April 2020

SAFEX NEWSLETTER NO.72

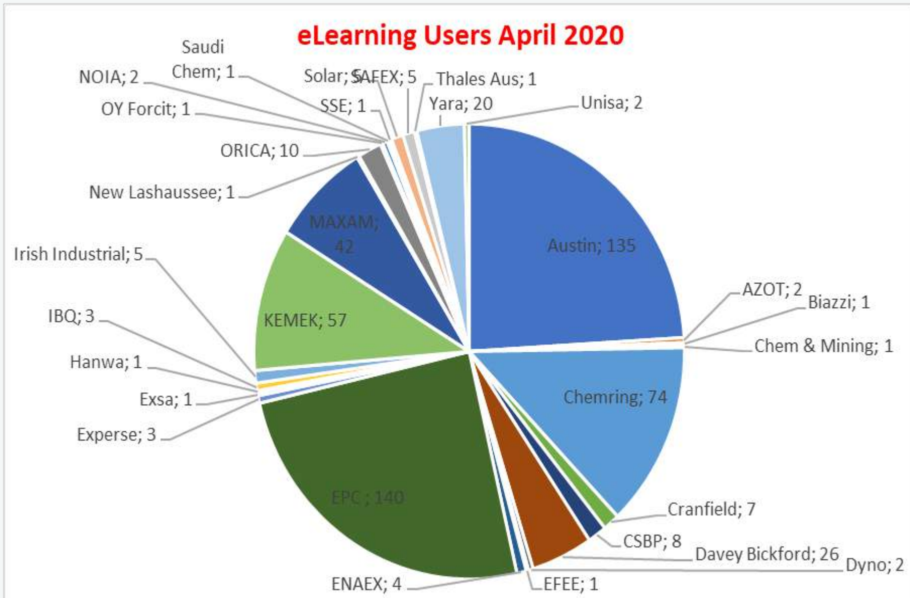
*While **SAFEX International** selects the authors of articles in this Newsletter with care, the views expressed are those of the authors and do not necessarily represent the official position of **SAFEX International**. Furthermore, the authors and **SAFEX International** cannot accept any liability for consequences arising (whether directly or indirectly) from the use of any advice given or opinions expressed in this Newsletter*

CONTENTS

From the SG's Desk

The year 2020 will forever be remembered as the time that our "normal" lifes changed! COVID-19 infected millions of people globally without discrimination, many thousands are dying, the global economy is staggering, and businesses and individuals are suffering.

Everything is affected and most of our members are in lockdown and working from home. In this period SAFEX is coming forward with news and informative articles from the industry. Our eLearning Portal and Emulsion Safety Module has been used very effectively by many members to train and retrain their staff whilst at home and we currently have nearly 600 individual users on our eLearning Portal.



The Portal upgrade is moving along well and within the next few months we will have moved the system to a new, modern base away from Adobe Flash to HTML5. The latter much more versatile and user friendly. At this stage, the Basis of Safety module will also be available in English, French, Portuguese, Spanish and Russian. The Emulsion Safety Training Module on the SAFEX website will also be translated into Spanish, thanks to the help of **ENAEX in Chile**.

As a result of COVID-19 the SAFEX Congress in Salzburg had to be delayed till March 21 till 27, 2021. The programme will be exactly the same and I will start the registration process in the last quarter of 2020. I would like to take this opportunity to thank **Wolfgang Schuster and his team from Austin Powder in Austria** for their massive input and invaluable assistance to support the 2020 Congress organisation . I am looking forward to working with them in ensuring a successful 2021 Congress!

DATE	ACTIVITY	CONCURRENT ACTIVITY
Sunday, 21 March	Registration - Training	
Monday, 22 March	Registration - Training Training Session	
Tuesday, 23 March	Training Session Registration – Workgroups	
Wednesday,24 March	Registration - Workgroups Workgroup Sessions Registration - Congress Welcome Reception	FEEM AGM
Thursday, 25 March	Registration - Congress Plenary Sessions – First Day General Assembly of Members	Spouses' Programme
Friday, 26 March	Plenary Sessions – Second Day Board Meeting Gala Dinner	Spouses' Programme
Saturday, 27 March	Congress Excursion	

Our members have not been idle, and we received a very comprehensive set of articles for the current edition of the Newsletter-I certainly hope that this trend continues!

Our first article has been submitted by Francois Le Doux (Yara International). This article was debated at the recent Explosives Transport Workgroup Meeting in Denver and more recently during a Skype Conference. The article is about the storage of technical grade LDAN (low density ammonium nitrate), i.e. oxidizer 5.1, UN1942, and with a density below 0.9 (cf SAFEX guideline). This is typically evaluated by making statistical analysis of past accidents. Different figures can be found in the literature, but often not how these figures were determined, with the risk that the figure may not be applicable to the case and/or making it difficult to attribute credit to safeguard when it is unclear if the base figure already includes it or not. The intention of this article to open the debate in the industry and through that ensure that robust conclusions are drawn. This will ensure that the information generated will be used to update the SAFEX GPG on AN storage and serve as a credible industry guideline. Comments are welcome and can be sent to:

Francois Ledoux - francois.ledoux@yara.com.
Noel Hsu- noel.hsu@orica.com.

I wish every SAFEX member a safe and healthy journey through the troubled times ahead- **this industry is known for surviving catastrophes and learning from them to strengthen the base of their operations to build a better future**.

Piet Halliday

How to assess the probability of the risk of explosion in AN storage ?

By

Francois Le Doux

Preamble: This article is about storage of technical grade LDAN (low density ammonium nitrate), i.e. oxidizer 5.1, UN1942, and with a density below 900 kg/m^3(cf SAFEX guideline for AN storage).

Introduction:

Ammonium Nitrate (AN) is handled every year in millions of tons, stored, transported, consumed. To assess the risk of these activities is crucial because the risk exists, and the consequences can be devastating in case of an explosion.

This article is focused on how to evaluate the probability of explosion of LDAN storage. This is typically evaluated by making statistical analysis of past accidents. The most credible scenario of an explosion in AN storage is probably an uncontrollable fire leading to an explosion.

Different figures can be found in the literature, But . But often not how these figures were determined. There is therefore a risk that the figure may not be applicable to the case and/or it makes it difficult to attribute credit to a safeguard when it is unclear if the base figure already includes the positive impact of this safeguard or not.

Therefore, the methodology proposed here is:

1) an attempt to determine the probability of fire-leading -to-an-explosion scenario, when there are no safeguards in place ("worst worst" case scenario a poorly-designed and poorly-operated storage with AN engulfed in fire),

2)) allowing to calculate the probability of explosion for the site by attributing fair credit to the best practices properly im plemented (fault-tree analysis and risk reduction)

The aim of this paper is fundamentally to generate feedback and with a view to developing industry consensus on the proba-bility of event to be considered.

Worst case scenario:

The worst thing that can happen with ammonium nitrate is a massive explosion, devastating the surrounding area. Such acci-dents have happened occasionally throughout history, and still today.

FGAN, West explosion, Texas , 2013. See CSB report, published on internet.

Deterministic versus probabilistic Risk Assessment

In a deterministic risk assessment study, let us say a QD approach (QD quantity distance), the occurrence of the explosion is simply assumed. It is not related to possible accident scenarios or to the sensitivity of the material. Still the sensitivity of the material must be considered in evaluating the fraction of product that actually would explode, and the possibility or not of sympathetic detonation to other stacks.

In a probabilistic risk assessment, let us say a QRA (quantitative risk assessment), the probability of occurrence of the unwanted event (here an explosion) is taken into account. Credits are considered for the safeguards and the best practices being applied. Performing a QRA involves estimating both the Probability of the event occurring, and the Consequences if it does occur.

In both deterministic and probabilistic cases, the risk assessor has to define and modelize the energy release. A traditional approach is to use TNT-equivalent as presented in the Safex guideline. Moreover there exists today tools such as IMESAFR that treats AN as AN, not as TNT, for consequence (and risk) calculations

QRA sensitivity

Quantitative risk assessment (QRA) is a probabilistic approach. The individual risk ("R_i") to people is quantified according to formulasuch as:

$$R_i = P \times C$$

P is the probability that the accident occurred, C is the consequence of it if it did occur. The calculated risk is compared to a threshold decided to be an acceptable risk, with typical figures such as maximum of 1E-5 or 1E-6 as individual lethality risk for a person from the general public.

The group risk or societal risk is then calculated as the summation of the respective R_i of the N persons exposed.

The overall calculated risk is very sensitive to the accuracy of any of these factors, because it is not a sum but a multiplication. If P or C is wrong by one order of magnitude, the overall risk is over or underestimated by one order of magnitude.

The factor "C" relies on scientific, medical, and historical evidence, and the number of exposed people "N" relies on data that are available at the time of the study, they can be considered as accurate and explainable.

Two remarks about C and N:

C: The estimate of the energy released (thus the fraction of AN considered to explode) is a decision based on knowledge of past accidents, specific tests, etc, i.e. expert judgment. This decision does obviously influence the final result (the factor "C"), but it is buffered to some extent by the one-third root (the distances for a given overpressure are typically proportional to Q^(1/3)) ; This AN amount involved in the explosion depends on many criteria, such as the type and amount of product, the lay out of the storage, with the presence or not of incompatible fuels, the type of insult to the product, etc.It is not one figure fits all. This is however not the topic of this paper.

N: The number of people "N" may evolve over time, and this must be reflected on (land use planning), as urbanization growth getting closer can modify the original risk assessment.

The probability of event, "P", is of a different nature. Indeed "**P" is the estimated frequency of a *__future__* accident** for *__the__* site being considered .

In situations where reliable data are available for similar cases under similar conditions, the *future* probability can be estimated with reasonable accuracy, based on solid data. This is one of the basis of preventive maintenance plans, based on probability of failure.

But with AN, it is different. The accidents occur but are relatively rare, and many occurred in conditions that may not be representative, or not representative anymore, of the product and type of site that is being considered.

To get sufficient number of accidents and build a statistical probability out of it, one may be tempted to cover a long period of time, for example back to early 20th century. But it is not representative.

For example, most AN products which were considered “on-spec” products some decades ago would be classified off spec and classified as 1.5 today. Such as AN involved in the massive explosions in Texas City (1947) or in Brest (1947), soon after WWII. Also, some practices such as the use of explosives in caked product, that led to catastrophic accidents after WWI (e.g. Oppau and Kriewald in 1921) and still some decades later (Tessenderlo, 1942), are unconceivable today.

The knowledge of these accidents is key; it is necessary to know the past to build a better future, but it is not relevant to evaluate the probability of explosion P for a well-managed and state-of-the-art storage today.

Looking into more recent accidents: The explosions in West Texas (2013) or Saint Romain-en-Jarez (France, 2003) are not representative in terms of probability of what can happen in a state-of-the-art storage in a manufacturing plant, respecting best practices.

But the truck accidents in Arkansas (2019; No official report yet) or Angellala Creek (2013; Very valuable public information available) are representative of road accidents with today’s products.

All these accidents are strong reminder of the dangers of AN that must never be forgotten.

For ammonium nitrate, what would be an appropriate P? Literature review

1) Safex guideline

The Safex guidelines for storage of LGAN (low density ammonium nitrate) mentions baseline event likelihoods in ~5E-5 for a manufacturing site. This figure is said to be derived from historical incident data. Unfortunately, it does not detail the source data.

Table B.3. shows baseline event Likelihoods based on history of such events. These Likelihoods can be reduced based on implementation of “best practice” control measures.

Table B.3: Baseline Event Likelihoods (F_{event}) for an AN Manufacturing Site [15]

STORAGE TYPE	F_{event} BY INITIATION MECHANISM			
	Contamination	Fire	High Energy Impact	Malicious Acts
AN Bulk (Per pile up to 5,000 tonnes)	[10×10^{-6}/yr]	[50×10^{-6}/yr]	[10×10^{-6}/yr]	Consult National Security Authority
Off-spec pile (Per pile up to 500 tonnes)	[50×10^{-6}/yr ^{1}]			
AN Bags or Containers (Per stack up to 2,500 tonnes)	[25×10^{-6}/yr]	[50×10^{-6}/yr] (with pallets) [25×10^{-6}/yr] (no pallets)	[5×10^{-6}/yr]	

Figure B.2 shows the probability of fatality (both indoor and outdoor) for a given overpressure ($P_{fatalOP}$). The overall Likelihood of fatality (R_{fatal}) is a combination of these two measures, and is the Risk of fatality.

$$R_{fatal} = F_{event} \times P_{fatalOP}$$

[15] Derived from historical incident data

The Safex guidance rightly mentions that these probabilities can be reduced, based on implementation of best practice control measures. The difficulty is of course that it is not clear which safeguards may already be in place in the base-line figure expressed in 1E-5.

Nevertheless the intent is clear:

1) These SAFEX figures cannot be used for a substandard storage
2) These figures can be directly used as conservative generic figure, for a storage respecting best practices,
3) Conclusion:

a) If using these generic figures, the quantified risk is deemed acceptable (i.e. below a locally defined threshold), there's no need to spend much further effort on the "mathematical part" of the QRA, but of course all efforts are to be spent on respecting the best practices, that must be well managed, quality-ensured over time, controllable, etc.

b) If using these generic figures the quantified risk is deemed too high, then it is possible to refine the probability to a lower figure (providing sound arguments and fault-tree analysis). T.

2)Other source in the literature, example

It is interesting to notice that some other data with similar order of magnitude in 1E-5 circulate in the literature and are sometimes used as reference.

For example, the Canvey Island report (UK, 1978) which is a comprehensive hazard assessment study, includes a section about the risk of ammonium nitrate explosion, with a probability of AN explosion P of 8.5E-5 sometimes reproduced without context..

The origin of this Canvey Island figure is very illustrating of the risk of picking up a figure, without checking the background of it. The way this figure was developedis presented in Lees (Lees' loss prevention in the process industries) and summarized below:

It was about hot AN solution, 92% concentration, stored in large tanks close to a railway.

The only scenario of accident that was identified as potentially possible was in relation to a potential derailment of a petroleum train and a pool of fuel taking fire. Considering additionally that the AN tanks would have been damaged by the derailment, AN would leak from the tanks and get mixed with the burning fuel. The combination was considered as potential for an explosion.

The probability of event was theerefore estimated by starting from the average probability of a train derailing per km, multiplied by the number of trains per year on that specific railway next to the AN tanks, considering the length of fence along the railway, the fact that train may derail on the right side or on the left (thus divide by 2 the probability of leading to an accident with the AN). Resulting in a probability of scenario 8.5E-5 considered as equal to the probability of explosion.

Most probably, this approximation was sufficient to justify this specific operation as it was at that time. As the reasoning was conservative, with some non-credible conservative assumptions, the risk assessors had no need to tune further the figure.

It is clear that it would make no sense to use it for any other storage. The reasoning, still, is interesting.

Conclusion: The key-learning here is to not pick up a figure from the literature without checking its background and applicability.

3) IMESAFR

IMESAFR uses an order of magnitude ~1E-6 as generic figure for the probability of an explosion, confirming that the 1E-5 is too pessimistic for a "good" storage, respecting best practices.

4) Probability of accidental explosion used for real explosives

For certain categories of explosives, probabilities of 1E-5 are considered applicable by regulators in different countries (see for example the Purple book in the Netherlands or https://www.hse.gov.uk/comah/assessexplosives/step2.htm in UK), providing they are stored according to best practices.

Similar figures are used as default value in IMESAFR (typical figure of 2.8E-5 for explosives in IMESAFR).

Conclusion: a figure in 5E-5 is very pessimistic for AN when comparing to figures used for explosives. Providing AN is also stored according to best practices, the probability for AN must possibly be some orders of magnitude lower.

What is the most credible scenario?

The most credible scenario of explosion in AN storage is probably a fire leading to an explosion.

As AN does not burn itself, this scenario requires combustible material to be present… which is not compatible with a well-managed state-of-the-art storage.

In a high-standard storage, fires still can occur, but AN will hardly be engulfed in the fire.

- if the fire is generated by e.g. a forklift taking fire while in operation close to the AN and that it cannot be moved away nor extinguished soon enough. Forklift or vehicles shall never be unattended inside a AN storage.
- A fire can also start on a belt conveyor and a best practice is to have sprinklers on the conveying systems that are entering the warehouse (fire wall) or located inside the warehouse.

But in some storages, combustibles can be present in large amounts. Below some examples (with best practice reminders are put between brackets):

- it can be the building itself (a state-of-the-art AN storage is not built in combustible material)
- a pile of pallets (pile of pallets must be stored far away from the AN, preferably in another building; AN use of pallets should be avoided whenever possible)
- some vehicles (vehicles in the AN storage shall never be left unattended),
- other goods co-stored nearby, such as solid or liquid fuels, metal powder, etc (only compatible goods can be stored next to AN, such as sodium or calcium nitrate), …
- All these practices are worsening factors.

Worth noting, when the product is bagged, the packing material is obviously combustible, however it is not a worsening factor (packing in today's bags, not in post WWIIbags such as in "Texas City").

This being said, it is very difficult to initiate accidentally an explosion of AN. Just as an illustration, no explosion could be achieved in the full scale tests of ANFO truck **fire**, that were performed in Canada after the Walden explosion, despite purposely worsening factors.

An explosion requires a combination of worsening factors in addition to the fire itself, such as:

- incompatible products to be present (e.g. the stuff that is currently burning), confined conditions, large amount of fuel from the vehicle, etc; and/or
- conditions that are created by the fire. For example molten AN flowing into a closed drain and reacting with incompatible products; Molten aluminum getting mixed with AN; Strong mechanical impact (for example generated by a gas bottle engulfed in the fire) into a pool of molten AN; Etc.

How to define appropriate probability of event for the risk assessment: use of the truck accident history

To quantify the risk, the fault-tree analysis requires a systematic study of the potential causes, thus allocate fair reduction of the probability (typically by a factor 10 to 100 from an independent safeguard on a given branch of the fault tree).

A baseline is required, ideally under "worst worst" case situation, so that credit can later be applied for the safeguard, applied fairly, but also applied only once.

In that perspective, the history of truck accidents, catching fire and leading to explosions, can be a very valuable basis to determine an applicable probability for a LDAN storage of a fire involving AN and leading to an explosion, under "worst worst" case conditions, without safeguard. Why:

- A truck contains significant amount of combustible material
- The accident can involve other vehicles transporting other goods

- A truck accident on the road can involve many uncontrollable elements and worsening factors.
- AN or at least a fraction of it is engulfed in the fire
- There can be confinement (e.g. in case of roll-over, or in a close drain under the road, or etc)
- Multiple wrong combinations and contamination can occur: Fuel and AN can get mixed, fuel and molten AN, molten AN and molten Aluminum can get mixed, etc.
- It is possible to build sound statistics on truck accidents because:
  - ◊ Quite some data are accessible and are public
  - ◊ AN truck fire leading to explosion do occur unfortunately (every 5 to 10 years)
  - ◊ The global truck transport can be estimated since all LDAN will be, at a time or another of its lifetime, be transported by truck, allowing to make a more accurate correspondence between LDAN transport accidental explosions and a global tonnage of LDAN, as explained below.

From the road accidents, the aim is to determine a probability over a sufficient period of time of the "Number of explosions divided by the Number of truck fire involving the cargo of AN" in order to quantify the baseline fire-to-explosion probability under worst case conditions.

The selected time period is 1989-2019,because: 30 years is sufficiently long to build statistics, with the development of the globalization and the changes in China, Russia, etc, information became further more accessible after 1989, and the LDAN products over this time period are basically similar to the products of today in year 2020.

Number of explosions: What are the explosions with LDAN transport that did occur over 30 years 1989-2019: The explosion of Angellala Creek in Australia is well documented. The explosion of a MEMU in Norway is not directly a transport accident but is considered in this evaluation.Thus two LDAN explosions are considered in this approach, over these 30 years. All known explosions in Spain, Romania, China, Brazil, USA, that involved FGAN or HDAN, and are also considered below.

Number of fires: On the other hand, the number of truck fires involving the AN cargo can be challenging to quantify. Many fires, involving or not the cargo, remain simply not reported, therefore an interesting approximation is to use national data of "significant fire" per truck.km, and to estimate the total kilometers made by trucks transporting LDAN.

A probability of 8.8E-9 serious fire per truck.km (7E-8 fire; 1 out of 8 serious) was calculated from French statistics (2013). "Serious fire" is understood here as involving the cargo and/or being sufficiently large fire. To consider all fires even minor ones would reduce artificially the probability (false safety, increasing the denominator thus reducing the calculated probability).

This figure was counterchecked: on the one hand using Australian statistics (using some insurance statistics, crossed with transport statistics) to estimate the number of fires of trucks with major financial impact (approx. 183 fires divided by 19.4 billion truck.km in 2019), leading to a similarestimate of 9.5E-9 major fire per truck.km; On the other hand, using approximate figures specific AN figures (LDAN transported in Australia and major truck fires reported in Australia), lead to a similar figure as well.

The approach is summarized in the table below, with references of the sources:

Period	30 years	Remark
Number of LDAN trucks that exploded in the years 1989-2019	2	(remark there were more truck explosions, but involving FGAN or HDAN)
Number of significant fire per truck.km (AN involved and engulfed)	9E-9	Crosschecked statistics
How many truck.km of AN per year	10000000/20*500=7.5E9	10 millions of LDAN divided by 20 tons per truck, transported on 500km in average.
Probability P	2 divided by [30 years] divided by [7.5E9] divided by [9E-9] = 3E-2 Or 1 explosion out of 34 worst fires involving LDAN under degraded conditions	Running the same approach using approx 50 million tons of HDAN & LDAN, and in total 7 explosions over the last 30 years, lead to a similar figure of 2.1E-2 or 1 explosion out of 43 fires.

A slightly different approach leads to similar figures. Considering the specific AN transport accidents in a significant market like Australia, with one major AN fire every 2 to 3 years and 2 million tons, leads to an estimate of 0.15-0.25 major AN fire at road per year per million tons AN. Considering the global AN tonnage and the 7 explosions in the world, it converts to a probability of 38 to 63 major fires engulfing AN for 1 explosion.

In addition, using public data from e.g. Western Australia (20000 double road-trains per year, about 1 million ton of AN per year), the probability of explosion for each long distance transport is approximatively ~1 to 2E-7 per voyage.

Considering this “worst worst” case baseline of 3E-2 and performing a thorough fault-tree analysis at fire potential, overall probability with an order of magnitude in 1E-7, 1E-8 orlower can be established for well-managed state-of-the-art LDAN storages.

Conclusion

Generic probability figure must be handled with care: Probability of explosion with an order of magnitude in e.g. 1E-5 per year is very conservative for a well-managed storage of LDAN. But it is too optimistic for a low standard storage.

To estimate **the anticipated frequency of a *future* accident** for ***the*** site being considered is not easy.

It requires ideally knowing what would be the “worst worst” case probability (i.e. no safeguard, no respect of the best practices, AN co-stored with incompatible goods, engulfed in a massive fire, etc…) in order to fairly attribute a quantified credit for each safeguard put in place.

The conclusion of this study is to propose for this “worst worst” case probability of a fire-to-explosion scenario with AN engulfed in the fire, if no safeguard would be in place and best practices would not be respected, a figure of 3E-2 for LDAN.

This means that after thorough fault-tree analysis study, anticipated frequency of explosion of 1E-7, 1E-8 or lower can be reached for well-managed state-of-the-art LDAN storages.

Last but not least, it is good to remind that a risk assessment is not a mathematic exercise but is about :

1) identifying, knowing and mitigating the risks
2) ensuring that the risks remain mitigated and that safeguards are controllable/auditable
3) evaluating potential deviation of the safeguards and have sufficient margin coping with it
4) planning for and implementing improvements
5) finally to consciously agree and decide that the risk is acceptable. Or not.

This article is the fruit of teamwork . Many thanks for the numerous contributors who helped me in the preparation of this document or for determining the relevant frequency of worst fires per truck.km.

Handling wastewater from explosives grade prill production

by

Ron Peddie

The porous prill or explosives grade prill (EGAN) tends to produce more ammonium nitrate (AN)-contaminated water than comparable fertilizer production. The reasons for this are that there are more stages in production, EGAN is less robust than fertilizer grade and it tends to break down more easily as well as create more dust than fertilizer grade.

When converted to product it is more likely to be handled in bulk as the receiving mines are large organisations with considerable daily demands. High standards of quality control can also lead to rejection of loads.

Many mines receiving EGAN are in inhospitable, hot and remote regions, meaning that thermal breakdown of EGAN is possible.

The variety of sources for wastewater has necessitated the development of multiple solutions which in turn may help other producers with wastewater problems.

1) Sources of wastewater

Basic plant design – process condensate

The design of a plant can contribute to the production of large quantities of wastewater. Modern designs of reactors help ensure that the process condensate (condensed steam from the neutralisation reaction) is reduced to low levels of contamination. However, in older plants this is not always the case, and the process condensate often has high levels of AN.

Poor process control, such as not controlling the ratio of nitric acid to ammonia and not setting scrubber pH optimally, can also lead to AN increase in both the quantity and concentration of process condensate.

Evaporator waste water

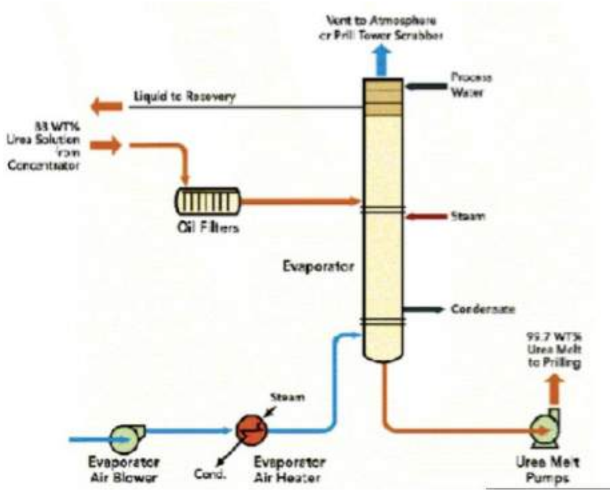
Typically, the ammonium nitrate solution (ANS) is less than the 96% concentration used for prilling into EGAN.

To reach this concentration, a falling film evaporator is used in order to achieve the operation safely.

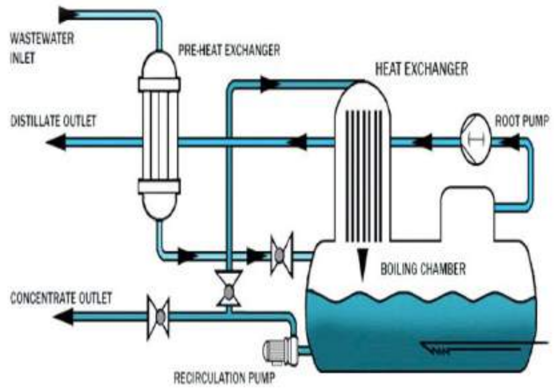
The falling film evaporator can either be vacuum-controlled, where the final concentration is achieved by controlling the vacuum in the evaporator, or air swept, where the final concentration is achieved by hot air removing the excess water.

However, the vacuum control method produces wastewater, unlike air sweeping which discharges its off gas as a mixture of steam and air.

Thus, the AN air swept evaporator is more useful in controlling the generation of wastewater. Nevertheless, there are multiple differences between the two types of evaporator which need to be considered when deciding which is the best for a given plant.



Air Swept Evaporator



Vacuum Controlled Evaporator

Waste from drums and ducts

Once the solid AN exits the prill tower dust is generated. Normally the dust in the air is controlled by water scrubbers which is then recycled.

The dust AN or broken prill can often agglomerate though and form sticky deposits in ducts and drums. Eventually this material has to be washed out, adding to a plant's wastewater load.

Washouts from solids handling

Once the EGAN is made, it is transferred to a dispatch area where it is sent off either in bulk or bags. This operation can lead to solids waste. If a front-end loader is used to load prill the loader itself can crush a portion of the prill. In the bagging operation, bags can go solid if a mistake is made during manufacture. These crushed or solidified materials from the bagging operation must be dissolved to recover the ammonium nitrate. This adds to the wastewater load.

2) Methods of handling waste

Recycle in production plant

The most cost-effective method of recovering wastewater is to recycle it in the production plant. The only cost incurred is the price of the energy required to evaporate the water.

However, this is only an option if the wastewater is clean as described in the section on safety there are serious considerations of safety to be addressed in recycling wastewater.

Recycle in other products

If there is a fertilizer market easily assessible then waste AN can be used as a raw material. However, it must match the requirement and regulations for use as a fertilizer. AN is a component of urea ammonium nitrate (UAN) and in many locations straight AN up to 60% concentration is used as a liquid fertilizer.

In many jurisdictions there are security considerations about selling AN that also cover waste AN. In some of the more remote mining areas there are simply no fertilizer markets nearby.

Emulsions

Wastewater from AN can be considered as a substitute for water in the manufacture of emulsion explosives. Typically AN solution is supplied either at approximately 90% strength or from solid material and emulsions are typically approximately 76% strength. So, there is considerable scope for the use of wastewater here. This also has advantages in both security, as most of the manufacturers of emulsions are security cleared, and also of economics if the emulsion manufacture is made within a single company. In the case of a single company all the value can be potentially recovered.

The main drawback is the presence of contaminants in the wastewater – particularly the internal additive – which can interfere with the stability of emulsions made with this water.

Solid fertilizers

If there is a market for solid blended fertilizers, AN that is not intended for use as explosives could be used as part of the fertilizer blend.

Liquid fertilizers

As mentioned before, liquid fertilizer does provide a possible market for wastewater: it can be used as a diluent to make the fertilizers in place of normal water. In this case typically the wastewater must be sold at discount or given away. There are also quality criteria for liquid fertilizer, as many are used in drip irrigation schemes where the presence of solid contaminate and grit is not acceptable, as it would block the irrigation nozzles.

Seasonality of fertilizer demand

Another important consideration in the disposal of waste is the very high seasonality of fertilizer demand. Typically, fertilizer is only shipped for a few months of the year. EGAN operations are different as they are constant throughout the year. This can lead, at times, to a shortage of available outlets for wastewater if it is being sent to a fertilizer operation.

3) Improvement of quality and reduction of volume of wastewater

There are different qualities of AN recycle:

- AN wastewater with a very low contamination level which can be reused for process applications. This is generally the process condensate produced by the reactor after a flash evaporation cleaning stage.
- AN wastewater with only internal additive.
- AN wastewater with external coating and possibly floor sweeping.
- The techniques for disposing of excess process condensate are:
- Addition as makeup water to the absorption tower.
- The recycle of the concentrated part and use of the clean part as water or to drain.

Reverse osmosis

Reverse osmosis can reduce the contamination levels by a factor of approximately 10. Therefore, a single stage of reverse osmosis may yield a condensate which is of a low enough concentration to be reused as water, and a concentrated stream with a high concentration but low volume which can be recycled.

Flash evaporation

Flash evaporation does the same job as reverse osmosis; it cleansone stream and produces one smaller more concentrated stream. This process is efficient if the steam for evaporation is from the neutralisation reactor.

Filtration

All the wastewater which has a coating agent or comes from floor washing need to be filtered. If it is not cleaned up, it is of no material value or has to be paid to be disposed of.

Diatomaceous earth filter

A diatomaceous earth filter is the best way to clean these filters. Plate and frame filters were previously used for this but more automated versions, such as a diatomaceous earth filter with an automatic cleaning cycle, are now used. These automated filters can provide a very efficient operation.

Filter bags

Bag filters can remove waxy coating agents and grit from floor washing.

Filter bags can be used but this is a messy operation as all the bag material has to be disposed of in landfill.

Neither filtration method can remove the internal additives used for EGAN manufacture. It can be a problem trying to use these cleaned solutions as a raw material for dilution of ANS for emulsions.

Evaporation at low temperature (by air humidity)

Another method to reduce the volume of wastewater to manageable level is to use atmospheric evaporation of the water. This can be achieved by either use ponds or by using an enhanced evaporation unit such as the units made by INCRO. The choice here will depend on weather conditions and the availability of land. It should be kept in mind that using large open ponds could lead to later ground contamination issues unless care is taken.

Evaporation at high temperatures (by steam)

It is also possible to use high pressure steam to evaporate excess water. Care must be taken here that no dangerous conditions are reached either in the bulk or at the tube walls. This is discussed further in the next section.

Using low pressure steam is the only safe option if the wastewater is contaminated.

4) Safety considerations

If AN wastewater is handled below 60% concentration and at close to atmospheric temperature, there are no significant safety concerns.

As the temperature and strength increase a more detailed safety analysis must be made.

This is one reason why it is easier to recycle AN wastewater into emulsion explosives. If AN is recycled into solid production then higher temperatures and concentrations are reached, particularly at the evaporation and prilling stage. In this case the temperature must be limited and controlled, in particular that of the heating steam. This should be controlled below 190℃ and the cleanliness of the solution proved. It is recommended that the advice of an experienced AN specialist is taken before any recycle is made to a solids manufacturing plant.

It is also desirable to avoid the use of the domestic water supply when diluting or washing AN. This water contains chlorides which can concentrate in a recycle loop, potentially causing instability in AN and damaging stainless steel equipment. A closed loop does not allow material from outside of the plant.

It is not recommended that any material from outside a plant be accepted for recycle. The source of any material must be known, and the contamination well understood.

5) Conclusion

All plants have different challenges and opportunities with wastewater, depending on locality and business opportunities. Some areas have no agricultural possibilities; this is especially true of most new explosives plants in remote areas. The ideal solution is to recover the full financial value of AN. However, safety problems prevent the recycle of solution in instances where it is too contaminated. The best method of analysing the problem is by straight chemical engineering, making a good mass balance for wastewater production which has been thoroughly investigated and includes verification with actual plant operational data. It is important that an AN-

How do we decide what materials can be used for the construction or fabrication of equipment designed to process explosives?

By

Andy Begg

This is a topic that is routinely raised when we make safety audits and inspections on explosives plants or when designing a new plant. We usually give a simple answer –"Use soft materials to reduce the potential for initiation by friction or impact". We rarely need to qualify this statement but if we did then we would need to consider the issues raised in the following extract from an R&D report from ICI Nobel Division.

The choice of materials for plant construction in blasting explosives manufacture. (note this was written for Nitroglycerine based explosives)

By Owen A Gurton

With minimal additional material from Andy Begg:

Summary

Our present knowledge suggests that explosives are only set off by application of heat. In the initiation of explosives by mechanical means, the first step is the conversion of mechanical energy into heat. This may occur throughout the explosives (bulk heating) or at local points within the explosive (local heating).

Bulk heating which may be caused by excessive working of the explosives can be avoided by adjusting the clearances in machines, or by the composition of the explosive, but cannot be controlled by the materials of construction.

Local heating may arise by rapid compression of gas or vapour during an impact, by friction between solid surfaces or by production of sparks. The heating by viscous flow is only likely if the approach rates are high, and it is unlikely in normal explosives manufacture.

Local heating by gas compression (which is usually the cause of initiation of explosives by impact) can be rendered less likely by the use of materials which deform under slight stress. On the other hand, the use of strong materials is probably to be recommended as a safeguard against mechanical collapse or deformation in any machines.

Local heating by friction can be controlled completely by using materials of construction of low melting point, provided no foreign material or explosive ingredient of high melting point (e.g. steel, grit or kieselguhr, aluminium, etc) is present. To avoid initiation of explosive the materials should have melting points below 400^{o}C. Above this threshold the local heating depends on other properties of the materials, e.g. thermal conductivity, hardness, ease of oxidation and ease of lubrication. It may appear impossible to use materials of construction of melting point less than 400oC, because of mechanical strength consideration. In any event, the heating by friction can be minimised by a suitable choice of constructional materials.

Heating by sparks begins by local heating during friction, but pieces of materials may get hotter by igniting in the oxidising material into which they are thrown. It may therefore prove advisable to avoid metals with large heats of combustion.

In the present plant for blasting manufacture the mechanical movements are fairly slow, and the hazards due to impact and friction are probably confined to approach speeds and sliding speeds up to 160cms. per second. However, the impacting masses must be considered to be very large, for the machines have very high inertia. Similarly, the loads under which sliding is likely to take place may reach the flow pressures of the metals.

It is unwise to judge the safety of constructional materials by their good record in use, for the number of explosions is happily too few to instil any confidence in comparisons which have been made between materials or machines. There is definitely no reason for believing that anyone mixing machine is better than all others.

At present, the only experimental test used to distinguish between various materials of construction is the torpedo friction test. The results it gives are unsatisfactory since the materials tested arrange themselves in completely different orders of safety when slight changes are made in the conditions of test. The test also suffers from the complex nature of the glancing blow, for at least two mechanisms of ignition are possible, namely, initiation following gas compression, or initiation due to boundary friction.

Propagation of Explosion

Although local or bulk heating may give rise to an ignition it may not grow into a large explosion. Even if complete decomposition of an explosive charge occurs it may take place as a thermal decomposition or fume off, as a burning, or as a severe decomposition (detonation). Of the 3 the detonation is so much more costly in life and capital that any precautions which might lessen the chance of the development of a local hot spot into detonation are extremely worthwhile.

The necessary precautions against propagation of a local explosion into detonation are unknown, but we do know that under similar conditions of ignition there is a critical mass which must be exceeded before deflagration develops into detonation. It might be, from this point of view, wiser to make and work with explosives in small batches. From general experience one would expect a minimum amount of confinement and a minimum thickness of explosive would be advisable. i.e. it might therefore be better to have a shallow open mixer than a deep closed one. It must be remembered however that local confinement within a mixer or cartridging machine is a far greater danger than the overall confinement. If a deflagration is started in a position which is locally confined it may develop a very high local pressure. When the pressure becomes great enough to burst the confinement, a local shock may be imparted to the surroundings, and if the surroundings are detonating explosives the shock may initiate a detonation. This hazard probably outweighs any danger resulting from increasing the size of the explosive batch.

Results from experimental tests

Tests have been carried out under conditions with a range of explosives, materials of contact and stimuli – friction, impact and sliding impact (torpedo friction or pendulum). (AB adds "The expectation was that the tests would indicate which materials of construction were the most suitable – "safest" - to use. Traditional thinking was that soft materials should always be better than harder materials"). However, when tests from different companies were consolidated, they presented some unexpected results. In some cases, there was a reversal of the order of safety when PETN was replaced by NG – the only point of similarity being that steels were the least safe. Generally, as expected, the soft materials including wood, soft rubber, lead and nylon were the safest.

Conclusions

In the opinion of the author the mechanical explosion hazards in the blasting explosives plant which can be modified by a suitable choice of materials of construction seem to be limited to two as follows: -

- The hazards associated with impact between a moving part and a foreign body, or another part of the machine. Explosion may develop from this cause if an air bubble is entrapped between the colliding surfaces.
- The hazards associated with friction between solid surfaces. In this case an ignition may develop due to local high temperature at the points of contact, or due to local high temperature at the points of contact, or due to the liberation of small pieces of oxidisable metal.

In both cases, under normal working conditions the hazards are confined to approach speeds or sliding speeds below 160 cms per sec, but the inertia of the impacting bodies, or the effective load during friction may be very large. All glancing blows may be defined as a combination of friction and impact and it is considered that only one of these effects operates at one time. The frictional and compressional energies are not released at the same spot. The most dangerous conditions are typified by: - (1) a flat impact without friction and (2) friction without impact.

The author recommended that the following investigations should be carried out:

- Fall hammer experiments should be carried out with various combinations of materials using aerated liquid or gelatinous explosives
- A friction apparatus of the turn-table type to deal with liquid explosives should be built and various materials tested for their ability to initiate explosion by friction
- A friction apparatus of the pendulum type should be built to deal with the solid and gelatinous explosives in the same way.
- The torpedo-friction test should be critically examined in an attempt to determine whether it is an impact or a friction test under various conditions of use
- Finally, the results should be considered in relation to the physical and chemical properties of the materials, and if possible, a general guide to the choice of materials of construction should be drawn up.

Specific points from the report

To initiate an explosion of several grams of nitroglycerine by bulk heating demands a rise in temperature of about 215°C. Larger masses of the explosive decomposing at much lower temperatures would probably explode. To initiate an explosion of nitroglycerine by a very small hot spot may require a local temperature of 480 -500°C

Bulk heating may arise in any mixing or cartridging machine by excessive working of the explosive, or by the conduction of heat from outside the machine e.g. from a bearing which is poorly lubricated.

To reduce bulk heating to a minimum it is necessary to limit the rate at which energy is dissipated to the batch. This may be done by keeping the machines in first class order and replacing all worn parts as soon as clearances exceed agreed tolerance.

Andy Begg adds

This report was written almost 70 years ago when Owen Gurton was a chemist in the R&D dept of Nobel Division of ICI at Ardeer. I knew him personally – he interviewed me for a position in the same R&D Dept in 1970 - by then he was the Research Manager. And so, my career in explosives began.

I came across this report a few years ago when I was fortunate enough to have access to the library of Nobel's in Ardeer – the company had been sold and the contents of the library were to be destroyed. The destruction of the contents was in my eyes a disaster as the library contained decades of detailed R&D reports like this one. So much information being destroyed.

So this report is almost 70 years old but I hope having read it the reader will realise the safety issues we face today with emulsions, watergels, PETN, primary explosives and so on are not new. Today we have the BOS system and the associated training module, but it is based on the same principles that Owen talked about all those years ago. And the issues are described in simple practical terms. We just packaged it differently as BOS.

The report also shows the detail that went into understanding the interaction of plant equipment and materials of construction with the explosives they were to be used with. When I was in the R&D dept I can recall undertaking tests often lasting 6 months to establish the compatibility of proposed new materials for use in the NG lines or in the watergel plants. All based on the principles established decades previously. And these principles are still as valid today as they were in the early 1900's.

My takeaway message from this paper is to all members and it is this:

Collectively in SAFEX and in our members' archives there will be a wealth of valuable information about basic safety principles of explosives similar to those in this report. We owe it to those undertaking work in explosives today to ensure that this information is made available and used.

A copy of the full report by Owen can be made available on request.

LETTER OF ASSURANCE –SAFETY PRACTICES

Dear Site Manager,

Following my visit to the factory last week and our discussion on the operation of forklifts could you please confirm by next week:

- Details of the safety systems that are on all company owned and leased forklifts and how these systems are assessed and maintained.
- That drivers are trained and licensed/authorised to operate all site forklifts. How is the currency of training records and authorisations maintained?
- Details of the traffic management plans when forklifts are operating within warehouses and around explosive magazines.

The above letter is an example of one on a specific Safety Area within the responsibility of the Management Chain. There are many examples within any explosives operation – which area is of a particular concern to you. Do you have a letter of assurance for critical operations? ? Please share your letter of your critical operations with the SAFEX community .This learning might prevent serious injury or harm!

Thanks to Paul Harrison for this initiative.

Tribunal Hearing on Safety of Mucking under Loaded Holes in Long Hole Mining by

Dr Chris Watson and Dr Joey Viljoen

In 2015, the CNESST - the workplace health and safety regulator of the province of Quebec - banned the practice of mucking under loaded holes, a part of the underground long hole blasting method, which had been in use for a number of years in several jurisdictions, without problems. The ban was unsuccessfully contested by the mining companies affected, and eventually was appealed to an industrial tribunal hearing. The tribunal overturned the ban in 2018, permitting the operation to resume. This account details the involvement of the authors in the proceedings, and can be regarded as a cautionary tale, both for regulators and for explosives manufacturers and distributors.

Long Hole Mining

The long blasthole mining method, "LBH – Large Blasthole" is a form of open pit bench blasting adapted for underground mining operations. Vertical Crater Retreat (VCR) or mechanical raise boring is used to open a slot raise, thus creating a vertical free face for the subsequent bench blasting operations. The drilling and mucking operations are carried out on two sublevels; the drilling and loading (explosives) level above and the extraction (mucking) level below. The diagram illustrates a typical layout for long hole mining.

Typical long hole layout

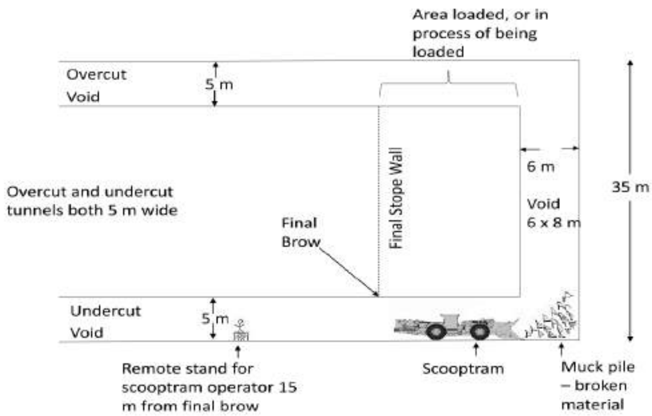


Figure 1

Loaded holes at the overcut level

VCR, also called vertical retreat mining, is a well-established underground mining technique, developed in Canada the 1960s and may be used in certain cases in lieu of or in conjunction with the "LBH". Both methods involve drilling large-diameter holes into the orebody vertically from the top, as opposed to the conventional blasthole stope method of drilling them in fans with upward and/or downward fans. LBH and VCR are beneficial mining methods because they reduce the cost of mining orebodies that are wide and steep. They also eliminate the need for a support system after the blasting occurs and increase mining safety because miners do not have to be in the area of the ore when blasting is taking place. In the operation considered here, mucking is carried out under loaded holes, some of which may be plugged breakthrough holes. This significantly increases the efficiency of the operation.

Miners are not present at the point of the mucking operation, which is carried out by a remotely operated scooptram (LHD vehicle).

Remote mucking at the undercut level

CNESST Actions, 2014-16

Mucking under loaded holes has been carried out routinely in Quebec and elsewhere without problems for many years. Nevertheless, in 2014 the CNESST informed the QMA of their intention to prohibit this practice.

Our involvement began January 2016, when one of us (CW) was asked by the Quebec Mining Association (QMA) to assess and comment on a document produced by the CNESST detailing their reasons for the ban. None of the scenarios appeared credible, and the reasons for this were presented in a report to the CNESST. Other documents presented to them included quantitative risk assessments (QRAs) of the operations carried out by the mines involved, and a report by Dr Ken Liu, a well-regarded mining consultant. The two sides met in August 2016, where the QMA attendees made several presentations explaining their conclusions, and requested questions. The CNESST attendees were silent during the meeting, asking no questions and making no comments. Shortly afterwards, the CNESST confirmed their ban on the method, citing inadequate evidence of safety. The CNESST objection to the practice of mucking under loaded holes was that it could lead to an accidental detonation of one or more holes with risk to the miners overhead or on the mucking level. They initially proposed 8 scenarios.

Potential Hazard Scenarios provided by the CNESST:

- A fall of rock causing explosives to fall from a loaded hole onto or near the scooptram (LHD vehicle)
- Fall of explosives on a hot part of the scooptram
- Impact or friction on explosives caused by scooptram
- A fire on the scooptram causing detonation of an overhead hole
- Impact by the scooptram on the rock face near a loaded hole
- Accidental detonation of a hole during mucking
- Impact or friction by scooptram on explosives in muckpile
- Detonation of booster assembly hanging from hole caused by impact of scooptram

Industrial Tribunal Hearing

In 2016 the QMA appealed the CNESST decision to an industrial tribunal hearing, which could confirm or overturn the ban. The tribunal consisted of a judge and a technical advisor; evidence was given under oath and both sides were represented by legal counsel.

Legal team, from left to right:

Caroline-Ariane Bernier and Jacques Rousse (McCarthy Tétrault LLP), Jean-François Séguin and Bernard Cliché (Morency Société d'avocats s.e.n.c.r.l.).

The QMA presented expert witnesses on mining, explosives and rock properties to contest the validity of the CNESST assertions.

The CNESST witnesses were members of their inspectorate, none of whom claimed expertise in the field of explosives. Their arguments depended mainly on documents produced by the IME and ISEE, and explosives manufacturers' Safety Data Sheets (SDSs).

Evidence used by the CNESST to justify the ban

The CNESST in large part justified their ban on mucking under loaded holes, or mucking while loading holes on the basis that it was not safe to do so because of the hazards presented by the explosives used.

This included the IME SLP 4 (2012 version). The 2016 version is currently available on the website (Institute of the Makers of Explosives, https://www.ime.org/products/category/safety_library_publications_slps), the 2012 version is available from IME), the ISEE – Blaster's handbook, 18th Edition – Appendix C, "Warnings and Instructions" (this used to be called "Always" and "Never" in older editions) (Stiehr & Dean, 2011) and information contained in the Safety Data Sheets for the relevant explosives. They also presented a video made by the Canadian Explosive Research Laboratory of tests of explosions inside magazines as evidence that if a booster exploded underground the results would be catastrophic. They clearly did not understand risk vs. hazards, their justifications to ban the practise only mentioned hazards, and never referred to risk.

From both the IME SLP 4 and ISEE Appendix C similar points were used as evidence of explosives hazards:

- NEVER fight fires involving explosive materials. Remove yourself and all other personnel to a safe location and guard the area.
- NEVER expose explosive materials to sources of heat exceeding 150°C (65°C) or to open flame, unless such materials or procedures for their use, have been recommended for such exposure by the manufacturer
- NEVER strike explosive materials with, or allow them to be hit by, objects other than those required in loading
- NEVER subject explosive materials to excessive impact or friction

Section 10 (Stability and Reactivity) from some Safety Data Sheets were presented by the CNESST as evidence regarding sensitivity of explosives products. Points specifically highlighted by the CNESST are listed in the extracts below, for various explosives.

Emulsion:

- Chemical Stability: Extreme risk of explosion by shock, friction, fire or other sources of ignition.
- Conditions to Avoid: Keep away from open flames, hot surfaces and sources of ignition.

ANFO:

- Conditions to Avoid: Keep away from open flames, hot surfaces and sources of ignition.
- Incompatible materials. Direct sunlight, extremely high or low temperatures, ignition sources, combustible materials, incompatible materials.
- Incompatible Materials: Combustibles, heat sources
- Extreme risk of explosion by shock, friction, fire or other sources of ignition.

Boosters:

- Chemical Stability: Stable up to approximately 70°C (158°F). PETN explodes at 190-210°C (374-410°F).
- Conditions to Avoid: Keep away from open flames, hot surfaces, sources of ignition. Extreme risk of explosion by shock or friction.

Detonator Assemblies:

- Chemical Stability: Extreme risk of explosion by shock, friction, fire or other sources of ignition. Stable up to approximately 70°C (158 °F).

Our strategy

After reviewing the evidence provided by the CNESST to support their ban, we came to the conclusion that it was pointless voicing our opinions that some of these statements exaggerated the hazards or were incorrect. We decided that the best route would be to present facts as counter arguments. We developed the following strategy to do this:

- We would explain to the judge what factors affected the behaviour of an explosive, and how these factors differed for different types of explosives;
- Both of us had copies of older versions of IME SLP 4 and ISEE Appendix C and we noted that they were practically identical to the later versions presented as evidence by the CNESST, so we thought that a review of the history of IME SLP 4 and ISEE Appendix C would show that it these safety precautions had not changed for many years and had not kept pace with the development of safer explosives;
- We would review the tests required for classification for transportation of explosives and the type of data these tests generated; and finally
- We would present some of the tests done by companies on explosive raw materials and products with some relevant data.

We assembled presentations covering the properties and behaviours of blasting explosive and explosives accessories. The presentations reviewed the types of explosives (primary, secondary and tertiary), and how they differed in general terms. They described how the properties of critical diameter, confinement and gap sensitivity affected the behaviour for different explosives. They also included reviews of tests typically performed on explosives for transport classification, determining the suitability of explosives for various applications, and manufacturer-specific safety and performance tests.

We summarized the Critical Diameter and Confinement relationships required to produce a deflagration-to-detonation event (DDT) for emulsion or ANFO initiated by heat:

- Sufficiently large critical diameter + Sufficient confinement = Sustained Detonation
- Critical diameter too small + Confined = NO sustained detonation
- Sufficiently large critical diameter + Unconfined = NO sustained detonation[1]
- (Note 1: except self-confinement by very large quantities)

For the gap sensitivity of emulsions in particular, we were able to use information from one of the explosives suppliers. Their tests indicated that these products typically had gap sensitivities from 0 – 13 cm, and that at distances greater than these the emulsions will not initiate. The data also showed that the gap sensitivities depended on the degree of sensitization. We noted that in Canada, emulsion used underground is booster-sensitive, (i.e. Division 1.5, but not Division 1.1), and will typically require good contact with the booster for propagation (i.e. typically has a gap sensitivity of 0 cm).

IME SLP 4 and ISEE Appendix C

The ISEE Blaster's Handbook 18th Ed. Appendix C is largely based on based on IME SLP 4. Chris contacted the IME for historical versions of the IME SLP 4. As luck would have it, the IME was in the process of digitizing historical materials, and a scan containing all the SLP precursors to the more recent versions of SLP 4 was provided to us. A review of this revealed that the "Don'ts" predated 1951, and at the time covered High Explosives, Black Blasting Powder, Pellet Powder, Blasting Caps. The document became "Do's and Don'ts" in 1955, still covering the same explosives. By *ca.* 1970, it had become SLP 4, and by then it included Non-electric detonator assemblies, detonating cord, blasting agents, water gel slurries and cast boosters. It was evident though that the actual "Do's and Don'ts" were virtually unchanged from the era of dynamite and black powder. The document had never been updated with specific sections to deal with ANFO and emulsion, with the unfortunate result that although the relative insensitivity of ANFO and emulsion was known to the explosives industry, this information never made it into referenced materials such as these.

We reviewed the requirements of UN Tests for the classification of Explosives relevant to the products in question, in particular Test Series 3 (which determines if a substance (i.e. a powder or liquid) is safe for transportation), Test Series 4 (which determines if an article containing explosives is safe for transportation) and Test Series 5 (which determines if an explosive is a very insensitive explosive with a mass explosive hazard, i.e. to distinguish between 1.1 and 1.5 explosives).

In regard to Test Series 3 and 4, we reviewed the Impact Sensitivity, Friction Sensitivity, Thermal stability Test and Ignition test for response to a fire (Small scale burning test on 10 g sample).

We pointed out that for the Thermal Stability Test a substance or article is heated at 75°C (167°F) for 48 hours, and that substance fails if an explosion occurs; and an article fails if it explodes, ignites, experiences a temperature rise of more than 3°C, the outer casing or packaging is damaged, or exudation occurs. This raised questions as to why some of the SDSs, IME SLP 4 and ISEE Appendix C noted that articles are unstable at lower temperatures.

We noted that friction tests are not done for articles, as containment and packaging of explosives in an article effectively eliminates friction as a hazard. We highlighted that because of containment and/or packaging, many explosives that fail Test Series 3 will pass Test Series 4.

We used the External fire Test from Series 5 to show that an explosive can only be classified as an 1.5 substance if a sample of 200 kg does not explode when subjected to a large fire.

Other tests

We discussed some of the tests manufacturers perform in addition to the standard transportation tests, to help them characterize their products better. This included bullet tests to evaluate the effect of impact for emulsions, and product-specific impact tests on boosters, detonating cord and detonators, demonstrating the effect of enclosing the explosives within an article.

Typical impact and friction tests used for explosives do not give positive test results for emulsions, even at maximum energy input. In one case a manufacturer uses a bullet test instead. The test consists of shooting a high-velocity projectile (rifle shots) into emulsion contained in a tube. These tests have shown that unsensitized (Division 1.5) emulsion does not detonate, that sensitized emulsion (Division 1.1) needs a bullet velocity of at least 550-600 m/s to detonate at 20°C , that the bullet has to be shot directly into the emulsion, and that the addition of 6 mm aluminum layer in between is enough to prevent detonation (Lightfoot, Research Notes from CERL: Initiation of emulsion explosives by projectiles, 2008).

A review of impact tests on detonators, detonating cord and boosters illustrated well how explosives sensitivity is modified by enclosing the explosives in an article and/or modifying the form in which they are used:

- Enclosing the explosive in an article (e.g. detonator tube, detonating cord) virtually eliminates friction;
- Enclosure / coatings provide protection and reduces impact sensitivity;
- Having the explosive present in a non-powder form reduces sensitivity (e.g. solid form instead of a powder for a cast pentolite booster).
- The enclosing material(s) also provide some protection against heat, slowing the time to reaction.

Detonators need significantly more impact energy before exploding than the explosives powders used in them (in powder form: Lead Azide: 3 – 6.4 Nm, PETN: 3 Nm, vs. 10 kg from a height of 80 cm (78.5 Nm) for a detonator (Franklin & Worsey, 2004). Cast boosters shatters when weights are dropped on them. The PETN in detonating cord required impact of 17 Nm for deflagration and 93 Nm for detonation, while the impact sensitivity of the powder is 3 Nm. The effect of impact on cast boosters was determined by dropping 100 kg on 150 and 400 g boosters from 1.8 m, with the boosters lying horizontally or standing vertically (impact energy 180 Nm). In all cases the boosters shattered, there were no initiation of any kind (test data for boosters and detonating cord from one of the manufacturers).

{Impact sensitivities of powders from (Meyer, Köhler, & Homburg, 2002).

Booster impact test

Shattered booster

Regarding the Safety Data Sheets, we came to the conclusion that the phrase *"Extreme risk of explosion by shock, friction, fire or other sources of ignition"* used in many of the Safety Data Sheets had its words in the wrong order. We noted that both emulsion and ANFO are not at all friction sensitive (We used the example that enormous amounts of ANFO have been augered over the years, and that the augering and its associated friction has never led to an explosion). We referred to the bullet test for emulsions to illustrate how impact-insensitive emulsions are. We pointed out that sufficient heating can result in burning, but unless an explosive is present in amounts sufficient to ensure critical diameter is present and the emulsion is properly confined, it will not detonate. We suggested that the phrase above would be more accurate if replaced by something along the lines of *"Some risk of explosion by shock, fire or other sources of ignition. Not friction sensitive, not very impact sensitive."*

The SDSs for some detonators and boosters stated that the products were *"Stable up to approximately 70°C (158 °F)"*, which is obviously not correct, as they must pass the UN thermal stability test of Section 14.4, which requires heating at 75°C for 48 hours), implying that they must be stable at least up to 75°C.

The Safety Data Sheets contained other questionable statements, such as the following for one of the detonator products: *"Explosion Data – Sensitivity to Mechanical Impact: Not expected to present an explosion hazard due to mechanical impact".* Anyone familiar with detonators will know that sufficient mechanical impact can cause a detonator to explode.

Worst Credible Event

After evaluating potential scenarios for things going wrong during mucking operations, we came up with what we regarded as the worst credible event. The risk of ANFO or emulsion detonating due to an impact or heat event vanishingly small, detonation under those circumstances was not credible. The gap from a potential explosion of a booster initiated in the muckpile, to the ANFO or emulsion in bottom of hole (several metres) is too great for effective initiation. If leaks occurred due to an improperly plugged hole, the amounts will be too small to detonate upon heating or impact and there will be insufficient amounts present to sustain detonation as the requirements for critical diameter or containment would not be met.

In the event that a primed booster extending through improperly plugged hole for some reason is caused to fall to the ground, the impact likely to shatter the booster, but there is small chance of detonation occurring instead. If a booster is subjected to heat, it will likely just burn due to insufficient confinement, but the burning may over time lead to a detonation. However, such an event would not be instantaneous, there will be time to react.

In the final analysis, the detonation of a 454 g primed booster was the worst credible event. Interestingly enough other explosives experts besides us independently came to the same conclusion.

CERL Magazine trials

In late 2009, the Canadian Explosives Research Laboratory performed two tests, blowing up magazines with 5 kg and 20 kg pentolite boosters (Ollerenshaw & von Rosen, 2010), (Lightfoot, Research Notes from CERL: Demonstrating the Effects of Detonating Small Quatities of Explosives inside Magazines, 2010). The CNESST presented the 5 kg video as evidence that if a booster exploded underground the results would be catastrophic.

Fortunately, one of us (JV) was present at the tests, as a representative of the Explosives Regulatory Division, to help set up the tests and pick up debris afterwards, and could describe the results of the tests from personal experience.

As the references above clearly notes,

chances for damage and injury are clearly fragment driven;
overpressure was already under 5 psi at 10 m in all three positions for pressure transducers for the 5 kg charge; and
the cement block barricades used in the second test appeared to be quite effective for stopping the metal debris of the magazines' sides.

It was noted that the scooptrams used for the mucking would be positioned between the operator and any potential booster explosion, and would likely offer similar protection against secondary rock debris as the cement blocks.

The proceedings were not without lighter moments. Strangely enough, none of the CNESST inspectors had actually bothered to go underground and observe the practice that they had banned. Dr Watson was not unfamiliar with the procedure, since he had worked at ICI's McMasterville Technical Centre during the years when this mining method was developed. Since Joey had not observed this procedure before, she requested to visit some mines for this purpose. Consequently, at the end of January 2017, she and another of the expert witnesses, Pierre Grolier, visited three mines near Rouyn-Noranda and Matagami, in Québec, to observe the long-hole mining procedure (both how the loading and the mucking were done), and to discuss how the explosives products were used with relevant mining personnel. This clearly annoyed the opposition lawyers during the testimony, as it highlighted the lack of rigour by the CNESST inspectors.

Another amusing incident occurred when commencing to review the tests from the UN Manual of Tests and Criteria for transportation classification, during Chris' testimony. The lawyers representing the CNESST and unions objected to the introduction of these as evidence, as in their view it was "foreign legislation, not applicable in Quebec". It was then politely pointed out to them that the UN Recommendations on the Transportation of Dangerous Goods Model Regulations, and Manual of Tests and Criteria are both incorporated in Canada's Transportation of Dangerous Goods Regulations as ambulatory references (http://gazette.gc.ca/rp-pr/p2/2017/2017-07-12/html/sor-dors137-eng.php) (ambulatory reference: the reference is always to the most recent version) and that Canadian federal legislation is applicable in all provinces and territories in Canada!

The tribunal and the decision

The hearing dragged on interminably (53 days, between February 2017 and March 2018) due to the stalling tactics of the CNESST lawyers. Finally, in June 2018, the Tribunal's decision was rendered, in favour of the QMA.

The judge gave a number of reasons for the judgement:

- There is nothing in the Quebec Regulations which forbids the practice;
- The prohibition orders spoke of possible risk, not probable danger;
- The inspectors who had issued the prohibition orders to the mines had not even witnessed the operations (they had never gone underground to observe the practice!)
- The inspectors relied on information provided for the general public (which is naturally very conservative) and were not even aware of more detailed and specific information provided by the manufacturers in their technical literature.

Overall, the judge was quite critical of the CNESST. The report severely criticized the lack of knowledge and professionalism of the CNESST inspectors and the tools they used to come to the conclusion that the mucking procedure was dangerous.

Lessons for the Explosives Industry

While eventually a favourable judgement was reached, the mining companies lost millions of dollars due to lost production and legal costs.

One of the contributing causes for the CNESST ban on the mucking practice was undoubtedly the inadequate and often misleading SDSs provided by the explosive manufacturers. These appeared in some cases to have been prepared by someone with little knowledge of explosives. Reportedly, due to the increased complexity of Safety Data Sheets compared to the older Material Safety Data Sheet format used in North America in the past, many companies now outsource the compilation of these documents, rather than doing this in-house. In addition to the risks of accidental explosion, the new SDS format also require information other issues, such as toxicological and environmental risk. This probably has led to problems as the software used to generate the SDSs were probably not written by people with adequate knowledge of explosives, and in addition, it appeared that no-one with the appropriate explosives knowledge reviewed the SDSs for accuracy. We notified the manufacturers in questions about issues we had noted with their SDSs. Fortunately, the feedback was quite positive, with indications that action will be taken.

Another contributing cause was the fact that the guidelines outlining the hazards of explosives and how to use them have not really taken the properties of modern explosives into consideration, they pretty much still reflect the hazard considerations and practices for dynamites and black powder. We have suggested to representatives of the IME that SLP 4 should be revised to add ammonium nitrate emulsions, and that SLP 4 needs an overall review. A positive development in this regard is that the Code of Good Practice for the Environmental Management and Properties of Ammonium Nitrate Based Explosives will now contain a section being developed by CEAEC (the Canadian Explosives Industry Association) will contain information on the chemistry, properties and hazards of these types of explosives.

A third cause was the lack of knowledge exhibited by the personnel of the regulatory body. In this regard, conversations with people in the explosives and mining industry have indicated that this is becoming more common as people are retiring. As a result of the slow or no growth in the mining industry from the late 1980's (due to the downturn in the mining cycle) to *ca.* 2002/3, (when the most recent global growth phase commenced), a gap for people recruited to the industries occurred from the 1980's to the early part of the new century (we can in fact both recall multiple retrenchments during the 1990's). This has left the industry with a so-called "double-hump curve" with a diminishing number of experienced people (approximately older end of baby boomer age), and younger people (millennials and a bit older), with a gap in between. Regulatory bodies have traditionally recruited experienced and knowledgeable personnel from the mining and explosives industries. The effect of the older group now retiring *en masse* is loss of corporate memory and knowledge in both industry and regulators.

Explosives manufacturers worldwide have spent many years and much money developing much safer explosives. Indeed, many of the traditional tests to asses the sensitiveness of explosives, developed in the days of nitroglycerin and black powder, would not serve to classify emulsion and ANFO as explosives at all. While the need to err on the conservative side when developing precautionary statements is recognized, not to acknowledge the safety of modern explosives is to the detriment of both user and producer. Organizations dealing with explosives and their manufacture could help address the situation by having suitable educational materials available for educating newcomers (including regulators) to the products of the industry.

References

Franklin, R., & Worsey, P. (2004). Impact Sensitivity of Detonators. *30th Annual Conference on Explosives and Blasting Techniques* (p. 411). ISEE.

Institute of Makers of Explosives. (2016). *Safety Library Publications*. Retrieved from Institute of Makers of Explosives: https://www.ime.org/products/category/safety_library_publications_slps

Lightfoot, P. (2008). Research Notes from CERL: Initiation of emulsion explosives by projectiles. *SAFEX Newsletter No. 27, 4th Quarter*, 6.

Lightfoot, P. (2010). Research Notes from CERL: Demonstrating the Effects of Detonating Small Quatities of Explosives inside Magazines. *SAFEX Newsletter, Nr 32, 1st Quarter*, 6.

Meyer, R., Köhler, J., & Homburg, A. (2002). *Explosives, 5th Edition.* Weinheim, Germany: Wiley-VCH.

Ollerenshaw, J., & von Rosen, B. (2010). Two Tests Demonstrating the Effect of Small Blasts inside Explosives Storage Magazines, Canadian Explosives Research Laboratory, Canada. *Proceedings of the 12th International Symposium on Fireworks.* Porto Gaia, Portugal.

Stiehr, J. F., & Dean, J. L. (2011). *The Blasters' Handbook, 18th Edition.* Cleveland, Ohio: International Society of Explosives Engineers.

Principles of Minimisation
By
Paul Harrison

With the ongoing improvement in the safety of manufacturing and handling all sorts of explosives over recent years, some fundamental principles that have been established over the last hundred years or so, and undoubtedly associated with loss of life, seem to have been forgotten by the new generation in the explosive industry. It is critical that these well-established principles not be lost and that all those operating within the explosives industry are constantly reminded of them. The principles are those associated with **MINIMISATION**.

The **Principles of Minimisation** are as follows:

MinimumExposure.

No matter where explosives are manufactured or handled, the number of people involved in the process must always be kept to a minimum.

In explosive manufacturing plants this Principle should already have been well established and followed, having been well ingrained into design engineers, operational supervisors and managers. With bulk explosives, manufacture has now moved to the blast bench where unfortunately this Principle is not fully understood and often ignored. The Principle is also often completely ignored during break downs, during maintenance activities and during plant commissioning with "live" explosives.

Minimum Input Energy.

Wherever explosives are manufactured, and handled steps must be in place to ensure that the energy that explosives are being exposed to is at an absolute minimum or, ideally, completely removed.

Many are aware of FISH. These energy inputs must be eliminated or, if unavoidable in the manufacturing or handling process of explosives, they must be set and maintained at minimum, predetermined, safe and acceptable levels.

Minimum Quantity.

Explosive quantities must be maintained at predetermined minimum levels throughout the whole explosive manufacturing processes and supply chain.

Minimum Concurrent Operations.

If processes within a facility involved in the manufacture and handling of explosives can't be separated by well-designed and established barriers, or by suitable separation distances to protect people and surrounding facilities, then the number of concurrent processes being carried out must be set to an absolute minimum and ideally to only one operation at a time.

This Principle is well established in the manufacture of NG/EGDN based explosives where raw material preparation, mixing, cartridging and final storage are generally separated by barriers and/or appropriate separation distances. The Principle is often forgotten in the design and operation of package and bulk emulsion plants, in open plan explosive laboratories and in detonating cord and safety fuse spinning processes.

In summary, wherever explosives are being handle ensure that there is

Minimum Exposure
Minimum Input Energy
Minimum Quantity
Minimum Concurrent Operations

****

POSTSCRIPT. Would a SAFEX member like to come up with a suitable acronym (like FISH for energy inputs that need to be managed with explosives) covering the four Minimisation Rules?

Reflections and Lessons Learned about managing a pandemic, like COVID19

by

Andrea Sánchez Krellenberg – MAXAM Global OH&S Director

On this day in 2020, while we are still fighting to deal with the COVID19 pandemic, it is a good moment to start reflecting on what we, the Health and Safety Leaders, have learned out of all the challenges we have and are still facing.

If we wait until everything is over, whenever it happens, we will probably miss the momentum and go back to business as usual very rapidly.

There're scientific researches and studies (Report of Imperial College of London) that are announcing we're not going back to normal in many, many months, but this is a different topic.

My first reflection is about engaging Top Management in the Crisis Management early enough so many actions, instructions and communications have the right support and commitment of Top Management right from the beginning.

We all have seen how the different governments have treated the crisis and how it took longer in some areas of the world until the authorities understood the real danger of the coronavirus and its consequences.

Apart from the Leadership Commitment, there are three key success factors from the health and safety point of view:

- To set the right Crisis Committees at the right levels and including all different needed functions. Crisis Committees will ensure the correct:
-
    - ◊ Sense of urgency
    - ◊ Capacity for decision making
    - ◊ Coordination among different business units, regions of the world and functions; unified criteria
    - ◊ Ownership and accountability in all different actions that are agreed and need to be implemented

- ◊ Agreement on IT tools to be used for deploying and cascading information and guidelines generated in the different committees.

- Development of the potential different scenarios of contagion so it is clear what to do and when. For every scenario, develop the containment and mitigation protocols well in advance and deploy them using your OH&S Teams at the different levels, insisting over and over:

  - ◊ Focus on protecting the most sensible and vulnerable employees because their medical history.
  - ◊ Identify the Critical Job Positions, what are the positions you need to keep operating under any circumstances, so you can provide them with additional preventive and protective measures.
  - ◊ Include IT department so it can be properly planned working from home or home-based.
  - ◊ Go beyond health and safety and include wellbeing. The pandemic is creating fear, stress and uncertainty to our people. Offer tools to overcome those situations.
  - ◊ Support and proactive collaboration with all your internal and external stake-holders

- Communication to the different stakeholders:

  - ◊ Periodic and transparent official communication to the employees, including institutional communication from the CEO and more technical communication about the whole situation and how it is impacting our lives, the way we work and the expected behaviours
  - ◊ Informal communication with the direct Teams, even if it is virtually, are key to manage emotions, avoid bad emotions contagion, to learn and to discuss about next steps.
  - ◊ Thank the Teams for the effort and engagement!!

Obviously, a pandemic like the one we're living now needs an important attention from many other perspectives, like security of supply to our clients, financial impact now and in the medium and long-term, etc, which was not in the scope of my reflection.

CHRONICLES FROM THE PAST:

This section is dedicated to past incidents, operations, good practices and all that the Explosives Industry holds dear over its long history

WHO IS THE SEARCHER NOW ?

By

Brian Allison

Did you know I can still remember when each 'danger area 'on an explosives manufacturing site had a dedicated 'searcher'. Back in the day at the ICI plant at Ardeer, employing around 4000 people in the 1970s, they had searchers for each area of activity, dynamite, propellants, detonators, PETN, det cord, boosters etc. Shows just how old I am.

They were generally grumpy, older gentlemen who stood for no nonsense. It was very much in your interest to be sure you passed their inspection, or you would not be allowed to enter the plant and specifically the 'danger area '.

No contraband materials were allowed, cigarettes, matches, lighters, watches, money, keys etc. I'm sure today many other modern items would be included, e.g. mobile phones, ecigs. etc.
You also had to ensure you were wearing the proper clothing for the area being visited, only approved work clothes being allowed. If a mechanic, then only approved tools and equipment could be brought into the danger area e.g. non - sparking tools.

Searcher (third right) inspecting all personnel entering and leaving the danger area.

Long gone are the searchers and many other old practices in the evolution of our new 'safer' explosives. Unfortunately for me, I believe we are losing some of these fundamentals of good practice which should not be forgotten but regularly emphasised.

Another function of the searcher was to ensure that only approved employees and visitors were able to enter the plant or danger area. In particular this included maintenance people, mechanics, electricians, carpenters etc. who had been trained and appointed for a specific area of operation. They were very strict about who was allowed on the plant, all visitors were closely screened to ensure they had an essential need to be there.

In the past maintenance people were dedicated to a plant. They were specifically trained for that area and only after a significant period of time in a workshop would they be permitted to go into the danger area. This after all training had been completed and validatedunder the direction of an experienced supervisor. This is generally not always the case today. Now most plants have their own permanent small core maintenance team which are usually supplemented by contractors at peak periods of activity.

The fundamental principal should still apply that only fully trained and validated contractors should be admitted. This needs to be very well managed as unfortunately contractors by the nature of their business will hire and fire people on a regular basis. It is important that plant managers and supervisors keep this well under control.

This needs to be carefully managed and particularly on remote sites where personnel are sometimes isolated, and contractors change on a regular basis. I have some first- hand experience of this at a remote bulk emulsion plant. A transfer pump had failed and operations at the mine were going to be delayed if it could not be repaired. The usual plant mechanic was not available, so a very good mechanic was sent by the mine to help out. Mechanics as with most of us, they want to do a good job and solve problems, after all that is what they are paid for. With all good intentions he removed the pump to his workshop for investigation and repair. He had some problems with removing corroded bolts and was considering applying some heat which would be normal practice for him, Most fortunately plant management realised the pump had been removedin time for them to prevent any external heat being applied.
This was a significant failure of management and systems which could have had a very serious outcome.Unfortunatelythis is not an isolated incident, I have heard of similar near misses in other operations.

Again, another role of the searcher was to ensure any material or equipment leaving the plant had to have the proper paperwork and clearances included, or it could not be removed. Not really practical now on remote sites but someone has to have that responsibility. Who is your searcher now?

Historically on explosives plants there was always recognised plant shutdowns for all maintenance work, cleaning, painting etc. to be completed. All operations would be stopped, all explosives and chemicals cleared away and equipment and buildings cleaned. Many times, now I can see teams of contractors working on operational plants doing these types of activities that really should be planned for a weekend or recognised plant shut down. All unnecessary exposure of people to risk.

In our modern day when we tend to drive rather than walk, supervisors, mechanics, operators all want an office / workshop / canteen/ labnext to the plant as this ‘saves time’ but significantly increases unnecessary exposure.
On many sites I have seen this trend being adopted when new plants are being built.
During construction contractors use portable office buildings close to the construction site for convenience. On numerous occasions I have seen that after construction these cabins are very often taken over by plant people, again for the convenience of being close to the plant, particularly during commissioning. After starting up, this very soon becomes the recognised plant office and over time can actually grow to include other functions, maintenance, logistics, meeting rooms, labs etc.

In some cases, this idea of having people close to the plant has been developed further. Permanent buildings being included in what should be considered as ‘danger area’ in the design and construction of new plants. A fundamental aspect of any manufacturing plant should always be to minimise inventory and exposure. Once the minimum explosives quantity is established then the proper Quantity / Distancecriteria should be applied and the explosive license quantity identified for each building, not to be exceeded. Many times, I have seen plants and magazines that are well over the licensed quantity for ‘operational ‘reasons.
There is also seems to be a tendency to interpret the Q/D tables as required for the optimum plant layout and best use of land. I have seen several examples where permanent offices have been built holding around fifty people within thirty metres of a manufacturing plant, with no physical barrier between. Any incident on the plant would have a major impact on this building with, finance, admin, logistics people etc. at risk, who should all be located well away from the ‘danger area’

I believe we should stick to the fundamental principal and ensure that only the minimum essential personnel are within the potential danger area of any explosives manufacturing plant.

Who is the searcher on your plant / site? Do you have the systems, procedures and training in place to ensure only approved personnel, clothing, tools and equipment enter and leave the plant at all times? Who is the searcher now?????

CAPPED FUSE AND IGNITERCORD, THE GOLDEN AGE

By

Tony Rowe

I was privileged to read Mr G Morgan's article in the SAFEX Newsletter No. 71 in which he discussed the industry stalwarts of yesteryear, safety fuse and ignitercord. I thoroughly enjoyed the piece. It brought back fond memories as it explored familiar territory and practices. Thank you Mr. Morgan, I feel thoroughly refreshed.

As you probably know, I inhabit the world of the arcane. That's a nice way of saying that I live in the past, it's my happy place you see.

I know, I know, my memory is not what it once was. I cannot remember simple stuff like the colour of my socks, whether or not I've had breakfast, the diameter of safety fuse, why I've got egg on my tee shirt, or the formula for ignitercord slurry, so it won't be very exciting. Thrill seekers should probably find something better to do, but I do believe there is some merit in the telling of the tale, so here it is, warts and all. I must warn you that I intend to ramble on about connectors, fuses, ignitercord plus their individual and collective contributions to the buzz words of yesteryear, sequential firing.

First of all what is 'Sequential Firing?'

Sequential (also known a rotational) firing was a mining practice used in narrow reef stoping operations. It means that the holes go off consecutively in a pre-determined order. For instance, the hole pre-designated as Hole#1 goes off first. This is followed by the hole pre-designated as Hole#2, then Hole #3 and so on. I suppose it could be achieved (in a fashion) using electric detonators. They were known back then as DAED's for delayed action electric detonators. There was a finite number of delays though - around 16 or so. Sixteen holes is a short stope indeed.

In theory and whilst not exactly millisecond timing, sequential firing could also be readily achieved using fuse and ignitercord. Up to 20 seconds between consecutive holes firing was not then seen as an impediment. Indeed, there was a bonus. There would be no limit to the number of holes or the length of a stope. On paper it could be accomplished by the order of connection of the individual capped fuses to the ignitercord trunk line. The fly in the ointment was that no mechanism to make that connection existed at the time.

Rose tinted spectacles I know, but we all wore them.

As we were to later learn (and assuming a reliable connection could be made) the three most important factors in achieving sequential firing using fuse and ignitercord were:

(1) Variations in the burning time of the ignitercord between connections.

(2) The consistency in the burning speed of safety fuse cut to similar lengths.

(3) The order in which each connection is made.

There are a lot more, but in the interests of brevity, these three will serve.

Today, blasting has become an extremely sophisticated process. It can often involve computers and the internet. Then there are the various boxes and keypads of the control equipment together with a host of complex integrated electronic circuitry and incomprehensible software. Electronic detonators appear alongside older shocktube based systems where the transition to rigid pyrotechnic delays may have improved timing. There are even intricate hybridised combinations employing both shocktubing and micro-electronics together, seamlessly in a single system.

There was once a simpler time.

I like to call it "The Golden Age of Concentrated Mining" and it came to be simply because the Holy Grail of Sequential Firing in Narrow Reef Stoping was finally realised. No batteries were required. It was just a slightly modified version of capped fuse and ignitercord. The change itself was, but a small one, yet it ushered in 'a Golden Age' that was to last for more than 50 years.
It was literally a 'Golden Age.' The most sought-after precious metal being gold, chemical symbol Au, No.79 on the Periodic Table.

I'm English, not that you can tell and I remember those early days very well. It was the end of the 1940s. The Second World War had ended. In my hometown the barrage balloons had all been wound down and our local military barracks were still packed with American GIs. All the local girls wore nylons and smoked either Chesterfield or Lucky Strike cigarettes. It was a strange time and I could never understand why the local boys always looked so glum.

We still used our ration books however and Mum continued to darn my socks, but changes were coming. Some of the technical knowledge acquired during the conflict was beginning to seep into the commercial sector. Both capped fuse and an early form of ignitercord existed, but the ability to connect a length of capped fuse to an ignitercord trunk line had not yet become a reality. At the time, fuses were more often than not lit using a 'Fuse Igniter,' more commonly known as a Cheesa Stick.

We can discuss the Cheesa Stick at length in another article should there be sufficient interest.

Fuses were lit by applying the flame from the cheesa stick to each fuse tip in turn. An athletic young man was often tasked with this duty which was clearly not without its hazards. The 'stick' itself consisted of a waxed-paper cylinder containing an incendiary composition. Once ignited, a stick would burn with a vigorous flame for at least 4 minutes. The last 30 seconds of that burning time being indicated to the user by a change in the colour of the flame from yellow to blue - adequate time to light a new stick.

Forward thinkers quickly realised that if a robust and reliable link between fuses and ignitercord could be realised it would have the potential to revolutionise the mining industry.

The link may have made its debut in Canada. As far as I have been able to determine, there was little fanfare. Admittedly, my personal knowledge around the early days of connectors remains somewhat sparse, but I suspect that the first available devices were manufactured by **CIL**, (formerly **CXA, and now Orica)** using a tube made from a copper/zinc alloy which was slotted after filling and pressing.

The device, though small. possessed a rather grand title. It was christened "The Slotted Ignitercord Connector." It was, quite frankly, an innocuous device that attracted little attention. Only when it was crimped onto a length of capped fuse did it come into its own. Firstly, it provided a waterproof seal, but it was so much more than a mere closure device. Its crowning glory was that it allowed a secure connection to an ignitercord trunk line to be made and an ignition pulse to pass.

South African versions of the connector utilised an aluminium rather than a copper tube. I seem to recollect that there were a couple of variants available (see Fig 1 below). They were known as the Mk1 and the Mk2. Now don't shout at me if I get this wrong. The Mk1 was supplied with a plastic collar, intended I believe, to more effectively secure the ignitercord in the slot. Also, in the Mk1, the lug formed by the action of slotting also had a thicker top lip.

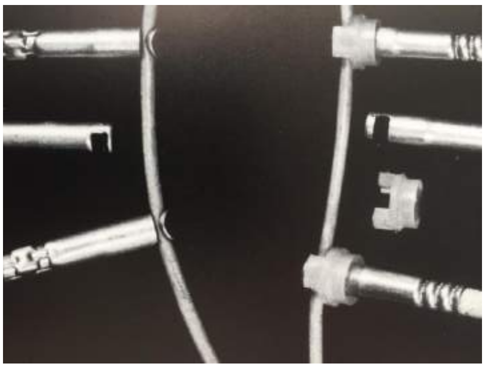


Fig 1. This is an early photograph, but clearly shows the differences described in the text.

The Mk2 connector is on the left and the Mk1 on the right

The Mk2 did not have a fitted collar and the slot was cut nearer to the closed end of the connector tube creating a much thinner top lip. This change in geometry allowed the lug that was formed to be readily closed onto and thus securely grip the ignitercord using finger pressure alone.

I seem to remember that the connector/ capped fuse assemblies manufactured by **CXA** were unique in that they included a small metal, possibly iron, staple. The staple's metal legs were caused to pass through all the outer protective layers of the fuse and on and into the black powder core. The crimping of the cap or detonator tube resulted in the now narrowed detonator tube wall contacting the staple. An electrical connection between the tube and the core was created. I think it was intended to deal with any electrostatic discharge issues that might occur between the electrically conducting black powder column in the fuse and the sensitive initiating explosives pressed within the detonator or cap, but staples aside, sequential firing had come of age.

Word spread and connector/capped fuse was soon in great demand. At first, end users would have received both connectors and caps (detonators) as loose items and would have been required to hand crimp a cap (detonator) to one end of a length of safety fuse and a connector to the other. Before long, not only did pre-cut fuses become available, but complete, factory-manufactured and commercially crimped connector/capped fuse assemblies would be on sale.

So, what was an ignitercord? An often-quoted contemporary description was as follows: "Ignitercords are essentially thin, flexible cords which when ignited burn at a controlled rate and with a vigorous external flame" (Fig 2.). This was achieved by coating an incendiary mixture in the form of a deflagrating slurry onto the outside of a combustible core consisting perhaps of paper yarns, textiles or fibres. Almost a wick I suppose. Wire cores would also appear in the fullness of time as would ignitercords offering different burning rates, but for now the optimum burning speed for the application was deemed to be in the region of 16 – 24 seconds per meter (the original burning speeds were specified in seconds per foot, but I did the math). By the way, the safety fuse of my day burned, within legal limits, at a rate of 90 – 110 sec/yard (you can do the math this time). I remember it because it was printed on the cases.

The Achilles heel of these early ignitercords was of course their lack of water resistance. Wet ignitercords simply wouldn't ignite or burn. The water resistance of such products depended almost entirely upon the integrity of a very thin waterproof sheath (applied as an overcoat) being maintained. If the thin plastic sheath was compromised, water penetration could occur bringing with it a high possibility of failure.

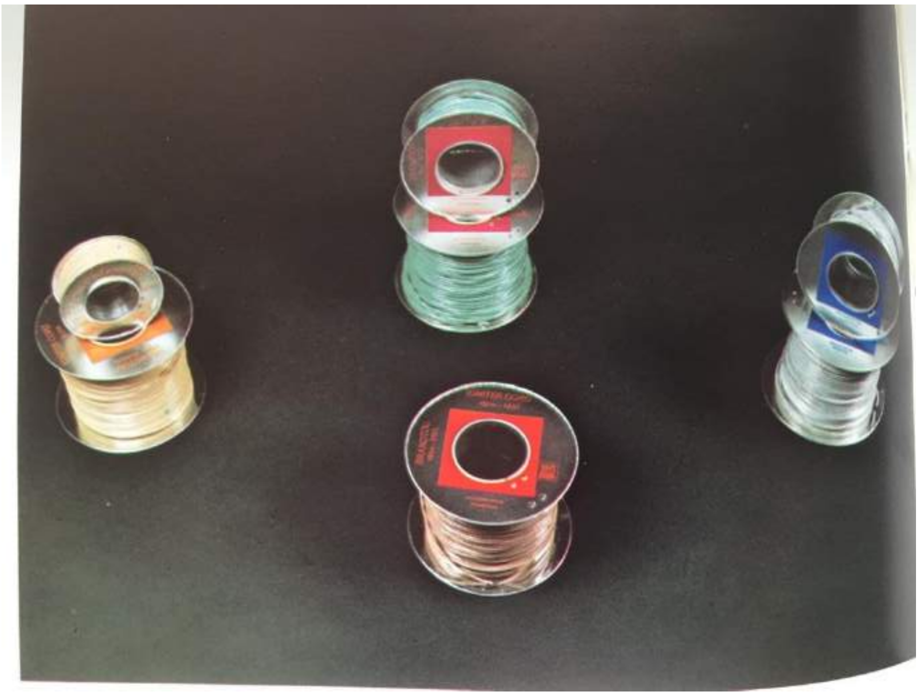


Fig 2. Spooled Ignitercords (circa 1960)

From left to right they are Slowcord,! C57, Medium Cord and front and centre, Fastcord

***

The construction of safety fuse is very different to that of an ignitercord. Safety fuse generally employs a central core of black powder surrounded and partially confined by multiple layers of natural and/or synthetic textile wrappings, paper tapes and waterproofing layers (see Fig 3). In the past those waterproofing layers have included bitumen, or asphalt, gutta percha, Alkathene and LLDPE.

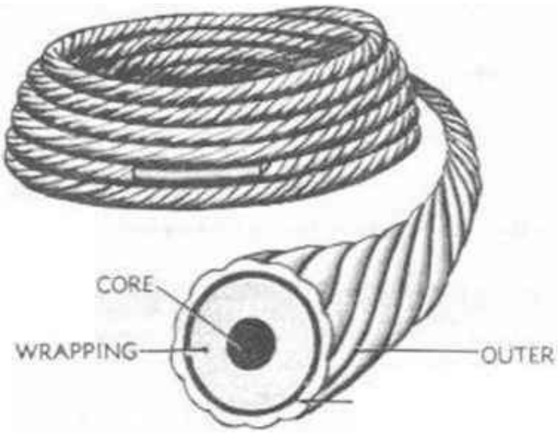


Fig 3. Typical Safety Fuse Construction

Safety fuse also has been marketed using a range of unique, but evocative brand names. Sadly, I can only clearly recollect four them, Sweden's 'Black Double Weave,' Ensign Bickford's 'White Sword' and 'Orange Sword' brands and finally, Canada's 'Yellow Sump.'

The central core of most commercial safety fuse consists essentially of black powder sometimes called gunpowder. The South African product called Wet Spun Safety Fuse did not, in the strictest sense of the word, possess a black powder core. The core of wet spun fuse did though contain all the ingredients used in the manufacture of black powder, but the manufacturing process of what came to be called 'paste' was significantly different. Unfortunately, neither black powder nor the core of wet spun fuse can tolerate adulteration by water. This is because a major component - potassium nitrate - is extremely water soluble.

Despite this shortcoming, a well-made length of safety fuse is perfectly waterproof along its length, but its two uncovered open ends provide a point of entry for water and possibly other contaminants. Additionally, if the open ends are mechanically abused black powder can fall out and be lost. In such cases ignition of the fuse is made more difficult.

Crimped to one end of a length of capped fuse the observer will notice a closed metal tube. This is the 'cap' or, as it was known, a plain detonator, that provides, alongside other features, an effective waterproof seal. Although quite small the tube contains pressed increments of powerful initiating and secondary explosives.

I think there were two variations of detonator available. The first was known as a 6D plain detonator and the second, longer and more powerful, was an 8D. The external diameters of the aluminium tubes remained the same in both cases. The 8D detonator though contained twice as much secondary explosive as its 6D counterpart. The initiating charge though was the same in both variants. The 8D was instantly recognisable due to its much longer tube. In both cases though should such a cap 'explode' within a closed fist, the traumatic and immediate amputation of several fingers is the most likely outcome. The difference might be in forever being only able to count to five or, if it was a 6D, seven.

This article was written to pay homage, not to the detonator, but rather to the connector. The Slotted Ignitercord Connector, an unsung and long forgotten blasting accessory provided the missing link in a chain that made so much possible. Of course, over the years efforts at improvement were made. I seem to recollect one such attempt. I guess it took place in the mid nineteen-fifties. The resulting device was called "The Pig Tail Connector" and it employed a short length of igniter cord, a twin holed, neoprene plug and a ca 10 mm long aluminium tube into which both the fuse and the ignitercord were secured and crimped. No other pyrotechnics were employed. A ca 20 cm length of ignitercord was thus left protruding which could then be attached to the main ignitercord trunk line. I suspect the device quickly morphed into a delay starter intended to ignite only the ignitercord trunk line rather than the individual fuses. I seem also to recollect an electric starter for ignitercord (ESIC) in which an electric fusehead replaced the length of safety fuse. I don't think it was a particular success and I mention it only for interest.

Whatever the success or failure of any particular connector design we must not lose track of its basic function, which then as later, was straightforward and clear; to reliably convert the fierce external flame of a propagating ignitercord into the 'safe' internal flame of safety fuse and to do so under all conditions of use.

Have you ever stopped to think exactly what that phrase "Under all conditions of use" actually means? We are talking underground here. It can mean storage, sometimes for weeks at a time, at temperatures (often cyclical) up to 40 degrees centigrade at 90% relative humidity It means a total absence of care and attention. It means flame transfer may occur when the connection is physically under water, being sprayed with water or when contaminated with blasting explosives or even diesel oil. When we discuss contaminants, just about anything is imaginable as well as a few things it is better not to think about. Damaged, old or moisture degraded ignitercord might also be used in the lacing up.

A connector was also expected to work when damaged, bent or even partially flattened, but by far the most amazing thing of all is that from the moment a slotting machine cuts that transverse slot through the body of the connector tube, the whole ignitable surface of the pyrotechnic composition is forever exposed to the environment. No other incendiary product that I am aware was ever saddled with such a burden. This semi-miraculous pyrotechnic composition known as CBC (Connector Base Composition) was though simply a mechanical mixture of various herbs and spices. Most of it was of course industrial nitrocellulose with just a pinch of the fabled pixie dust.

CXA though had employed FNH powder in their formulation. FNH was an acronym for flashless, non-hygroscopic, nitrocellulose. Unfortunately, FNH powder was/is of military grade. In South Africa and entirely due to political sanctions, FNH powder became unobtainable. A replacement, based on industrial nitrocellulose, was therefore devised.

In addition to the pressed increment of CBC there was also a small, pressed increment of black powder. It was referred to as 'a pill.' Burning black powder catalyses black powder to ignite and so the rapid combustion of a fast burning black powder, confined within a tube and in such close proximity to the open end of the fuse core, pretty much ensures fuse ignition.

A connector must light first time, every time despite whatever horrors it may have experienced or must still undergo. It gets only one chance. Amazingly, connectors mostly met their obligations. There were exceptions. Changes in either raw materials or process parameters were the main causes. One event though was truly awful. Connectors across South Africa began to fail en-masse. The cause was eventually determined and rectified. To say that the identification of the cause was difficult would be a massive understatement. It was simply not understood and for a long time could not be duplicated in the lab, but after much effort and experimentation, answers came, and the necessary remedial action was swiftly taken.

In addition to all of the above, a connector must be 'safe to handle' and be relatively insensitive to ignition by impact. It must be compatible with all types of ignitercord. Connection must not damage the ignitercord and connection or disconnection of large numbers should be easy and not result in operator fatigue. Connection should not require tools either. It should also be self-evident that the cord is incorrectly attached. I could go and on but take it from me the list is a lengthy one and all of this for just a few cents. Few bargains have ever been this good.

Memories of Modder

By

Jack Hedger

Reading Gordon Morgan's article in the last Newsletter, 'Reflections on Safety Fuse Manufacture in South Africa', brought back memories for me as I'm sure it did for anyone who worked at Modderfontein in the '70's and '80's. I was one of a group of graduates recruited from the UK to work in the Research Department. Sunny South Africa certainly sounded enticing at the interview on a grey day in London and the claim that this factory was the largest commercial explosives factory in the world was no idle boast. The way it was put to me was that they made a million meters of safety fuse every day, cut it into 1-meter lengths and then crimped a detonator on one end and a connector on the other. The reason for this incredible demand was that at that time, South Africa was the world's biggest producer of gold and platinum and both were mined underground from narrow reefs. This mining method, known as narrow reef stoping and which I think is unique to South Africa, takes out a narrow slice of ore-bearing rock using numerous small diameter (25-35mm) holes, usually about one meter in length. It was an incredibly labour and detonator intensive method of mining.

I arrived at Modder (as it was always known) in March '76 and my over-riding memory of my first weeks at the factory was the feeling of 'What on Earth have I let myself in for'? Tours around the various plants introduced me to the hammer-blow headaches of NG, the century old technology of safety fuse, the dystopian manufacture of Black powder and the Kray twins of the detonator world, lead azide and it's manic brother lead styphnate. I was decidedly underwhelmed. Then, mercifully, I found electric dets and pyrotechnics (I also worked with Peter Seligman who was an inspiration). Unfortunately, whilst I found fuseheads and delay compositions fascinating, these were a minor part of the product range and I did not see a great future for myself. But times they were a changing. As Gordon Morgan remembered, the manufacture of black powder and ignitercord were transformed with the development of water-based technology (under the guiding hand of Boet Coetzee no less). NG was giving way to water gels and emulsions, and electric dets were to be challenged by shock tube. And this was my salvation.

'Nonel' as the original shock tube from the Nitro Nobel company was, and still is, known, was, in my opinion, a brilliant invention. A short length of it was handed to me in 1978 with the words, 'We don't think it has much of a future, but we need to evaluate it'. I thought it was absolutely stunning. The major problem with electric dets was their complexity. Connecting up anything but the simplest array involved deciding whether to have a series or parallel circuit and then matching the circuit to the shot exploder capacity. An uninsulated joint could cause earth leakage. A poor joint caused an open circuit. Stray currents caused premature firing and electrostatic discharges were a constant fear both in use and in manufacture. It seemed obvious to me that 'Nonel' solved all these problems at a stroke.

I imported two 3000m reels of tube and was given carte blanche to develop a whole range of new products. The basic technical problem with replacing the fusehead in an electric delay det with 'Nonel' tube was that electric delay dets were in effect, a mini pressure vessel and needed to remain gas-tight while the delay composition burned. Nonel was a hollow tube and so the system was vented. Under these conditions existing delay mixtures either did not ignite or gave very erratic burning times. After exploring several dead ends, I found a solution in a minor product that had been developed by Canadian Safety Fuse (later CXA) known as an Anodet. The basic construction included an interface between a shock wave from the signal tube and the main delay column and, thanks to some very smart chemistry, provided a gas-tight seal for the delay train. (I could tell you more but, unfortunately, I would have to kill you afterwards.) This proved a winner. It has been the basic design for Orica non-electric dets ever since and kept me thoroughly and enjoyably employed for the next thirty something years. One of my warmest memories at Modder were the demonstrations I gave to Mining Students: these took the form of demonstrating the difference between detonation and deflagration, sequential firing with 'Nonel' and always fished with a loud bang. They always elicited a round of applause and my rejoiner was 'Can you believe they actually pay me to do this?'

I still find it hard to believe I was in the right place at the right time. There hadn't been an innovation like that in detonators for over twenty years and there wasn't another for another thirty.

In the early days of non-electrics in South Africa, the target markets were tunnelling and quarries. Both areas where safety fuse and igniter cord were not very user friendly. The much simpler concepts of bunch firing in a development heading or the limitless combination of a surface connector and in-hole delay in a quarry, were very quickly appreciated. The concept of stoping with shock tube was certainly thought about and some proof-of-concept trials were conducted in the platinum mines using a double ended unit with an in-hole delay and a surface connector. However, it was obvious from the start that functional reliability, particularly of the surface connector was going to be paramount.

So, there was no real competition at that stage between the up-start shock tube and the behemoth of safety fuse and, as Gordon noted, it took over twenty years for this to happen.

It was around this time that I moved to ICI Australia where the focus was much more on surface mining. The initial focus was on removing detonating cord from the surface and was fairly straight forward except that normal practice with det cord was to have two initiation paths to each hole ('boxing-in' was the term we used). To have a sequential firing system with shock tube was going to require an unprecedented level of functional reliability. It was also going to require a level of unprecedented delay time precision if sequential firing was to be a reality.

This is really why I'm writing this article because I doubt that many people realise the effort that went into achieving these joint objectives.

There have always been two key parameters for delay detonators: these are (1) delay time accuracy and precision and (2) failure rate in the field. The first is very easy to measure the second is much, much harder. Obviously, delay dets are sampled during manufacture, usually according to a Military Standard sampling scheme, that allows the delay time accuracy and precision to be measured. There are several statistical measures that combine accuracy and precision but one very simple one is called the coefficient of variation (or CoV for short). This is simply the standard deviation i.e. the variation or precision, as a % of the mean or average. Historically for delay detonators, a CoV of <3% would be reasonable. In fact, I had a project at one stage to produce high precision electric dets but I was never able to consistently produce detonators with a CoV of <1.5% and, believe me, I tried. With today's non-electrics there are many products with CoV's of around 0.5%. That shift in delay quality was the result of some very deft chemistry and an exacting attention to detail. If you think of what that actually means for a 400ms delay, the SD is around 2ms or put another way 95% of a batch will have a delay between 396and 404ms. How remarkable this is was brought home years later when we built a plant in China. The plant had been subject to the usual scrutiny from the authorities, but I was told there was a special inspection required. Three officials arrived and were taken around the plant asked for samples to be taken from the product coming off the production line. These were taken to the laboratory and were duly fired and gave the expected results. After the officials left our Chinese technician told me that she had been asked what secret ingredient we were using as the timing results were too good. Obviously, there was no 'secret ingredient' there was a lot of know-how and attention to detail. I'm reminded of the cookery analogy that we can all buy the same ingredients, but we can't all produce a gourmet meal.

Now we come to the second parameter: failure rate in the field. This is very hard to measure because it has to take into account both in-production failure modes and end-of-use failure modes. If I tell you that in over thirty years in three different factories I have never seen a failure of a routine sample of a delay detonator, you will understand that simply firing more samples is a fruitless approach. I always remember when I began working on electric dets they were mostly used in tunnelling. When I enquired about the failure rate I was given an off-cuff reply of 'about 1 in 10,000'. I don't know where this figure came from but with non-electrics, where they are frequently connected in a 'daisy chain', this level of failure would be totally unacceptable. To minimise the possibility of failure we identified possible failure mode and then designed the in-process capability and monitoring to eliminate them. We didn't get it right all the time but just how far we have come can be gauged from comparing the number of non-electrics produced and the number of field failures. Taking Australia as an example, during in my time, there would have been around 20 million non-electrics used each year but reported misfires would have been in single figures. My estimate from the data I could gather was a misfire rate of around one in several million. A reduction of two orders of magnitude is no mean feat and one I am particularly proud to have been part of.

In my first years at Modderfontein there were two NG plants that were destroyed, a spent acid tank that detonated and took the lives of the technical team involved and the black powder plant burned down. We have all come a long way since then. Emulsion explosives, water-based processes such Gordon described and (in my opinion) the inherently safer non-electric initiation system, have all made our industry an inherently safer place. I had a fantastic career and I am very proud of my small part in that process.

My thanks to Gordon for his article, it brought back some wonderful memories, and thanks to all the terrific people I worked with.

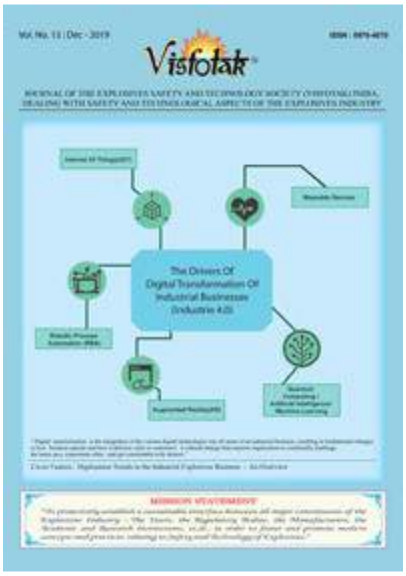
Stay safe.

A primary explosives joke:

Will you find azide, b-zide the c-zide? Answers on a signed blank cheque please.

(Modderfontein in Johannesburg , South Africa, was the largest explosives manufacturing site in the world, at the time)

Please find below the link to the SAFEX Associate Member, VISFOTAK in India's recent Newsletter:



Click to access.

ARTICLES FOR NEWSLETTER

This is a reminder that through the Newsletters we share knowledge in the areas of Safety, Health, Environment and Security pertaining to the Explosives Industry. SAFEX thus call on all members to submit articles on these subjects within their own companies and countries.

The deadline for articles for the October Newsletter is 10 October 2020 .I look forward to your continued support .

SAFEX BOARD OF GOVERNORS

UPCOMING EVENTS:

International Society of Explosives Engineers — 47th Annual Conference on Explosives & Blasting Technique, to be held Feb. 7-10, 2021, at the Caribe Royale in Orlando, Fla.,

SAFEX International Congress 2021,Salzburg, Austria 21-27 March

International Explosives conference, London, UK, 608 July 2021

SAFEX thanks all the authors and contributors as well as the editing team Andy Begg and Noël Hsu for their for their invaluable support.