Explosive Selection

Techniques to Select the Most Economic Solution

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Principal Drill and Blast Engineer
Blast It Global
Presentation Overview

Topics
• Presenter
• Introduction
• Explosive properties
• Detonation of explosives
• Blast impedance
• Cost evaluation
• Conclusion
Presenter

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International Society of Explosives Engineers (ISEE) (Member)
Institute of Quarrying Australia (IQA) (Member)
• WASM 1993 to 1994 (Lawler Gold Mine/Darlot Gold Mine) – Blast Hole Sampler / Blast Crew
• Placer Dome (Granny Smith Mine) 1995 to 1999 – Sampler / Blast Crew / Mine Supervisor
• WASM 1999 to 2001 (Mesa J Robe) – Blast Crew
• KCGM 2002 to 2003 - Trucks / Blast Crew / Dispatch
• Newcrest (Cadia Valley Operations) 2003 to 2004 - D&B Engineer
• Orica Mining Services / Quarry Services 2004 to 2012 - Technical Services Engineer
• Rio Tinto (Technology and Innovation) 2012 to 2014 - Advisor Drill & Blast
• Blast It Global 2014 to present day Drill & Blast Consultant
Introduction

As mining professionals our roles sometimes require us to assist or manage the explosive selection process. To select the most cost effective explosives for a specific mine site requires us to have some fundamental understanding of explosive chemistry and detonation physics.

Selecting explosives on price only, without any other background information, quite often will ensure that your site will not have the most cost effective solution.

To be able to select the most cost effective explosives for your site you must have an understanding of the following:

• Explosives properties (composition),
• What ground conditions are required for an effective detonation to occur (maximise delivery of chemical energy to rock)
• The ground conditions (confinement for detonation to occur);
• How to measure cost of explosive energy;

This presentation is not about promoting any specific explosive suppliers or explosives types. The session is aimed at providing information to better equip professionals to make better choices if aiming to select the most cost effective explosives for your operation.
Price Only Selection Process

As the manager of the procurement of bulk explosives we have been given prices for a wet hole product from 3 different suppliers (Imaginary suppliers & product for demonstration purposes)

<table>
<thead>
<tr>
<th>Supplier 1</th>
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<td>Bulk Strength: 180</td>
</tr>
<tr>
<td>Weight Strength: 110</td>
<td>Weight Strength: 107</td>
<td>Weight Strength: 112</td>
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<tr>
<td>TDS Disclaimers#: 10</td>
<td>TDS Disclaimers#: 6</td>
<td>TDS Disclaimers#: 2</td>
</tr>
<tr>
<td>Marketing claim: The Future of Fragmentation!</td>
<td>Marketing claim: Maximum Fracture Guaranteed !</td>
<td>Marketing claim: Finer Fragmentation !</td>
</tr>
</tbody>
</table>
Price Only Selection Process

An effective selection of bulk explosives cannot be made based on price and the claims made on a specific company’s Technical Data Sheet (TDS).

- Buying on a product name guarantees the user of nothing:
  - Weight strength and Bulk strengths are determined using proprietary detonation codes and assume infinite confinement during detonation (Ideal Detonation - not real world);
  - Chemical composition unknown. Composition can be changed at the supplier’s requirement, as long as detonation occurs, to maximise profits;
  - Information on TDS cannot be compared between companies, relative to specific company only;

- Side by side trials – provide more informed ??
  - If judged on appearance only, will not provide any real information for evaluation;
  - If measures like instantaneous dig rates, fragmentation, KwHr/T the evaluation process can be improved;
  - Geology variation between blast locations can also provide a +5% variation;
  - Operators can provide over a 5% variation in results (Dig rates and fragmentation measurement)

What do you need to consider to improve the selection process?
Explosives Properties - Types

ANFO – 5.7% Diesel or Fuel with 92.3% Porous Prilled Ammonium Nitrate (PPAN).

HANFO – 70% ANFO with 30% Emulsion (most common mix) Can vary between 10% emulsion and 50% emulsion.

Emulsion – 30% ANFO with 70% Emulsion (most common mix) Can vary between 60% emulsion and 100% emulsion.

Watergel – 100% Watergel to 60% Watergel mixed with ANFO (most common 100% Watergel).
Explosives Properties

ANE – Ammonium Nitrate Emulsion (Emulsion)
- Water +16% to -25% (More water less energy and lower cost);
- Solid AN – dissolved into water (65 to 70%);
- Sodium Nitrate – dissolved in water (Up to 7% (dual salt))
- Emulsifier (1 to 2%);
- Catalysts (Gassing) < 1%
- Fuel – (≈6%) Diesel, Mineral Oil, Canola Oil, Paraffin, Waxes.

ANS – Ammonium Nitrate Suspension (Watergel)
- Water +8% to -25%, typical ≈ 12%
- Solid AN – dissolved into water (45 to 85%);
- Solid AN – solid in solution (5-15%);
- Cross linkers - < 1%
- Organic sensitisers 10 – 30%
- Fuels 6 -15%
Explosives Properties

The key element of clarifying a bulk explosives properties, to enable a true evaluation, would be to ask the question from your supplier with regards to ANE or ANS:

- Water content % by weight;
- Fuel content % by weight;
- Oxidiser % by weight;

Ensure the information being provided is for the ANE or ANS not the explosive mixture which includes a percentage of ANFO.

- Increasing water content reduces the recrystallization temperature, if no heated tanks and cool climate. At 15% water the crystallisation point is at a higher temperature than at 23% water.
- Increasing water reduces the energy of the explosives, less oxidiser and fuel per tonne of product.
- Increasing water cools the heat of reaction. Even in an oxygen balanced composition as ground confinement reduces (soft ground), unwanted by products are produced.
Detonation of Explosives

When referring to Relative Bulk Strength (RBS) or Relative Weight strength (RWS) of explosives, the values are typically calculated using detonation codes that apply to an infinite confinement (constant temperature, pressure and volume) detonation, which does not happen in the real world.

- **Ideal** detonation requires – Constant volume, pressure and temperature at the instant of detonation;

- The majority of bulk explosives will undergo a **Non Ideal** detonation. The maximum explosives energy available is not realised. This is due to:
  
  - Explosives sensitivity. The higher the density of a bulk explosives the less sensitive the explosives when comparing the two equal explosives formulations, for bulk explosives using mechanical or chemical gassing technology (very common);
  
  - Blast hole confinement. Soft clay oxide material poor confinement, massive basalt lava flow (high confinement). High confinement provides improved detonation conditions as the temperature, blast hole pressure and volume are closer to being constant.
Detonation of Explosives

Bulk explosives is sold by weight. The higher the density the greater weight per hole, the greater the sales volume. Based on the common belief that higher powder factor per hole will improve blast results.

Have you ever tried a lower density product at your site and measure? Is there a variation in fragmentation, dig rates or crusher throughput?

• Is the density of the bulk explosives reducing the sensitivity and making the detonation of the bulk explosives even less non ideal (less energy). This is common occurrence and in softer ground (Iron Ore mines) in the Pilbara has been measured to be occurring.

• Large Magnetite mine ran 1.05 gcm⁻³ density bulk emulsion explosives for 6 months compared to a base case of 1.2 gcm⁻³, with no change to power draw at primary crusher ≈ 10% reduction in bulk explosives usage.

• Goldfields miner reduced bulk explosives from 1.15 gcm⁻³ to 1.05 gcm⁻³ cup density, measured no change in fragmentation or load and haul productivity using same blast parameter.
Detonation of Explosives

The key information required when clarifying your explosives detonation, to assist with optimum explosive selection:

• What density explosives is optimum for the specific rock types at your mine +1.1 gcm\(^{-3}\) ask why, as the improvement in sensitivity (more gasser, improved detonation) will in most cases provide the same result as a denser product that will be less sensitive.

• Where has this been demonstrated, or can the supplier demonstrate optimisation process at your mine. Not all rock types will be the same;

• Velocity of detonation is a good indication of product sensitivity, this can be used an indicator of the right product selection. Needs to be measured through a blast front hole to back holes. 1 hole VOD provides no information;

• Look to validate with science not opinions or marketing material with no data.
Blast Impedance

Blast impedance is not a very well known concept. In summary its is matching the sensitivity and energy of your explosives to your ground conditions.

Blast Impedance Equation

\[ \rho_1 v_1 \approx \rho_2 v_2 \]

Where:
- \( \rho_1 \) = Density of rock
- \( v_1 \) = Seismic velocity of rock
- \( \rho_2 \) = Density of explosives
- \( v_2 \) = Velocity of Detonation
Blast Impedance

Blast impedance is a simple method of defining that explosive chemistry and physics must be matched to the ground geology.

Soft geology (oxide over burden) ≈ ANFO (high sensitivity, low density, high gas energy per weight) (low confinement) (requires high sensitivity product)

Hard geology (Granite) ≈ HANFO (moderate sensitivity, mid range density, high gas and shock) (Medium to high confinement) ≈ (Performs well in medium to high sensitivity)
Cost Evaluation

A true cost evaluation requires the procuring company to understand key components of explosives chemistry and physics, as discussed, to select the optimum product for the site geology.

• Optimal explosives density for geology 0.85 g cm⁻³ to 1.3 g cm⁻³;
• KJ/kg of explosives. Use Q values – Heat of Explosion;
• Volume of gaseous products of explosion – Use V values m³/g;

With the above values you can equalise the explosive products that you are comparing and make informed decisions.
## Cost Evaluation

<table>
<thead>
<tr>
<th>Name</th>
<th>Formula</th>
<th>Molecular Weight (g/mole)</th>
<th>Oxygen Balance</th>
<th>Contribution to Energy at Oxygen Balance Composition (kJ/g)</th>
<th>Contribution to gas Volume (STP) at Oxygen balanced composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>Al</td>
<td>26.98</td>
<td>-0.8889</td>
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<tr>
<td>Ammonium Nitrate</td>
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<td>Calcium Nitrate</td>
<td>Ca(NO3)2</td>
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<td>0.4876</td>
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<td>Carbon</td>
<td>C</td>
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<td>-2.667</td>
<td>32.791</td>
<td>1.867</td>
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<tr>
<td>Diesel Oil</td>
<td>C12H26</td>
<td>170.34</td>
<td>-3.48</td>
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<td>3.288</td>
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<tr>
<td>Glycerine</td>
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<td>76.1</td>
<td>-1.216</td>
<td>16.151</td>
<td>1.703</td>
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<tr>
<td>Guargum</td>
<td>C6H10O5</td>
<td>152.15</td>
<td>-1.185</td>
<td>16.226</td>
<td>1.521</td>
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<tr>
<td>Hydrazine</td>
<td>N2H4</td>
<td>32.05</td>
<td>-1</td>
<td>16.82</td>
<td>2.1</td>
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<tr>
<td>Monometh/amine Nitrate (MMAN)</td>
<td>CH5O3N2</td>
<td>94.07</td>
<td>-0.34</td>
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<td>Paraffin</td>
<td>C25H52</td>
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<td>Potassium Nitrate</td>
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<tr>
<td>Potassium Perchlorate</td>
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<td>138.55</td>
<td>0.4619</td>
<td>0.0603</td>
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<tr>
<td>Starch [cellulose]</td>
<td>C6H10O5</td>
<td>152.15</td>
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<tr>
<td>Sugar</td>
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<td>Sulphur</td>
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<td>Teepol 474 (Emulsifier)</td>
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<tr>
<td>Urea</td>
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<td>60.06</td>
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<td>1.49</td>
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<tr>
<td>Water [liquid-gas]</td>
<td>H2O</td>
<td>18.02</td>
<td>0</td>
<td>-2.322</td>
<td>1.244</td>
</tr>
</tbody>
</table>

Source:
Rock Blasting and Explosives Engineering, Per-Anders, 1992
Chemistry of Explosives, Akhavan K.,
## Cost Evaluation

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<td>Price $/T: <strong>$1301</strong></td>
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<tr>
<td>Bulk Strength: <strong>175</strong></td>
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<td>Weight Strength: <strong>110</strong></td>
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</tr>
<tr>
<td>Exp Density (gcm⁻³): <strong>1.15</strong></td>
<td>Exp Density (gcm⁻³): <strong>1.05</strong></td>
<td>Exp Density (gcm⁻³): <strong>1.25</strong></td>
</tr>
<tr>
<td>% H₂O: <strong>20</strong></td>
<td>% H₂O: <strong>16</strong></td>
<td>% H₂O: <strong>24</strong></td>
</tr>
<tr>
<td>Q Value (kJ/g): <strong>0.68</strong></td>
<td>Q Value (kJ/kg): <strong>0.80</strong></td>
<td>Q Value (kJ/g): <strong>0.51</strong></td>
</tr>
<tr>
<td>V Value (m³/g): <strong>1.03</strong></td>
<td>V Value (m³/g): <strong>1.02</strong></td>
<td>V Value (m³/g): <strong>1.04</strong></td>
</tr>
<tr>
<td>Unit Cost $/MJ: <strong>$1801.47</strong></td>
<td>Unit Cost $/MJ: <strong>$1626.25</strong></td>
<td>Unit Cost $/MJ: <strong>$2166.67</strong></td>
</tr>
</tbody>
</table>

Cost per 10m 165mm Blast Hole. 3.5m stemming and 0.5m subdrill. Replacing powder factor calculation with kJ per m³. 5 m burden x 5 m spacing.

| Charge weight per hole: **172 kg** | **157.2 kg** | **187.1 kg** |
| Bulk Exp $/Hole: **$309.85**      | **$266.65**  | **$405.38**  |
| Exp MJ per blast hole: **117 MJ** | **125 MJ**   | **95 MJ**    |
Application Evaluation

Matching the energy per kg of bulk explosives, along with matching the bulk explosive to the ground type is very important BUT the quality control of the explosives manufacturing and delivery should be evaluated also. Any company with the right skill set can manufacture and deliver their own bulk explosives. Whether your site manufactures their own explosives or you seek an explosives supplier to deliver the explosives, the following must be demonstrated to have confidence in the product being delivered:

• Raw material quantities auditable for each load (Fuel, oxidisers);
• Explosive densities (cup densities, bucket weights, truck weights);
• Quality tests on oxidiser solutions (% H2O, Sleep time, Crystallisation temperature);
• Operator training records and competencies;
• Records of daily, weekly, monthly and annual quality checks of products and equipment;

All of the above information enables the user to have high levels of confidence that the explosives product being delivered is of the correct specifications.
Conclusion

When securing bulk explosives do not select your explosives using opinions, previous experience of specific suppliers. Use science to specify your bulk explosives selection process, which should include:

- Explosive properties;
- Detonation of explosives;
- Blast impedance;
- Cost evaluation;
- Application evaluation.

By using science you will be able to quantify what bulk explosives is the most economic for your site. In combination with chemical and physical evaluation, scientific trials using measurement KPI’s will improve the confidence in the selection process.

Thank you – Questions