas or complex shapes extend beyond the information available from a single stereoscopic image pair, the area is recorded by several overlapping 3-D images. Once the 3-D image of a bench face is generated, users can employ Blast Planning software, entering basic geometric parameters such as burden, spacing, or inclination of the boreholes and allowing the system to place them accordingly. Each borehole is profiled, and hole locations are viewable in 3-D and plan view.

9.2 Monitoring During the Blast

High speed photography/ videography (initiation, time to first movement, stemming ejection, flyrock movement)

- Velocity of detonation
- Face velocities
- Flyrock
- Airblast
- Ground vibration

As a part of blast monitoring process, utilising modern video technology, which provides high-definition, high-speed (ultra-slow motion) capabilities, makes it possible to calculate first burden movement times and face velocity profiles. A video archive can shed light on a pit's 'blastability', fuming and dust generation propensity, for a quick qualitative overview of many key blast performance indicators-Timing accuracy, face profiles, flyrock and fuming timing and origins, and the final muckpile shape. If the video records are archived, they can be used to identify blasting problems in particular areas of the pit.

As part of the blast lifecycle, miners are additionally undertaking ongoing analysis derived from routine monitoring. Monitoring systems (Figure 9), conveying a variety of data via 3G, radio, or satellite links, process information in real-time. In one case, Blast Monitoring Program has six dedicated monitoring units permanently installed at specific locations throughout a coal mine, feeding back into an automated web-based system, providing real-time vibration and overpressure data.

Utilisation of modern communication and web interfacing can enhance blasting efficiency. Monitoring blasts with modern web enabled blast monitors can save operators a significant amount of time, improve their efficiency and provide near instant feedback on the blasts.

Historically, monitoring of ground vibration and air blasts were performed by monitors which were installed on site and the data were downloaded after the blast event. However, improvements in communication and software technology have now enabled blasting data to be monitored online via a web portal.

Modern blast monitors can now be installed on site which continuously and automatically supervised by a remote software package on a web server. This server software communicates both with the remote monitoring stations and users via the internet. Blast results can be automatically collected from the stations, collated and are then available to users within minutes of the blast. Users view blast results, produce reports and interact with the server software via the web browser.

Using 'internet aware' mobile devices that have GPRS or 3G capability, such as a notebook PC, pocket PC, PDA or mobile phone, blast results can be retrieved from the office, home or vehicle – regardless of the geographical distance of the user to the blast site. This allows the users of these types of devices to retrieve blast results and control the blast monitoring system from virtually anywhere.

The use of this technology provides near real time data to mine operators, enabling them to access the impact of each individual blast and take corrective actions should a blasting campaign threaten to exceed local regulations. The system also provides defendable data that can be provided to regulatory authorities to illustrate the mine operator's compliance with regulations.

Blast Vibration Monitor permits the measurements of air overpressure and ground vibration resulting from all blasts, with a waveform record that permits the peak levels recorded to be verified. The new blast vibration monitor continuously records full waveform data, and does not require triggering to record an event. This ensures that a full waveform record is available for all blasts. In-built GPS unit provide accurate time and position details. Remote transmission of recorded data is possible.

In another case, consists of five real-time dust samplers, transmitting back to a central database, sending an alarm (on the basis of a rolling three hour average) to environmental personnel when particulate matter levels reach trigger levels at neighbouring residences.

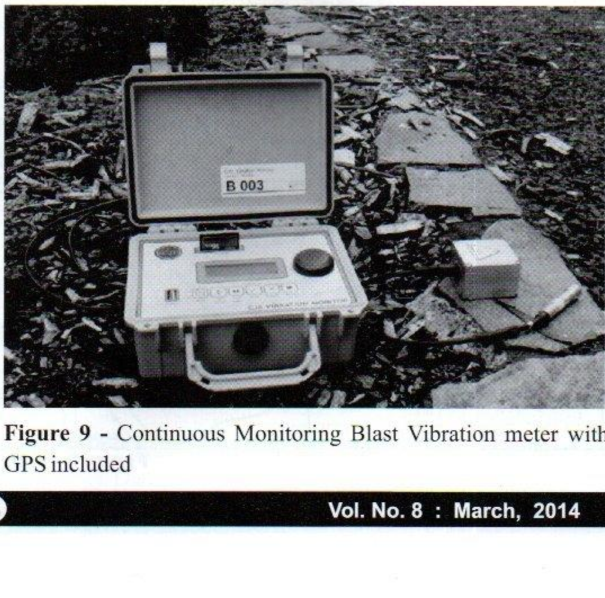


Figure 9 - Continuous Monitoring Blast Vibration meter with GPS included

9.3 Post Blast Measurements/Observations

- Muck pile characteristics (Geometry, height and displacement/ swelling)
- Induced cracks and overbreaks (rock damage at blast limits) and toes, floor
- Fragmentation/size distribution; oversize/fine assessment
- Loading performance of excavator
- Crusher performance

The fields of applications of new technologies can be listed: muckpile shape, muck pile profiling to determine throw, cast blasting, muck-pile models to determine swell & blasting effectiveness, flyrock and oversize, new computer aided techniques to better calculate actual burdens at all points on rock face.

Quick and accurate measurement of fragment size distribution is essential for managing fragmented rock and other materials. Various fragmentation measurement techniques are used by industry/researchers but most of the methods are time consuming and not precise. However, several automated image based granulometry system use digital image analysis of rock photographs and video tape images to determine fragment size distribution are being used by industry. Recently technique has been adopted with video camera and fragmentation size and quality assessment directly on shovel, with continuous, detailed fragmentation results combined with shovel GPS information produces results that are attributed to a specific area of the pit, ore-type and blast. The embedded computer is designed for a high-vibration environment, has no moving parts and is sealed for dust and moisture resistance.

10.0 Conclusions :

Blasting operation limits for vibration and flyrock imposed by regulatory authorities or by management needs to use innovative technology. Blast engineers are ideally trying to predict three outcomes in blast design: fragmentation (the size distribution of the blasted material), movement (where the grade and waste will end up), and environmental impacts.

Use of information technology for storing data, design, analysis and prediction of results helps in better control and optimization of mining operations. Data base helps to quickly respond to information and remain successful in today's competitive market place. By the use of information technology many projects can reduce complaints and improve efficiency. It is worthwhile to look at some technologies which are being adopted in the mining industry to make blasting operations efficient and reduce environmental impact. Use of a drilling machine with a GPS guided system can accurately locate the planned location and can determine the exact collar elevation at each drill location. The overall success of a blast is usually assessed by the speed and efficiency of subsequent digging operations. Thus the fragmentation, position, shape and looseness of the rock pile must be suited to the equipment available.

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Determination of Small-scale Detonation Pressure Determination of Explosives from Crater Size Effects on Spherical Indentation - Part 1

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Abstract

Explosives power and detonation pressure are two of the performance characteristics that define the reactive behaviour of explosives. Experimental evidence to the detonation in confined geometry is the depth and shape of the dent created on a lead witness plate. Plate dent tests are commonly used to compare the performance of different energetic materials. The indentation depth resulting from the shock wave can be related to the peak pressure of the detonation and the width of the cavity at half depth can be interpreted as a function of the detonation wave spreading. The depth and width can thus be correlated to the energy output of the energetic material. In materials science, continuous indention tests allow the amount of penetration of an indenter into a material to be measured as a function of an applied load and are commonly used to measure the elastic moduli of materials. Understanding the witness block material properties allows for indentation profile variations to be ascribed to variations in the energetic material properties. This paper reports on the work conducted towards establishing a sphere indentation test method that can reliably produce measurable indentations on witness plates. These measurements will be interpreted to quantitatively show the detonation pressure characteristics of the explosive formulations evaluated.

Keywords : *Explosives, Power, Performance, Indentation, Sphere*

1.0 Introduction :

Energetic materials are developed for use in specific environments and hence the characterisation of such materials can form a fundamental part of the development process. Over many years small-scale tests have been used to determine explosive characteristics even though these results are largely qualitative. Explosives power and detonation pressure are two of the performance characteristics that defines the reactive behaviour of explosives. Explosive performance of an energetic material can be influenced by numerous factors which include particle size, density, morphology and the geometry of application. When these factors are combined with the variations induced by the experimental test set-up, it is probable that accuracy and repeatability can often be compromised. Experimental evidence to the detonation in confined geometry is the depth and shape of the dent created on a lead witness plate [1]. Plate dent tests are commonly used to compare the performance of different energetic materials. The Floret test is an example of a plate dent test. The Floret test measures the dent produced, on a copper witness plate, as a result of a detonating explosive [2]. The depth and shape of the cavity produced are considered to be a semi-quantitative measure of the explosive energy and detonation spreading divergence characteristics respectively.

Later developments of the floret test led to a more quantitative results but even this method described by Kennedy et al. focus on indentations created by an acceptor explosives and entails a complex data acquisition methodology. Similarly the lead plate test produces qualitative experimental evidence to the detonation reaction through the depth and shape of the dent created on a lead plate [3]. The indentation depth resulting from the shock wave can be related to the detonation pressure of the detonation and the width of the cavity at half depth can be interpreted as a function of the detonation wave spreading [4]. The depth and width can thus be correlated to the energy output of the energetic material.

In material science continuous indention tests permit the amount of penetration of an indenter into a material to be measured as a function of an applied load and are commonly used to measure the elastic moduli of materials [5]. A characteristic feature these indentation experiments is the development of a plastic zone created in the witness plate or block. Selectively combining the theory around the continuous indentation test and explosive indentation tests will better describe the indentation profile obtained by the detonating explosives. Understanding the witness block material properties allows for indentation profile variations to be ascribed to variations in the energetic material properties.

This paper reports the work conducted towards establishing a sphere indentation test method in measuring indentations on witness plates, ensuring an interpretation of objective measurements of detonation pressure in establishing explosive performance of the formulations. These measurements will be interpreted to quantitatively show the detonation pressure characteristics of the explosive formulations evaluated.

2.0 Experimental :

The test set-up primarily consisted of Explosives filled initiators that were positioned on top of the 10 mm sphere. The 10 mm hardened sphere and initiator was then positioned on top of an aluminium witness block. An initiator was then placed so that the initiator rests on top of the sphere. The sphere was ground down to have a flat surface with a diameter similar to the outside diameter of the initiator. Aluminium grade 6082 was used as the material of choice for the witness block.

The initiators used were prepared to contain the different explosives formulations that were evaluated. The explosives mass was kept constant at 400 milligrams (mg). The explosive formulations were consolidated at different pressure intervals in order to obtain different explosives densities. Copper shells were used as the standard carrier into which the explosive formulations were dosed before being consolidated (figure 1). A second initiator was positioned ontop of the test explosive charge. The second initiator is used to initiate the test explosive. This test configuration is shown in Figure 1

In order to ensure that the initiator and sphere were perpendicular to the witness block, the initiator and sphere were positioned inside a plastic holder. Figure 2 shows the experimental set-up. The sphere was cut to have a flat surface with a diameter equal to the outer diameter of the detonator shell. The formulations evaluated were PETN and PETN 95% / EVA 5% (THR 211). EVA is the polymer Ethylvenylacetate.

2.1 Methodology

The diameters of the indentations obtained during the test set-up described earlier were measured using a light microscope. Barbato and Desogus refer to optical methods used to measure the indentations obtained when performing the Vickers and Brinell tests (indentation tests performed to measure harness characteristics of materials). They concluded that the effects of differences in optical microscopes are not taken into account and thus questions the accuracy of measurements taken using an optical microscope [6]. A multiple of variables are present in the test set-up used in this evaluation. The mass of explosives, the height of the explosives after consolidation and the density were all measured to a two decimal accuracy. Considering these parameters the use of an optical light microspore to measure indentation diameters was accepted as an accurate means to measure indentation depth.

Richmond et al went a step further and stated the problem of sphere indentation to be a three variable problem, two dimensions and time [7]. Brinell observed that the mean indentation pressure generally increased during penetration whereas the ration of force to surface area of the indentation was nearly constant. The proportionality coefficient depends on the work hardening of the material giving negative values (sinking-in type impressions) for materials with high work hardening [8]. The work hardening effect will thus be visible in the profile of the impressions obtained. Raised lip impressions were obtained for all of the tests conducted (Figure 3)

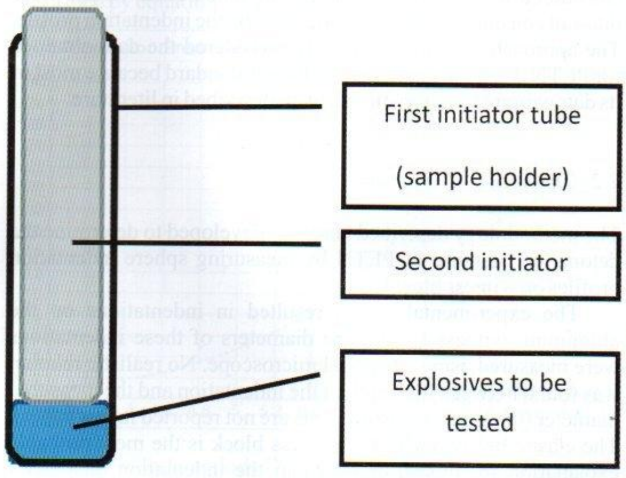

Figure 1 - Initiator Construction

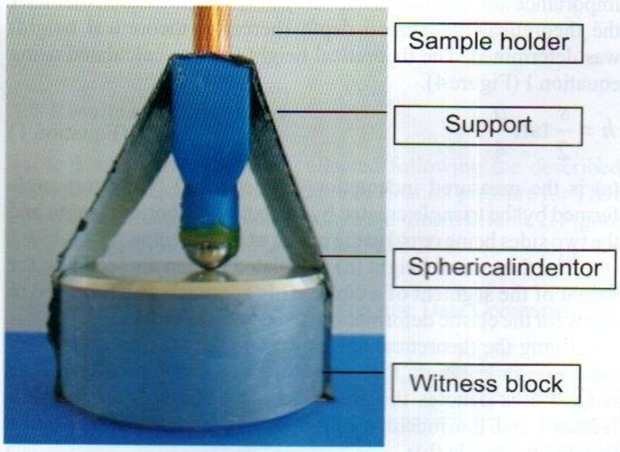

Figure 2 - Generic Experimental set-up

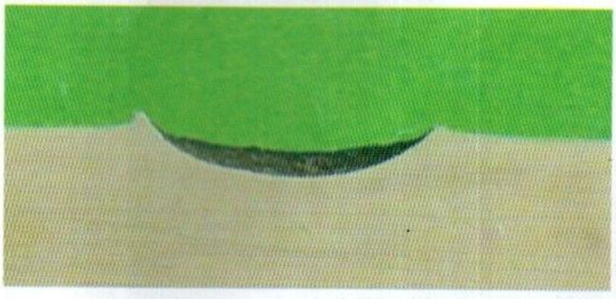

Figure 3 - Raised Lip Indentations Indicating no Work Hardening of Witness Block.

Accepting that workhardening did not occur in this test and that indentation pressure generally increases with penetration, other possible effects that can influence the indentation profile was considered to be negligible. These so-called other effects were thus not considered as having any effect on the indentation profile. The approach described next only considered the data obtained for PETN. PETN was selected as the set standard because most of its detonation characteristics are well described in literature.

2.2 Theoretical Evaluation

The methodology described here was developed to determine the detonation pressure of PETN by measuring sphere indentation profiles on witness blocks.

The experimental set-up resulted in indentations on the aluminium witness block. The diameters of these indentations were measured using an optical microscope. No realistic relation was found between the depth of the indentation and the measured diameter (the actual measurements are not reported in this paper). The elastic behaviour of the witness block is the most probable explanation for this discrepancy in the indentation diameter / depth relation. In this study the diameter of the indentation was taken as the most accurate dimension instead of the indentation dept. In further calculations the indentation depth (h) is of importance and claimed that h = f(s). From the measured diameter the theoretical indentation depth (hereafter theoretical height) was determined. The theoretical height (h) was calculated using equation 1 (Figure 4).

$$h = \frac{s}{2}\tan\frac{a}{4} \qquad \text{(Equation 1)}$$

(s) is the measured indentation diameter and () the top angle formed by the triangle created by (s), being the bottom length and the two sides being equal to the radius of the indentor.

The theoretical height (h) calculated is then argued to be the height of the segment of a circle. This approach was followed to allow for the elastic deformation of the witness block.

Using the theoretical height (h) and the measured diameter (s) of the indentation, the contact area (φ) was calculated. The contact area denotes the area of contact between the indentor (sphere) and the indentee (witness block) at maximum depth (theoretical height (h)).

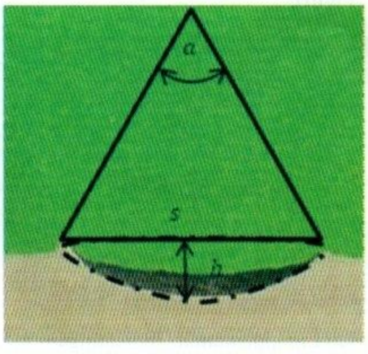

Figure 4: Describing Equation 1

The indentation is three dimensional and assumes the profile of a segment of a sphere. The contact area used further in this study is the area of the segment of a sphere minus the area of the circle (top of the segment of the sphere). In equation 2 (φ) denotes the calculated contact area, (h) is the theoretical height and (r) the radius of (s) (therefore r=s/2), the measured diameter.

$$\varphi = 2\pi sh - \pi r^2 \qquad \text{(Equation 2)}$$

The indentation on the witness block has been formed when applying energy for a certain period of time. The amount of energy and the duration of the available energy will contribute to the magnitude of the indentation observed. During the detonation process energy retention is a function of the geometry and environment of application of the explosives in question. Different models exist that can be used to allow for energy losses due to lack of confinement or other factors. The cylindrical charge driving plate principle is a Gurney model used to determine the fragment velocity of a fragment accelerated from the end of a cylindrical charge. These models allow for velocity predictions of fragments accelerated from unconfined and confined explosives charges to be conducted [10]. This Gurney model was the first step in determining the fragment velocity and later the time of reaction. The Gurney model mentioned however produced questionable fragment velocities (results of this evaluation are not shown in this report). A possible explanation for this can be that the experimental set-up is too small for the Gurney model to be applicable in this case. If we consider the actual test set-upwe can argue that we transmit a detonation between two cylindrical charges. Johansson and Perssonreported that the detonation front of the receptor charge (in this case the test explosive charge) has emanated from the interior of the charge a certain distance from the end surface of the charge. This distance is however a critical value dependent on the explosive and charge diameter [11]. In this experimental set-up the charge diameter is approximately three times the critical diameter of the explosives used and the initiating explosives is of significant mass that the transfer of initiation can happen almost instantaneously.Based on this argument it is claimed that the test-explosive reacts completely. Based on preceding argument this time (t), or the duration of the reaction is assumed to be equal to the duration of the detonation reaction of the test explosives. The time (t), or duration of the reaction, is calculated using the theoretical velocity of detonation (VOD_t) with the actual (measured) height (h_e) of the explosives column. The time (t) was calculated using equation 3.

$$t = \frac{h_e}{VOD_t} \qquad \text{(Equation 3)}$$

Using Newton's motion equations, acceleration (ω), was determined next. The displacement into the witness block is the theoretical height determined earlier (h), (t) is the time taken for the reaction of the explosives to be completed. (v) is the initial velocity of the indentor and taken as nil (assuming the metal sphere is stationary upon application of the detonation energy).The sphere changes from a stationary position to a position where it travels at maximum velocity in the witness block. Hereafter it decelerates again until it reaches a point where it no longer moves. The acceleration (ω) determined here is thus a normalised acceleration over a specific time (t) and distance (h).

position where it travels at maximum velocity in the witness block. Hereafter it decelerates again until it reaches a point where it no longer moves. The acceleration (ω) determined here is thus a normalised acceleration over a specific time (t) and distance (h).

$$h = \upsilon t + \frac{1}{2}\omega t^2 \qquad \text{(Equation 4)}$$

The force (F) that has been applied during the detonation can now be determined by:

$$F = M\omega \qquad \text{(Equation 5)}$$

(M) is the mass of the sphere in kg, (ω) is the acceleration obtained from equation 4.

The detonation pressure (P) in pascal was determined by equation 6.

$$P = \frac{F}{\varphi} \qquad \text{(Equation 6)}$$

(F) is the force determined above and (φ) is the contact area. (γ) denotes a Young's modulus fraction. The Young's modulus is a measure of the ability of a material to withstand changes in length when under lengthwise tension or compression [12]. In this study a Young,s modulus fraction was used to allow for material behaviour of the witness block material and the indentor.(ξ) is the Poison ration and € represent the Young'modulus. (*w*) represent the witness block and (*b*) the indentor.

$$\gamma = \left(\frac{1-\varepsilon_w{}^2}{E_w}\right) + \frac{\left(\frac{1-\varepsilon_b{}^2}{E_b}\right)}{2} \qquad \text{(Equation 7)}$$

From equation 7 a value of 0.01488 is obtained when the Young's modulus of aluminium is 70 and the poison ratio is 0.33 and the ball values are 213 and 29 respectively. When determining the pressure given by equation 6 it is found that it differ from the theoretical detonation pressure given by equation 8 [1]:

$$P_{cj} = \frac{(\rho)VOD^2}{4} \qquad \text{(Equation 8)}$$

Here the density of the explosives and VOD the velocity of detonation. By dividing results obtained from equation 6 by the results from equation 8 an average valueof 0.01484 is obtained (let this value be □). This correlates well with the value described by equation 7. The value obtained from equation 7 is not unit less as and could therefore not be used as a correction factor. The value (□) is used as the correction factor.

The following equation can now be used to determine the detonation pressure (cj pressure) of PETN by obtaining its indentation diameter.

$$P = \frac{F}{\varphi}\alpha \qquad \text{(Equation 9)}$$

Where:

$$F = M\omega$$
$$\varphi = 2\pi sh - \pi r^2$$
$$\alpha = 0.01484$$

When the data from equation 9 are plotted (Figure 5) it follows the function given in equation 10. The detonation pressure and indentation diameter relation of PETN can now be described by equation 10;

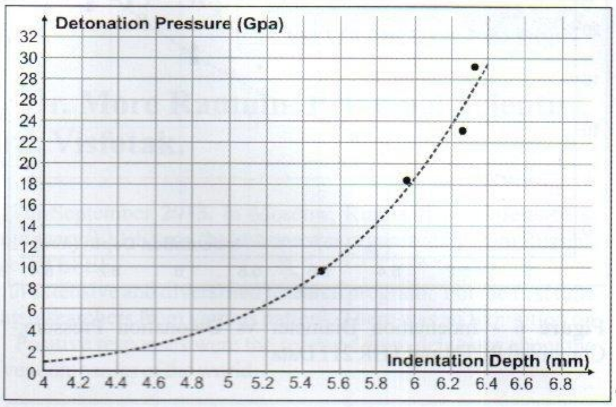

Figure 5 - Indentation Diameter vs Detonation Pressure showing the Function of the Curve

$$\frac{dy}{dx} 3.2265659x10^{-5}(x)^{7.396452} \qquad \text{(Equation 10)}$$

3.0 Results and Discussions

Table 1 summarise the data collected following the described methodology. From equation 10 the detonation pressure for THR 211 was calculated. The data obtained are shown in table 2. Figure 6 & 7 compare the results of PETN and THR 211.

Table 1 - PETNVOD Corrected Pressure Data Comparison

Density ρ (G/cc)	VOD Calc. (Km/sec.)	VOD Vixin-i (Km/sec)	Pressure (P) Calc. $(x10^9)$ (Pa)	Pressure (P) Vixen-i $(x10^9)$ (Pa)	Correction Factor Y	Pressure (P) Corrected $(x10^9)$ (Pa)	% Deviation P Vixen.vs P cor.
1.03	6.370	5.751	10.449	9.120	0.014840	9.5718	4.72
1.33	7.270	6.918	17.573	16.822	0.014840	18.149	7.31
1.51	7.810	7.486	23.026	22.285	0.014840	23.002	3.11
1.66	8.260	7.942	28.315	29.434	0.014840	29.030	1.37

Table 2 - THR 211 VOD Corrected Pressure Data Comparison

Density ρ (G/cc)	VOD Calc. (Km/sec.)	VOD Vixin-i (Km/sec)	Pressure (P) Calc. $(x10^9)$ (Pa)	Pressure (P) Vixen-i $(x10^9)$ (Pa)	Correction Factor	Pressure (P) Corrected $(x10^9)$ (Pa)	% Deviation P Vixen.vs P cor.
1.05	6.283	5.940	10.362	9.909	Equation.10	8.090	18.35
1.31	7.183	6.937	16.897	16.271	Equation 10	13.763	15.41
1,53	7.783	7.408	23.170	24.414	Equation 10	21.199	13.17
1.69	8.383	7.969	29.691	27.726	Equation 10	26.895	3.00

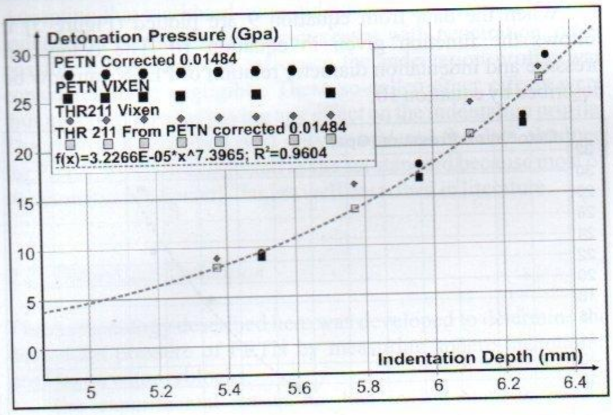

Figure 6 - Indentation Diameter vs Detonation Pressure, Combined PETN and THR 211 Data

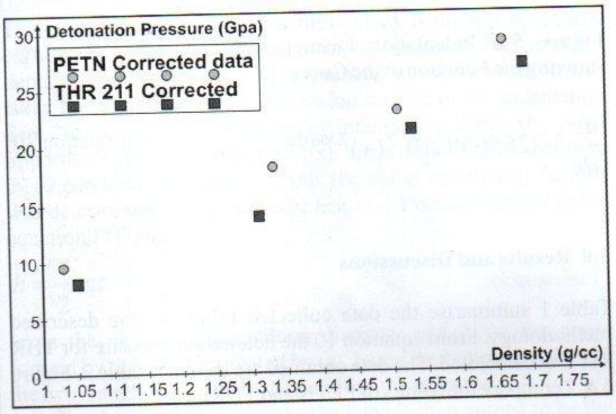

Figure 7 - Density vs detonation Pressure, Combined PETN and THR 211 Data

When developing new explosive formulations certain characteristics can be easily obtained from theoretical calculations and or tests. The test methodology described in this paper sets the platform to determine parameters such as detonation pressure and velocity of detonation through a fairly simple and cost effective test. The method developed, accurately relates the indentation profile on a witness block to the detonation pressure of the explosive formulation tested. PETN is a well described explosive formulation and was therefore used as the standard in the development of this methodology. The results obtained allow for quantitative interpretation in contrast with traditional plate indentation tests that only produce qualitative data. The main reason for the improved accuracy is that the sphere impact test eliminates the effect of the spreading detonation wave in the witness plate. In this evaluation the explosive formulation THR 211 was characterised by determining the detonation pressure of the formulation compared to that of PETN. From the detonation pressure the VOD could be determined.

The results obtained for the detonation pressure of PETN described in this study is applicable in the density range of 1.0 to 1.9 g/cc from a 400mg explosive column. In this evaluation copper shells were used as the means of confining the energetic material. This novel test methodology, to determine the detonation pressure of an explosive formulation, is valid when the test is performed inside these parameters and only for PETN. Efforts to bettor relate this methodology to other explosives formulations are currently being conducted.

4.0 Acknowledgments

The authors would like to thank AEL Mining Services for their financial support and use of their facilities.

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EFEE

The 7th World Conference on Explosives and Blasting, Moscow, Russia, 15th-17th September, 2013.

НОИВ

I. Summary Report on the Conference by Dr. More Ramulu, Principal Scientist, CSIR-CIMFR / Member, Editorial Board, Visfotak.

The 7th World on Explosives and Blasting, was held during15th-17th September 2013, in Moscow, Russia. The conference is organized in every two years by European Federation of Explosive Engineers (EFEE) and the last one was organized by from Russian National Organization of Explosives Engineers, Moscow under the ages of EFEE.

It was a successful conference with technical papers presented with extensive and diversified research program. For the first time - it included about 80 technical papers, by almost all the active blasting researchers from various nations. There was an Exhibition on advanced blasting instruments and services, which was very useful. Positive responses were the received from delegates about the exhibits of goods and services, presented by most of the large explosives companies of the world.

The brief summary of the conference is as follows:

- Delegates - 334 (190 English-speaking, 144 Russian-speaking).
- Sponsors - 32 (11 English-speaking, 21 Russian-speaking).
- Exhibitors - 70 (48 English-speaking, 22 Russian-speaking).
- Media partners - 19 (19 Russian-speaking).
- Total - 455 (249 English-speaking, 206 Russian-speaking).

The technical programs covered in the conference include:

- Blast casting
- Blasting Case studies
- Demolition
- EU directives and Harmonisation work
- Management covering blast design
- Physics and mechanics of blast destruction
- Special blasting techniques
- Technological developments

Dr. More Ramulu (R) with Prof. R. Holmberg, General Secretary, EFEE (C)

Despite the great efforts for the success of the conference from organisers, local language had become a barrier for English speaking delegates. The participation from India include **CSIR-Central Institute of Mining & Fuel Research, Orica (India), Rocktech projects and systems. Although the participation is very less in comparison to other active mining countries,** the quality of papers was well appreciated by participants and organisers. As the event was conducted freshly after the grand event of Fragblast-10 in India, there was a special attention amongst most of the delegates towards India and its upcoming R&D endeavours.

The conference ended by a very high technical note. The next **8th EFEE World Conference will be held during April 26th-28th, 2015 in Lyon, France.**

More details of the conference can be known from the following link: www.efee.eu

Conclusion :

India is lagging behind in keeping abreast with the latest explosive technology and also the global trends in blasting technology.

The scale of application of blasting technology and the amazing quantity of muck throw by cast blasting are decades ahead of Indian applications. In this context, software applications and modelling, the day to day application of state of the art instrumentation for measuring and monitoring pre-blast and post-blast effects, are routine aspects of blasting methodology, where India has to quickly catch-up.

II. Selected Abstracts from the Proceedings of the Conference

We are grateful to Prof. R. Holmberg, Secretary General, EFEE for granting permission to publish the selected abstracts from the proceedings of the 7th World Conference on Explosives and Blasting, Moscow, Russia, vide his e-mail dated 7th February, 2014.

Editor

The Sonic Effect : Revolutionizing Drilling and Blasting

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Abstract

Over the last two decades, technical innovations have led to an improved scientific understanding of optimum detonation, fragmentation and the reduction of unwanted ground vibrations. This enables blast engineers to design and tailor blast operations on a statistically sound basis and to assess the results in a physically objective manner. The results of analysing hundreds of open pit and underground blasts performed by the first author have revealed sonicity (ratios between detonation velocity and wave speeds) to be the single dominant parameter which controls vibrations both above ground and underground. Since sonicity controls the relationship between detonation, fragmentation and vibration immission, it can be harnessed to achieve higher fragmentation accompanied by lower levels of vibrations without increasing the energy of a blast. As a result, new advanced blasting theory based on sonicity enables blast engineers to design larger blasts and optimize fragmentation without increasing unwanted Vibrations.

The Sonic Effect

Austrian physicist ERNST MACH discovered in 1886 that the sonic effect is caused by a body moving through the air at (P) or the speed of sound. The acceleration of an aircraft causes air to be highly compressed and then expand explosively behind the aircraft when it reaches the sound barrier. The sudden changes of pressure emanating from the aircraft at this time are perceived on the ground as a 'sonic boom'. C p

H.P. ROSSMANITH and colleagues (1998) found out by numerical modelling and laboratory blasting tests on Plexiglas models that this interaction between velocities also occurs in liquids and solids. Various sonic effects are produced around a detonating charge by the reaction of the shock wave with the (pressure) wave velocity and S (shear) wave velocity of the rock mass (Figure 1).

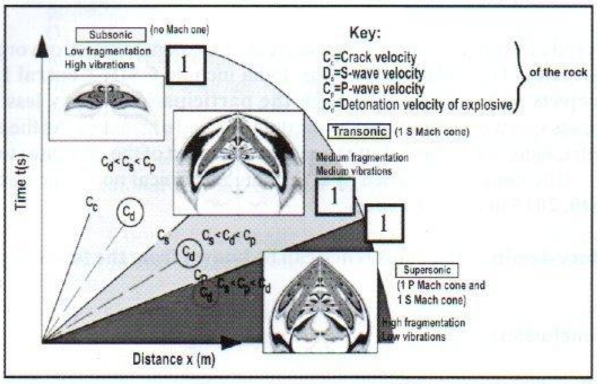

Figure 1 - Principle of the sonic effect shown in relation to the velocities cS, cP and cd in a simplified TIME-DISTANCE (LAGRANGE) DIAGRAM (the images marked 1 are taken from ROSSMANITH ET AL 1998)

The Development of a Novel Non-metallic Initiator for Explosives

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Abstract

This research study reports on the design and development of a novel non-metallic initiating system. The current commercial initiating system comprises highly toxic and environmentally unfriendly primary explosive called lead azide, encapsulated in a metallic shell. This study encompasses the development of a non-metallic delay element, the development of a deflagration to detonation transition system (DDTS) and the development of a non-metallic detonator shell. The current system consists of an aluminium element that is filled with a pyrotechnic delay powders that, upon burning, produce extremely high temperatures and a large. This development appears to overcome the problem of uncontrolled generation of excess heat and gas to a more reliably constant burning rate in a non-metallic environment. The deflagration to detonation system has been developed to replace the traditiona l lead azide used in the current initiator design. A DDTS has been designed to successfully pick up from a flame stimulus and then produce a detonation output strong enough to initiate a Pentaerythritol tetranitrate (PETN) base charge in the initiator. The DDTS functions within the geometrical constraints set by the initiator shell design. The non-metallic shell design thus contains the non-metallic delay element, the DDTS and a base charge which reliably initiates either an explosives booster or a cap sensitive emulsion explosive. This development paves the way for more modem and technologically advanced manufacturing and assembling techniques to be used in the manufacturing and assembling of initiators and initiating systems.

Non-metallic Explosive Initiator

The non-metallic explosive initiator has been developed to reliably pick up from the energy input given by shock tube. This energy was taken up by the first increment of a chemical delay element. The material of the casing of the delay element was identified to be super toughened nylon that has been cross-linked. The delay element transfers its energy to a DDTS consisting of a nano-porous based silicon explosive formulation utilising a tetrazole explosive as oxidiser. The second and third increments of the DDTS are tetrazole explosives. The DDTS is strong enough to initiate the pressable PBX explosive formulation specifically developed for this application. This PBX explosive formulation a power output that is strong enough to reliably initiate the next step in the explosive train. The non-metallic initiator is completely heavy metal free.

Figure - New non Metallic Initiator Design

Detonation Characteristics of Alternative Mining Explosives Based on Hydrogen Peroxide as the Oxidising Agent

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Abstract

The detonation properties of mixtures made with Hydrogen Peroxide (HP) and fuel were studied. The mixtures were formulated in a similar way to commercial explosives that are currently used in the mining industry. Unconfined velocities of detonation (VoD) tests of HP sensitised mixtures were conducted. For reliable detonation to occur a minimum level of sensitisation must be accomplished. The adequately sensitised mixtures are able to detonate at velocities in the range of 2600 to 5000 mis, with a critical diameter of the order of 23 mm. The recorded detonation velocities were clearly dependent on the mixture density and charge diameter. Based on these preliminary trials, we can envisage that, if properly managed, HP fuel-based explosives may be an alternative to Ammonium Nitrate (AN) based products. However there is still a long way before moving to a commercial product, as many aspects associated with the safe use ofHP-based explosives must be further studied.

Improved Blasting Performance through Precise Initiation

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Abstract

Blast-induced fragmentation is an important factor in optimization of downstream processes in a mine. Several researchers believe that the fragmentation can be improved by means of precise short inter-hole delay times. Six full-scale trials with different interhole delay times of 1, 3, 6 and 42 ms (0.14, 0.42, 0.84 and 6 mslm of burden, respectively) were conducted in BolidenAitik open pit copper mine in Sweden. Electronic detonators were used for short inter-hole delay times, which correspond to different wave interactions between the neighboring blast holes. All the trials were carried out in more or less similar geological conditions. MWD data, swelling, fragmentation and crusher efficiency have been evaluated in the trials. Based on these trials, the short inter-hole delay times did not have a significant effect on fragmentation, swelling and crushability. However, a reduced number of boulders was observed for short delays, suggesting that the coarse region of the distnlrution curve was influenced rather than the fine part of it.

MWD Analysis

Drill rigs in the Aitik mine are equipped with Aquila Drill Management system. One of its sub-systems is Measure While Drilling (MWD) that measures and logs various drilling characteristics. The data from MWD were used to evaluate specific drilling energy (SE) as a measure of rock hardness. SE is a concept that combines measured drilling parameters, e.g. torque, penetration rate, feed force etc., and represents the work done per uuit excavated, see Eq.l (Schunnesson & Mozaffari, 2009).

$$SE = \left(\frac{F}{A}\right) + \left(\frac{2\pi}{A}\right) + \left(\frac{NT}{P}\right) ....(1)$$

Where:

SE : Specific Energy [Nom/em^3]
F : Feed Force [N]
A : The cross-section area of the drill hole [cm^2] N: Rotation Speed [RPM]
T : Torque [Nm]
P : Penetration Rate [m/min].

SE, combined with crushing energy of the broken rock, provides an opportunity to comparatively evaluate the hardness of the rock before blast and its correlation to crushability of the same material after blast.

The MWD data were aualyzed for every single blast hole; the analysis included several filters to eliminate the systematic errors due to e.g. fractured areas, drill bit problems, etc. The data were used to provide an average value for rock hardness in each trial.

Principles of Emulsion Explosives Design for Sulfide Rocks Safe Breaking

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Abstract

It was shown that chemical inertness of natural sulfides can be ensured only in alkaline media, due to an almost complete passivation of surface and absence of initiate factors. Stabilization by traditional inhibitors is short-lived due to hydrolysis and inhibitor destruction. It was found that emulsions based on binary solution of oxidizer (ammonium and calcium nitrates) with pH = 7.8-8.4, which do not contain granular ammonium nitrate or ANFO, have the greatest inertness to pyrite and resistance to thermal self-decomposition. To sensitize such emulsions glass (plastic) microspheres or gas generation with solutions based on hydrogen peroxide should be used. The mentioned approach has been implemented in the development of emulsion explosives Ukrainit.

Conclusions

According to the research results, we can formulate general requirements for emulsion explosives used in corrosive sulfide ores: salt base of emulsion and emulsion explosives in whole should have a neutral or slightly alkaline media (PH = 7-8); the emulsion should have a high stability at low temperatures, and enable the manufacture of emulsion explosives using the "cold" emulsion (20±lO°C); emulsion explosives must not contain additives of granular AN and/or ANFO.

Innovative Radio Remote Blasting System

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Abstract

Under the pressure of market requirements the issue of safety and better performance is brought forward. This paper investigates the background of the situation in miuing industry, highlighting possible problem areas and ways of effective solution. One of the solutions is radio remote blasting, which eliminates the human factor and any mechanical disturbance on the blasting cite. The present paper gives a general overview of the invention, listing all the properties and technical characteristics of the device. In addition to that the computer interface is described together with the blast network design. The concluding part of the paper states extra features of the system, depending on the component parts, and its technological advantages which ruight be of some interest for the engineers as well as ruiners.

Background

At the present moment there is an ongoing process of globalization of the mineral resources complex, the framework of which presupposes optimization of production citing, minimizing expenses on extraction, processing, transportation of raw materials and manufacturing of the end product.

Another tendency consists in gradual substitution of small-scale rich ore deposits for large-scale deposits with lean ore, difficult to concentrate. The growth of mining expenses, dictated by low concentration ore is compensated by huge amounts of ore processing and, hence, large-scale blasting works.

Thus, despite unstable economic situation in the world there is a steady growth of mining, and, therefore, blasting works. It raises the acute problem of blasting work optimization.

Responding to the market challenges and changing customer demands "Novosibirsk Mechanical Plant "Iskra", OSJC, constantly develops new blast initiation devices, new methods and means of blast initiation.

One of such inventions is the newly-developed radio remote blasting system.

Aim

The primary aim of the complex development is to provide the possibility of remote initiation of blasting circuit based on electronic detonators EDEZ, EDEZ-S andlornon-electric surface detonators Iskra-P and millisecond detonators Iskra-S. In addition to that, thanks to the use of radio waves to connect the on-site actuating unit with the operator's console, which is placed at a safe distance, the necessity of main wire (in case of EDEZ) or initiation of shock tube (for non-electric blasting systems) is excluded. It quickens the assembly of blasting circuit and lowers the expenses on blasting works.

In case of a deep-seated opencast mine, placing the main (initiating) wire or initiating shock tube may present a certain problem because of the increased linear distance to the dangerous zone (high resistance of the main wire or connection of multiple initiating lead-in lines).

Moreover, simultaneous work of the on-site operator with several actuating units and, therefore, several units prepared for blasting is possible from one place. A number of blasting companies apply such tactics as their main guideline.

There is one more interesting option: the possibility of direct work with electronic and non-electric detonators, which eliminates the necessity for electric detonators, frequently used at the plants for remote blasting.

Figure - Actuating Unit - Retransmitter is designed for transmitting the data in the radio network in poor radio exchange conditions (remoteness, almost zero visibility, and presence of RFI - radio frequency interference)

Recent Developments in 3D Imaging for Bench Face Profiling and Blast Planning

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Abstract

The knowledge of the precise blast pattern geometry including profiles and volume to blast enables the optimised use of explosives, leading to economic and safe blasting including fly-rock prevention and vibration reduction. 3D images are an intuitive and cost-effective solution for providing geometric and visual data of blast sites and they allow for a straightforward assessment of the rock mass during the blast planning. The basics of the technology, including several improvements and developments since its introduction to the blasting industry in 2005 are described in this paper.

Introduction

Statement of Problem

One of the fundamental problems in production blasts is inaccurate or even lacking knowledge on the blast site geometry. An essential consequence is improper loading, not adapted to the actual site conditions, which leads to blasts that differ from the blaster's expectations.

Safety and environmental consequences are:

- Fly-rock
- Vibration
- Air blast
- Uneven bench faces, back breaks
- Excessive fracture formation

Production consequences:

- Uneven floors, bootlegs
- Non-uniform/undesired fragmentation
- Boulders
- Suboptimal drill length
- Higher specific explosives consumption
- Increased efforts for loading and hauling
- Increased energy consumption for crushing
- Additional stockpiling efforts

Conclusions

Surveying is one of the requirements to economical and safe blasting. When having thorough three-dimensional information of the blast area, then the drill pattern and/or the borehole loading can be adapted to the actual geometric conditions by the blaster.

Better blast planning leads to blast results as expected: fly-rock incidents are mastered; vibration is lowered; and work safety is increased. Additionally, due to the resulting better fragmentation production efficiencies are increased while costs are reduced usually exceeding the efforts for conducting the surveying.

The use of digital photographs for the generation of 3D models and its use for optimising blast sites was introduced in 2005 and as the technology has matured it is now in use in many countries around the globe. Strong arguments for the technology are the ease and speed of application as well as the self-explaining photorealistic results in form of 3D images that also allow for an assessment of the geological conditions of a blast site at the same time when doing the geometric blast planning.

Further developments have been introduced over the years ranging from better modelling and volume calculations, cost-effective aerial imaging, and the direct linking of the blast plan data to drill rigs, and updating the blast plan with the actual drilled data for each borehole.

Although geological mapping is not a standard procedure in daily production blasting, the assessment of the discontinuity network is possible directly from the same data (the 3D image) that is used for blast planning which makes this a versatile combination for future research and application.

Influence of MgH2 on Anti-pressure Desensitization Ability and Explosion Power of Emulsion Explosives

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Abstract

Traditional emulsion explosives appear pressure desensitization and low detonation power problems in utilization, which seriously affect construction safety and blasting quality. In order to improve performance of emulsion explosives, Hydrogen type of emulsion explosive was invented. This type of emulsion explosives is sensitized by hydrogen storage material MgH2, and MgH2 plays double roles as sensitizer and energetic material in emulsion explosives. Compared with traditional emulsion explosives, Hydrogen type of emulsion explosives has excellent anti-pressure desensitization property and detonation characteristics. When compressed by the same intensity of external shockwaves, desensitization ratio of Hydrogen type of emulsion explosives is far less than Glass Microspheres type and NaN02 type of emulsion explosives. Shockwave total energy and peak pressure respectively increased over 24% and 17% than that of Glass Microspheres type of emulsion explosives. In recent study, the brisance of Hydrogen type of emulsion explosives even reaches 24.50cm.

SPECIAL REPORT

Safex International

'Safex Incidents Notices' : April, 2013 to March, 2014

Summary

Activity			No. of Incidents
* Manufacturing :	Fixed Plant		
	HE	3	
	Explosive Accessories	11	
		14	14
Mobile Manufacturing Unit (MMU)		-	-
* Handling :	Within Plant Area	1	
	Outside Plant Area	2	
		3	3
* Storage :		-	-
* Transportation	Vans	-	
	MMU	1	
		1	1
* Waste / unused explosives disposal, etc.		1	1
		TOTAL	**19**

1

1) **INCIDENT TITLE :** 15 April 2013: South Africa – Pyro powder spray drying fire

2) **INCIDENT OUTLINE**

a) **What material was involved :** About 5kg of G composition pyrotechnic powder

b) **What happened**: Spray Drier 1 was on shutdown as result of producing out of specification powder. The operators were preparing the unit for start-up. After placing an empty container under the spray drier chamber, the operator left the spray drier compartment to reheat the spray drier. As he did so, a fire occurred.

c) **Why did it happen theory** : The pyrotechnic powder used for delay detonators is produced in a spray drier. In this process pyrotechnic slurry is atomized and the resultant droplets dried in a drying chamber with hot air. The ultra-fine and coarse particles are separated from the in-spec powder using a bag filter and cyclone respectively. The ultra-fine powder is more sensitive to friction and impact.

The stainless steel bag filter compartment has a conical base from which the accumulated fine powder is discharged into a container filled with water via a pipe and Posi-flate butterfly valve. This valve has an inflatable seat that seals with air pressure to minimize friction. When any one of the doors of the spray drier compartment is opened, the Posi-flate valve closes. When the operator leaves the compartment he closes the door and the Posi-flate valves opens again. This is the only moving part during the spray drying operation.

The ultra-fine powder flows with greater difficulty and does not discharge easily despite the presence of vibrators. Unbeknown to the plant, it also sticks to the sides of the compartment and a layer had built up over 4 years of operation of the plant.

It was concluded that the fire was caused by a piece of powder caking that came lose and got caught between the valve seat and the side of the valve as it closed. When it opened upward it created friction which ignited the fine powder underneath the filter bags.

d) **What was the impact** : There were no injuries and damage was minimal as result of the fire.

3) **COMMENT**

a) **Value of incident** : This incident illustrates the hazards associated with fine explosives powders. They tend not to flow easily and can build up on the inside of vessels if not regularly cleaned. In this case the interlock system that was installed ensured that the operator was not in the compartment when the fire initiated.

b) **Observations :** None

2

1) **INCIDENT TITLE :** 4 May 2013: South Africa – Detonation during shocktube assembly

2) **INCIDENT OUTLINE**

a) **What material was involved :** 25 detonator assemblies each consisting of 2 detonators with delay elements joined by a piece of shocktube. These assemblies are used in underground mining.

b) **What happened**: Spray Detonators in non-propagating blocks are fed into the machine where they are automatically crimped onto a length of shocktube. This assembly is then hooked by robot onto a pallet fixture where 25 are grouped and then bundled. (See Figure 1 below).

During normal production a pallet fixture with the 25 assemblies was pulled out of the roller guide and fell on top of one of the detonators. The impact caused a series of explosions involving all 25 assemblies (50 detonators in total).

The transparent polycarbonate panels that enclose the machine have been designed to withstand the shrapnel from the initiation of one detonator, not multiple detonations. As the panels will not provide sufficient protection in the event of a detonation, the risk is very high to the operator who has to remove the assemblies from the pallet fixtures and place it into a bundle in a box. This packaging operation occurs directly next to the machine. The panels do not reach to the floor where there is a 100mm gap that can allow shrapnel to exit the station.

c) **Why did it happen theory** : The label on one of the shocktube assemblies came loose on the pallet fixture. When the pallet fixture rounded a corner on the conveyor the assembly which was on the pallet fixture got caught on a conveyor bracket. This pulled the moving pallet fixture out of the guide rail and it fell on top of one of the detonators. (See Figure 2 below).

Although there was wear on the pallet roller guide, this was not unusual or of concern. There are combinations of one or two weights on the various

Cont. from Safex Incidents No.2

pallet fixtures that are being used on the conveyor on the modular machine.

d) **What was the impact** : There were no injuries and the damage to the equipment was minimal.

3) COMMENT

a) **Value of incident** : The following recommendations were made to avoid any future incidents of this nature:
- Re-design the label application to prevent the label from coming loose during the operation.
- Verify and ensure that guarding around the machines is sufficient to allow safe operation and at the same time prevent propagation outside the machine and risk to the operator. Proper tests must be conducted to ensure that the guarding can withstand the blast from the maximum number of detonators permitted inside the enclosure.
- Design or provide a sliding door in front of the open hatch at the station where the operator removes the complete assemblies.
- Redo the risk assessment to reduce the risk of accumulation of detonators on the conveyor and to prevent propagation outside the machine enclosure.
- Implement proper schedule maintenance to eliminate wear and tear.
- Update Operating Instructions to prevent operators from accumulating assemblies on the pallet fixtures.

b) **Observations :** None

3

1) **INCIDENT TITLE :** 10 May 2013: USA – Reaction of incompatible chemicals.

2) **INCIDENT OUTLINE**

a) **What material was involved :** 20 to 30 gal of 25% hydrogen peroxide, 30% sodium thiocyanate and 40% sodium nitrite

b) **What happened**:

Background: A 20 ft x 8 ft metal ship container is used to prepare batches of solution for subsequent use in the manufacture of emulsion explosives. The process entails pumping one 55-gallon drum of sodium nitrite into a mix tank and then adding one drum of sodium thiocyanate, or vice versa. The mix tank is a 300- gallon polyethylene tote without agitation or pressure relief, as the process for which it is designed is not reactive

Event: An operator unknowingly started pumping hydrogen peroxide into the mix tank containing sodium thiocyanate and sodium nitrite. After about 2 minutes he smelled an unusual acrid, pungent odour. He looked at the drum and saw that he was working with hydrogen peroxide. At this point he attempted to shut down the pump to stop the process. However, the pressure and the heat caused by the chemical reaction between the residual solution in the mix tank and hydrogen peroxide caused the mix tank to rupture and release its contents.

c) **Why did it happen theory** :
- The supplier of sodium nitrite mistakenly delivered a 55 gallon drum of 25% hydrogen peroxide instead of the sodium nitrite indicated on the shipping paper.
- The hydrogen peroxide drums are similar in appearance to drums of sodium nitrite
- Hydrogen peroxide is not a chemical managed at the location and a material safety data sheet (MSDS) for hydrogen peroxide was not provided
- The Sterling, CT location received the drum of hydrogen peroxide without internal verification.

d) **What was the impact** : Operator failed to wear the prescribed personal protective clothing (PPE) and was burned on one sidearm, leg, face. He recovered and is back at work.

3) COMMENT

a) **Value of incident** : The Company introduced the following preventive measures:
- Implement a "double-count" system that requires two persons to receive, verify the identity and amount of chemical delivered to the location prior to acceptance. Each drum of chemical will be marked with a label that indicates the date of arrival and initials.
- The actual processing of the solution will be verified by a second person, prior to the dispensing of chemicals into the mix tank.
- The use of personal protective equipment consisting of chemically resistant gloves, splash apron, goggles and face shield will be strictly enforced for ALL chemical handling operations.

b) **Observations :** This incident highlights that raw material handling and preparation is not trivial. Mistakes at this stage do not only have immediate consequences as indicated in this case but can also impact subsequent stages in the process.

4

1) **INCIDENT TITLE :** 20 May 2013: China – Seismic booster factory explosion

2) **INCIDENT OUTLINE**

a) **What material was involved :** 3.7 t of emulsion matrix and recycled PETN. The facility was licensed for 2.4 t of explosives.

b) **What happened**: A 3-storey factory collapsed when there was an explosion in a workshop manufacturing seismic boosters. There were 34 workers in the house and 8 construction workers close to the house at the time of the accident. Photographs suggest there was some new construction taking place in the vicinity.

c) **Why did it happen theory** : The official inquiry identified the cause of the accident to be an explosion in the cartridge machine loading seismic charges with re-cycled PETN mixed into emulsion matrix. The following management violations were identified during the investigation:
- Illegally combining workshops resulting in the seismic plant having more than the number of persons permitted by license;
- Simultaneous manufacture of large diameter emulsion cartridges and emulsion seismic charges;
- Exceeding the license quantity of explosives (was 3.7 t instead of the licensed quantity of 2.4 t);
- Poor management of re-cycled emulsion. 300 t was stored in a nearby warehouse with emulsion, emulsion seismic, AN TNT seismic and PETN charges;
- Construction work was permitted too close to the plant during production;
- Maintenance was being conducted during production;
- Management and safety rules were ignored;
- Regulators were deceived during inspections by removing illegally installed equipment for the duration of the inspection and then re-installing the same. This involved 2 additional loading machines, seismic hot sealing and packaging machines. It resulted in the exposure of an extra 18 people;
- Exceeding permitted production volume by 100% in 2012 and doing the same in 2013,
- Management team did not function well and focused on profit at the expense of safety.

Our information is that 6 managers have been arrested and the role of the provincial authorities is being investigated.

d) **What was the impact** : 33 people were killed and 19 injured. A number of people are still missing. The facility was destroyed

3) COMMENT

a) **Value of incident** : In the absence of more information, this incident is primarily of statistical value

b) **Observations :** None

5

1) **INCIDENT TITLE :** 4 Jun 2013: UK – Unplanned double detonator crimp
2) **INCIDENT OUTLINE**
   a) **What material was involved :** Approximately 100 non-electric detonators
   b) **What happened:** An operator was assembling non-electric detonators by crimping the detonators onto shock tube. Having assembled approximately 100 detonators on the machine that morning, the operator was removing a crimped assembly from the crimper pocket when the machine suddenly crimped for a second time. The 2nd crimp was approximately 21mm from the base of the detonator which was then held firmly by the crimping tool's teeth. The operator immediately switched off the power and the air to the machine, thereby releasing the detonator, and contacted management. The assembly of all detonators was terminated and an investigation was carried out.
   c) **Why did it happen theory :** A basic PLC (process logic controller) program had not been updated from the initial development program.
   d) **What was the impact :** This was a "near-event" incident with loss of production but no injuries.
3) **COMMENT**
   a) **Value of incident :** This incident highlights the potential for unplanned events in automated processes and the need to keep programs that run those processes updated.
   b) **Observations :** Additional levels of protection were added following the investigation to reduce the likelihood of a similar incident

6

1) **INCIDENT TITLE :** 15 June 2013: South Africa – Pyro powder fire in wash bay
2) **INCIDENT OUTLINE**
   a) **What material was involved :** Estimated 1kg of pyrotechnic powder
   b) **What happened:** Delay powder composition is handled in various containers which have to be washed when they areused for a different delay powder composition. Theyare washed by hand with water in a basin and dried ina hot air drying cupboard prior to reuse.
   The operator entered the Wash Bay to clean buckets which had contained pyrotechnic powder. After she washed the first bucket, she placed the bucket on the steel grid on the floor. The grid facilitates draining of the Wash Bay floor which has to be kept wet. As she turned on the grid to fetch a second bucket to clean, a fire occurred. All the equipment in the Wash Bay caught fire including the buckets and equipment in the steel drying cabinet used to dry the containers that had been washed. She tried to contain the fire with the cleaning hose but without success.
   c) **Why did it happen theory :** Pyrotechnic powders are relatively safe when wetted and therefore the floor of the Wash Bay must always be kept clean and wet.
   The previous shift left the Wash Bay in a very poor housekeeping state with dry pyrotechnic residue on the floor. Furthermore, the operator failed to wet the area as required. Some of the residue must have been present below the grid; between the grid and the floor. When she turned the grid moved on the floor resulting in impact/friction which ignited the powder.
   d) **What was the impact :** The operator was injured and there was superficial damage to the equipment inside the Wash Bay. The dust mask and safety glasses which she wore at the time of the incident limited her injuries.
3) **COMMENT**
   a) **Value of incident :** This incident highlights two key issues:
      - Maintenance of the highest standards of housekeeping when working with pyro powders. Ancillary operations such as cleaning and waste disposal tend to be neglected.
      - A good handover procedure should be initiated between shifts.
      - Design of the Wash Bay facility and the operations that take place in it. This must be based on good risk assessments and include attention to detailed operating procedures, personal protective equipment (PPE) and emergency procedures.
   b) **Observations :** None

7

1) **INCIDENT TITLE :** 9 Jul 2013: Finland: Smoke from IBC with emulsion waste
2) **INCIDENT OUTLINE**
   a) **What material was involved :** Unknown amount of emulsion waste in an IBC-container
   b) **What happened:** Smoke was observed coming from an IBC-container containing emulsion waste. The container was placed alongside other containers with emulsion waste. A major emergency evacuation took place. With the help of a remote-controlled small helicopter and army remotely operated vehicle (ROV) a hole was punched in the IBC-container. This enabled water to be injected into the container to cool the smoking material. The cooling was successful and the emergency was called off on the following evening (Wednesday) at 21:00.
   c) **Why did it happen theory :** The cause is unknown and under investigation
   d) **What was the impact :** While the community was disrupted as result of the emergency there was no fire or explosion. No injuries or damage occurred.
3) **COMMENT**
   a) **Value of incident :** While the exact cause of the reaction that took place in the container is unknown at this stage, the manner in which Forcit handled the incident is worth noting. In the absence of good information about the event and possible consequences, they were cautious and acted conservatively.
   b) **Observations :** None

8

1) **INCIDENT TITLE :** 16 Jul 2013: Argentina – Unplanned double detonator crimp
2) **INCIDENT OUTLINE**
   a) **What material was involved :** One non-electric detonator
   b) **What happened:** During the assembly of non-electric detonators, the detonator was not released after crimping. In the event of such a failure, the procedure requires the operation to be stopped in order to check the equipment, air valves and air lines. In this case the operator pushed the crimping button a second time to release the detonator. She tried to extract the detonator quickly but the detonator was crimped a second time lower down the cap. The detonator shell was damaged but there was no ignition. The supervisor was contacted and all assembly operations terminated until the immediate cause of the incident could be determined.
   c) **Why did it happen theory :** The operator pulled out the detonator too quickly and that coincided with the delay interval set for crimping.
   d) **What was the impact :** This was a near-event with loss of production but no injuries or physical damage.
3) **COMMENT**
   a) **Value of incident :** This incident reveals the potential for unplanned events in partially automated processes that involve critical man/machine/process logic interfaces.
   b) **Observations :** The entire process logic will be reviewed in order to prevent manual and/or technical failure resulting in similar events.

9

1) **INCIDENT TITLE :** 12 Aug 2013: Slovakia - Unplanned underground detonation
2) **INCIDENT OUTLINE**
   a) **What material was involved :** Several kg of explosives (packaged product and ANFO) and a non-electric detonator from an underground borehole
   b) **What happened**: Approximately one hour after the blast, the night shift was cleaning a round at an underground blast site and identified a partial misfire. The shocktubes of the undetonated boreholes were checked and a couple of smaller controlled blasts were conducted to clear the site. While checking the shocktubes in preparation for another blast, a detonation of a borehole occurred. The blaster in charge (an Austin employee) suffered severe injuries and died subsequently.
   c) **Why did it happen theory** : The cause of the detonation is under investigation and unknown.
   d) **What was the impact** : One person was killed, two others severely injured and three slightly injured.
3) **COMMENT**
   a) **Value of incident** : Given SAFEX members' commitment to Product Stewardship and the direct involvement of some manufacturers in mining operations, the lessons from this incident may be important. If the investigation reveals a malfunction in the product, this can also be of value. The incident also illustrates the need for extra care when dealing with abnormal situations.
   b) **Observations :** None

10

1) **INCIDENT TITLE :** 20 Oct 2013: South Africa: Lead azide drying plant explosion
2) **INCIDENT OUTLINE**
   a) **What material was involved :** 5kg of lead azide powder for use in detonators.
   b) **What happened**: The lead azide process involves washing with alcohol, then vacuuming and drying the powder for storage in a holding magazine prior to use in the detonator priming process. All these operations are performed remotely to ensure the safety of employees in the area. The process can be observed through a small reinforced glass window to the compartment or via camera in the central control room.
   A 5kg batch of lead azide was already washed and vacuumed twice. During the 3rd vacuum process the pot filled with lead azide was placed in a potholder which allows the operator to remotely tilt the pot onto a sieve to start the drying process. The operator neglected to fasten the clamp holding the lead azide pot in place. As the operator started to tip the pot with lead azide onto the sieve remotely the pot landed on the sieve, cartwheeled over to the back of the machine and an explosion resulted.
   c) **Why did it happen theory** :To lift the pot onto the pot holder requires the use of both hands. On this occasion the operator also held a pen between his fingers. As a consequence the operator neglected to clamp the pot into the holder after it was placed in position. Furthermore, the operator lifted the pot 8 times and allowed it to drop back to break-up the lead azide cake inside before tilting the contents onto the sieve. The pot was loose within the holder and fell out on tilting.
   The lead azide pot was inspected and it was evident that the inside of the pot is coarse thus making it more difficult for the lead azide to be emptied. Furthermore, the filter bag at the bottom of the pot is made of calico which absorbs water and allows the lead azide to stick to the bottom of the pot after the vacuuming step.
   d) **What was the impact** : There were no injuries but extensive damage to the compartment and roof occurred. The outer structure of the building remained intact.
3) **COMMENT**
   a) **Value of incident** : This case also illustrates two specific operating principles:
      - Do not hold anything else in your hands when handling explosives
      - Do not tolerate lose articles (e.g. operator's pen) in an explosives compartment that are not specified on the list.
   b) **Observations :** The following preventative actions were implemented:
      - The inside of the lead azide pot was polished to allow powder to be tipped out with greater ease and minimize residue.
      - The calico cloths were replaced with a water resistant cloth.
      - Air vibrators were installed at the bottom of the pot holder to facilitate pouring of the lead azide.
      - Check sheets were changed to include the checking of the clamp before initiating the tipping sequence.
      - Operating instructions were adapted and all employees were re-trained accordingly.

11

1) **INCIDENT TITLE :** 8 Nov 2013: Mexico - Leak in MMA tank
2) **INCIDENT OUTLINE**
   a) **What material was involved :** Monomethylamine (MMA) stored in a railcar tank
   b) **What happened**: A routine check (wet pH paper) at the beginning of the shift around the tank domes and valves of MMA storage tanks indicated an absence of MMA vapour. An operator smelt MMA coming from one of the two railcars and discovered that it was leaking from the outlet of a safety valve. The leak rate was permanently monitored but proved to be low. Explosive levels in the atmosphere at a 2m radius around the valve were never exceeded during the event. Manufacture of MMAN was continued and once the second tank was empty, MMA was transferred from the leaking tank into the empty storage tank. The leaking tank was then purged with nitrogen so that the dome that contains the safety valve could be dismantled.
   c) **Why did it happen theory** : Ownership of the tanks was transferred from the railcar contractor to Austin Bacis in 2012. The maintenance contract for the tanks still existed between the railcar contractor and a local authorised subcontractor. A list of authorized (and compatible) spare parts from the tank manual was provided to the subcontractor by Austin Bacis. For the safety valve, O-rings made from EPDM and Teflon sealant were required. However, the subcontractor used Viton O-rings for the tank valve that leaked. This was confirmed in the inspection report submitted to the railcar company (owner at that time) but was not reviewed by Austin Bacis. Viton is not compatible with MMA. After more than one year in operation, the O-ring failed and the valve started to leak. In the interim period, the valve had never been activated by overpressure.
   d) **What was the impact** : No injuries or material damage occurred. The total amount of MMA that leaked is not known at this time.
3) **COMMENT**
   a) **Value of incident** : Toxic gases such as MMA liquid vapour can be hazardous and should be handled accordingly. For sensitive material and operations the use of compatible materials is crucial and third party repairs should be scrutinized and double-checked.
   b) **Observations :** This incident also demonstrates the extra care required when any handover occurs - whether it is ownership as in this case or other transfer of responsibilities.

12

1) **INCIDENT TITLE :** 9 Dec 2013: India - Explosion in PETN drying unit
2) **INCIDENT OUTLINE**
   a) **What material was involved :** 140 kg pentaerythritol tetranitrate (PETN)
   b) **What happened**: In this operation PETN is dried in open, circular steamheated pans which are agitated at very slow speeds. Reportedly, drying was completed at the end of the 2nd shift the previous day i.e. around 10 pm on 8 December. At about 07:00 am on the morning of 9 December, the supervisor accompanied by an operator went to the drying room to remove the dried PETN from the drying pans. It is possible that the explosion occurred while they transferring the PETN into bags.
   c) **Why did it happen theory** : Causes are still under investigation
   d) **What was the impact** : The supervisor and the operator were killed in the explosion. Damage to the plant and buildings was significant
3) **COMMENT**
   a) **Value of incident** : Until we receive further details of this incident, it is primarily of statistical value. It does serve to remind us that dry PETN is very sensitive to friction, impact and static electricity. These possible ignition sources must be eliminated during handling.
   b) **Observations :** If at any time anyone is able provide more information on this incident, we will gratefully publish it.

13

1) **INCIDENT TITLE :** 20 Dec 2013: Brazil - Blackpowder plant explosion
2) **INCIDENT OUTLINE**
   a) **What material was involved :** Unknown quantity of blackpowder
   b) **What happened**: According to reports an electrical power outage led to an unplanned shutdown of the plant. Some employees were doing maintenance work which may have involved cleaning of the corning machine (granulating equipment) when the incident occurred. Unconfirmed reports mention that there were two explosions.
   c) **Why did it happen theory** : The cause(s) of the explosions are unknown. The plant has been shut down pending the official investigation which is underway.
   d) **What was the impact** : Reports mention that two people were killed and one seriously injured in the incident.
3) **COMMENT**
   a) **Value of incident** : Besides its statistical value, the incident reminds us of the added vulnerability when an unusual occurrence such as a power failure occurs in our manufacturing operations. Blackpowder is sensitive to impact, friction and electrostatic discharge.
   b) **Observations :** SAFEX extends its heartfelt condolences to the family and friends of the deceased as well as the management and staff of Elephant Industria Quimica.

14

1) **INCIDENT TITLE :** 6 Jan 2014: Australia - Fire in Explosives Incinerator
2) **INCIDENT OUTLINE**
   a) **What material was involved :**Single base propellant
   b) **What happened**: A fire was observed coming from an ash drum in the Confined Burn Facility (CBF) building 851. The fire originated from a drum used for the storage of ash generated from the kiln at the CBF. The fire burnt for approximately 10 seconds generating a ball of flame of about 3 m in diameter. The production operation is remotely operated and the gate to access the area is interlocked to prevent access during operation.
   c) **Why did it happen theory** :Under investigation
   d) **What was the impact** :None
3) **COMMENT**
   a) **Value of incident** : Highlights the hazards of explosives disposal operations
   b) **Observations :** None.

15

1) **INCIDENT TITLE :** 09 Jan 2014: Mexico - Explosion in nitric acid plant
2) **INCIDENT OUTLINE**
   a) **What material was involved :** The estimated amounts of ammonium nitrate (AN) that decomposed/ exploded are 100 g – 250 g for the recovery filter and 500 g – 750 g in the pipe bend
   b) **What happened**: During start-up after annual maintenance and inspection, two explosions occurred in the line between the nitric acid reactor and the cooling condenser. One explosion occurred in the platinum recovery filter, the other explosion in an 8" pipe bend connected to the cooling condenser. Residues/crusts of AN were identified on the remaining parts of the filter.
   c) **Why did it happen theory** :The nitric acid plant has been in operation since the 1960's. While the PLC control system has been upgraded several times, start-up still requires significant manual operation.
   The operator was following the operating procedure for plant start-up. This requires opening a manual valve to start the flow of ammonia and then monitor the reaction (with air) at the catalyst gauze in the reactor. The flow of ammonia was stopped after the first attempt to start the reactor failed. This is not an unusual occurrence. Prior to restart, the entire line has to be purged with air for a certain period of time to ensure that no ammonia remains in the line after the reactor. The presence of ammonia could lead to the formation of AN in the colder part of the line towards the cooling condenser where water vapour from the reaction condenses and dissolves nitrous oxides.
   It is believed that the ammonia line was leaking through its valves and the purge air was also carrying ammonia that reacted leading to the formation of AN. Once a high system temperature was achieved after the second (successful) start-up, AN decomposition started and resulted in the explosions. Though (ammonium) nitrite was not identified, its formation cannot be ruled out. Ammonium nitrite is much less stable than AN and also decomposes violently.
   d) **What was the impact** : Material damage only. Loss of production for three weeks.
3) **COMMENT**
   a) **Value of incident** : Critical plant items such as the ammonia valves in this case have to be inspected very carefully to verify it is functioning safely (i.e. To stop flow). In this case the gasket was replaced routinely, but this only prevents leaking to the atmosphere.
   b) **Observations :** Though there are no explosives operations involved in this incident, it would be of interest to SAFEX members involved in ammonium nitrate manufacture. Furthermore, the incident illustrates how the accidental formation of AN can lead to its decomposition and a subsequent explosion.

16

1) **INCIDENT TITLE :** 20 Jan 2014: Australia - Fire in Propellant Pressing/Cutting Building
2) **INCIDENT OUTLINE**
   a) **What material was involved :** Single base propellant
   b) **What happened**: An initiation of single base propellant occurred during a normal production activity involving the pressing and cutting of solvent wet colloid. The resulting fire caused an explosion in the building ductwork which damaged the adjacent services building. The building is fitted with a fire detection and suppression system that activated as a result of the initiation. The fire system activated the building alarm generating a response by the onsite Emergency Response Team (ERT). Three operators were in the building at the time of the incident. Two operators exited the building through the doors without harm. The third operator was working on the mezzanine floor of the two storey building. He climbed through a hand rail and jumped from the crane access door which is approximately 2.6 m above the ground floor level landing on the concrete path below. He suffered a compound leg fracture and was taken by ambulance to a local hospital. There were no other injuries to any employees.
   c) **Why did it happen theory** :Under investigation
   d) **What was the impact** : Operator injured and building damaged.
3) **COMMENT**
   a) **Value of incident** : This incident highlights the importance of providing and utilising approved exit routes during emergency evacuations.
   b) **Observations :** None.

17

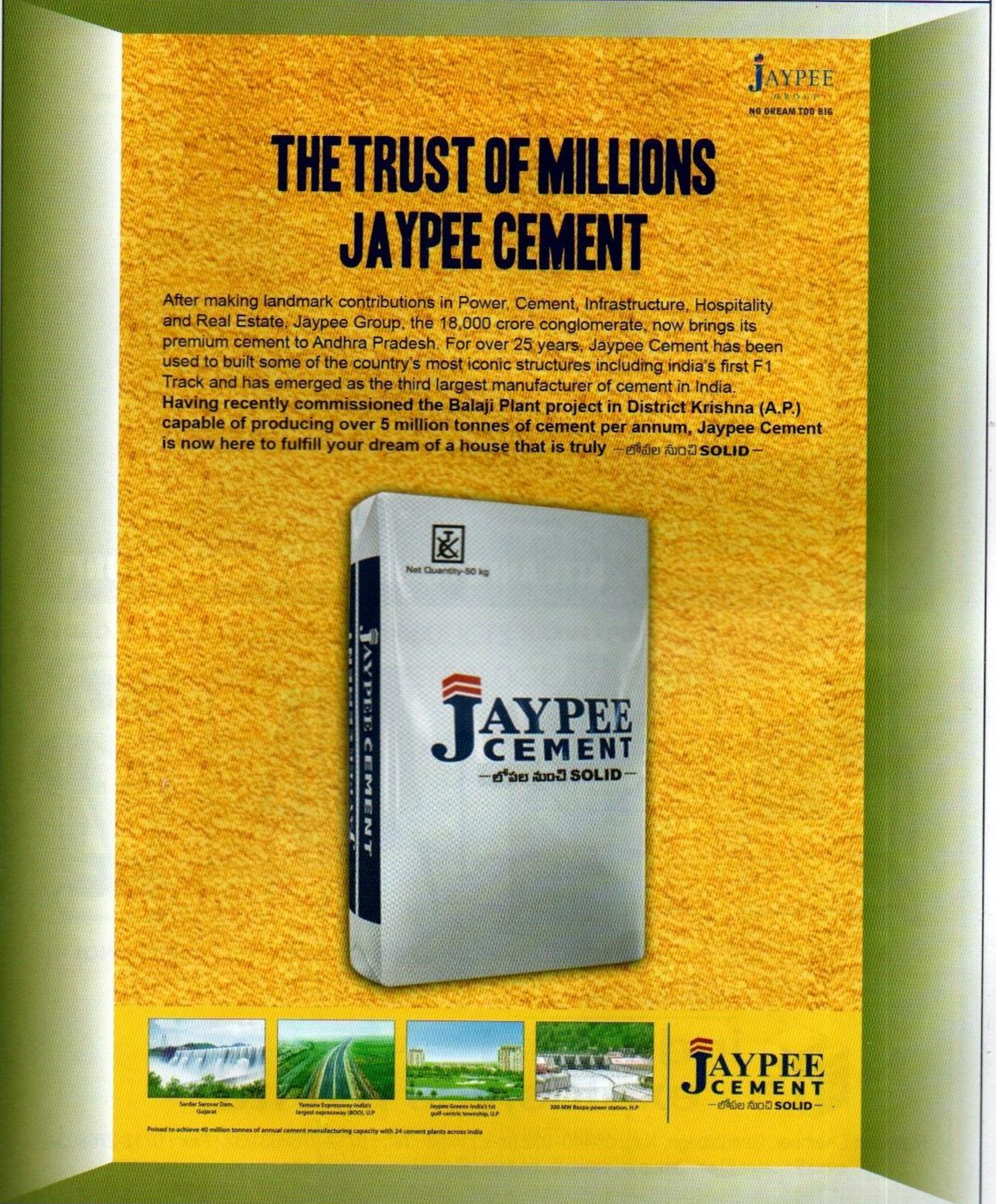
1) **INCIDENT TITLE :** 13 Feb 2014: Spain – Propellant deflagration during pressing
2) **INCIDENT OUTLINE**
   a) **What material was involved :** 20 Kg of triple base composition.
   b) **What happened**: A deflagration occurred during the prepressing operation of a triple base composition when the dough initiated and all the material in process was burnt. The pressure on the dough at the moment of initiation was 160 kg/cm2.
   c) **Why did it happen theory** :The investigation determined that adiabatic compression was the most probable cause of the ignition. No evidence of foreign materials or friction between the piston and the wall of the press was found. There is some doubt about the correct addition of nitrogen for the displacement of air in the interior of the press.
   d) **What was the impact** : The consequences of the incident have been negligible. Nobody was injured and there was no damage to the equipment.
3) **COMMENT**
   a) **Value of incident** : This incident is primarily of statistical value. Attention to detail such as the addition of nitrogen to reduce the risk of ignition is of interest.
   b) **Observations :** The following actions were adopted to prevent a recurrence:
      - Establish the quantity of nitrogen that has to be added to the press before prepressing.
      - Interlock the movement of the piston with addition of nitrogen.

18

1) **INCIDENT TITLE :** 07 Mar 2014: Belgium – Underwater propellant detonation
2) **INCIDENT OUTLINE**
   a) **What material was involved :** About 30kg of single base propellant powder
   b) **What happened**: While pumping single base propellant granules in water phase with a centrifugal pump, a violent detonation occurred in the main line made of DN100 stainless steel about 3m above the pump.
   c) **Why did it happen theory** :Investigators are at a loss for an explanation given the notion that the initiation of propellant granules under water is considered unlikely.
   d) **What was the impact** : There were no casualties but the explosives facility was badly damaged, 2 storage tanks in the vicinity ruptured and windows in a 150m radius from the facility broken.
3) **COMMENT**
   a) **Value of incident** : The true value of this incident will depend on finding a plausible explanation for the event. In the meantime it is primarily of statistical value
   b) **Observations :** PB Clermont requests recipients of this Notice who may have experienced such an incident in which propellant granules detonated under water or know of such an incident to contact SAFEX. Theories that can explain this event will also be welcomed.

19

1) **INCIDENT TITLE :** 20 Mar 2014: Italy – Fire in truck tractor transporting Hydrogel
2) **INCIDENT OUTLINE**
   a) **What material was involved :** Unknown amount of Hydrogel
   b) **What happened**: While transporting Hydrogel in an articulated vehicle, smoke was seen coming from the tractor. The crew contained the fire with an extinguisher until the firefighters were able to extinguish it.
   c) **Why did it happen theory** :The tractor was sent to an official workshop to identify the cause of the fire.
   d) **What was the impact** : There were no injuries but the tractor was damaged.
3) **COMMENT**
   a) **Value of incident** : Until the IR has been issued, the incident is primarily of statistical value.
   b) **Observations :** None.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ABOUT THE SOCIETY

Visfotak

Explosives Safety & Technology Society

Secretariate

Address :
Maimoon Chambers
Gandhibagh, Nagpur - 440 032

E-mail : visfotak@yahoo.com

Website : www.visfotak.org

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.

The Society has been accepted as an ***Institute Associate Member*** of SAFEX INTERNATIONAL at a General Meeting of SAFEX members on 30 May 2008 with the privileges and obligations that pertain to the membership.

SAFEX INTERNATIONAL is a non profit global organisation founded by the manufactures of explosives and pyrotechnics; currently having 110 members in as many as 46 countries. Visfotak is committed to discharge its obligations as a member by sharing information with SAFEX on all accidents with industrial explosive in India. Visfotak urges all the explosives manufactures and users to cooperate by reporting all accidents to the Society.

Membership

The membership application form which is enclosed, may be filled and sent to the Secretary General at the Secretariat along with the membership fee by a crossed account payee Cheque (add. Rs. 30/- for outstation cheques) or Demand Draft in favour of **Visfotak, payable at Nagpur.**

Student Chapter : This is a new initiative launched by the Society to promote the mission of the Society amongst the students/academics who are associated, directly or indirectly, with the science and technology of explosives.

The membership application form which is enclosed may be filled and sent to 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 along with the membership fee by a crossed account payee Cheque (add. Rs. 30/- for outstation cheques) or Demand Draft in favour of **Visfotak, payable at Nagpur.**

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 to its individual members.

Tear along this line

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) ____________________

____

Membership of Professional Bodies, Awards, Recognitions ____________________

____

____

Professional Experience ____________________

____

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

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admas

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 ______

Membership of Professional Bodies, Awards, Recognitions ______

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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- Controlled blasting (urban blasting, trench blasting, blasting near structures/habitants, dams).
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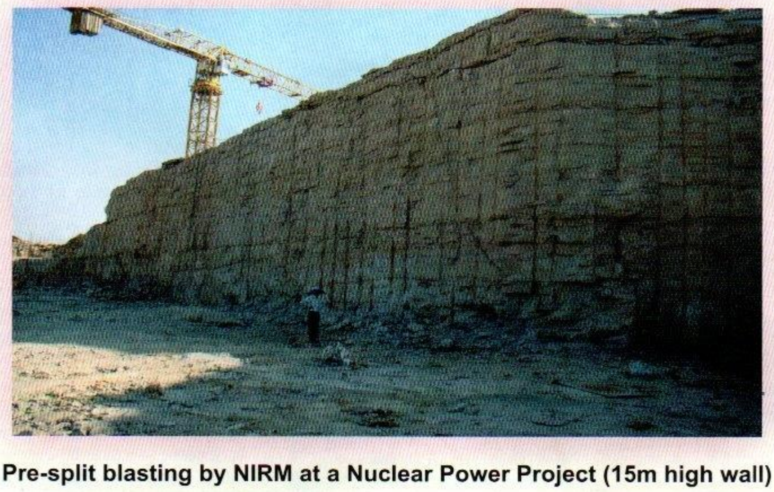
- Assessment of fragmentation through Image processing and computerized sieve analysis.
- Suggestions on alternative to blasting and mechanical excavation.
- Problem solving through innovative approaches to evolve site specific solutions.



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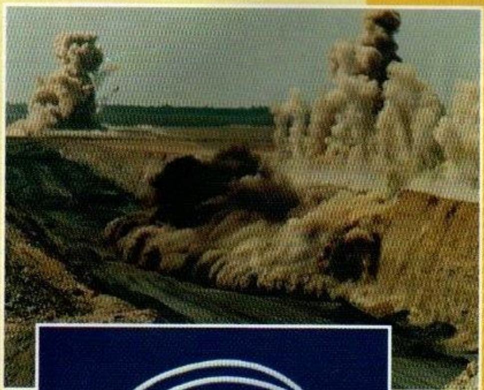

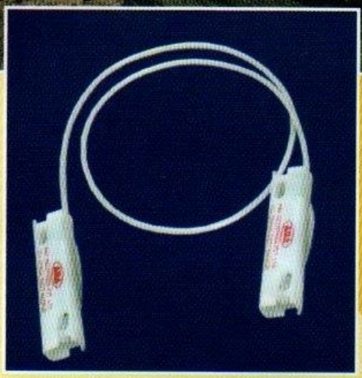

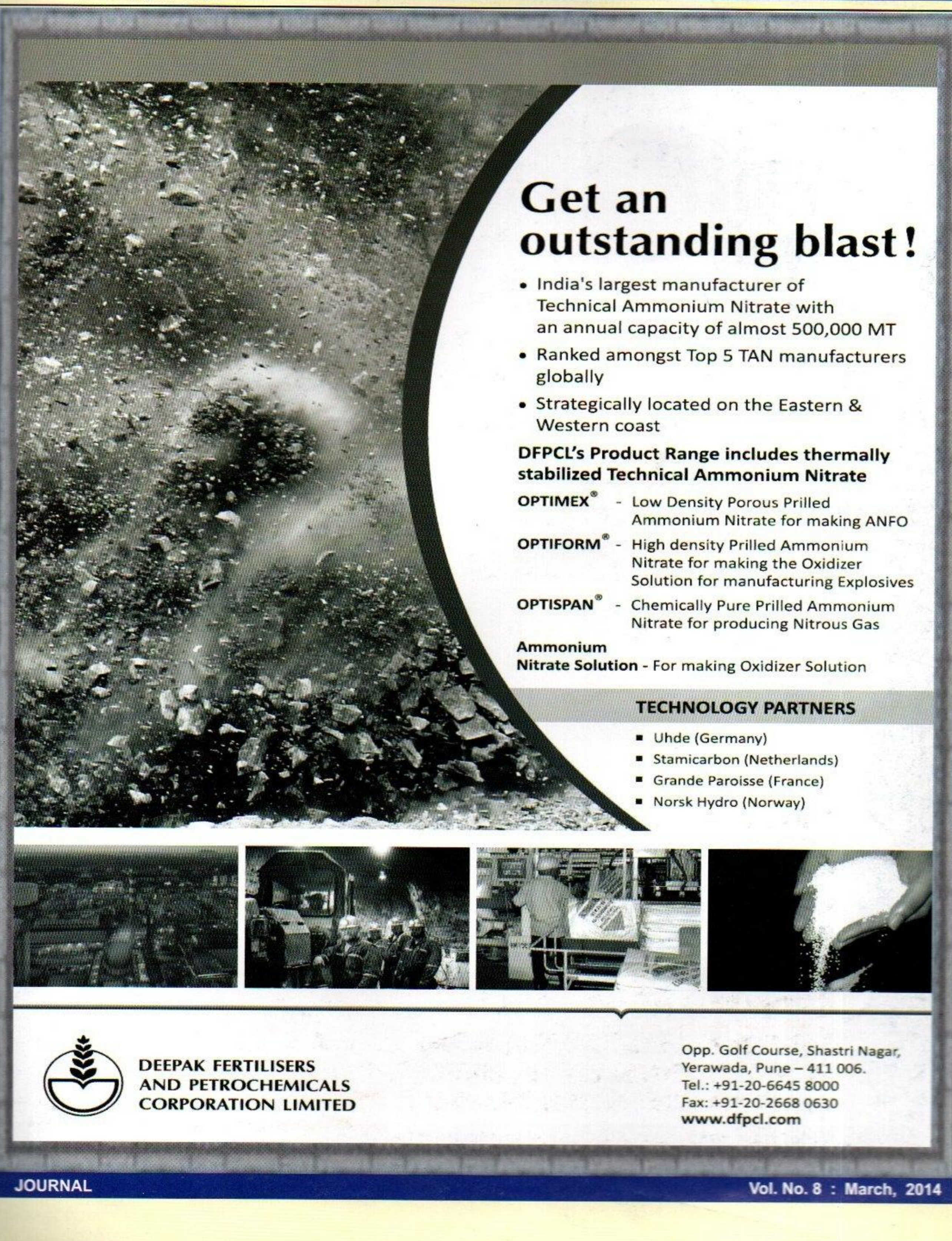
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