Evaluation of Advanced Bulk Emulsion Explosive and Loading System

Greg Gibson, AngloGold Ashanti
&
Lawrence Mirabelli, Dyno Nobel Inc.

Abstract

Cripple Creek & Victor Gold Mining Company (CC&V) operates the largest surface gold mine operation in Colorado and is located west of Colorado Springs in Teller County between the towns of Cripple Creek and Victor. Gold was first discovered in the Cripple Creek mining district in the 1890’s. CC&V has been conducting gold mining and precious metal extraction operations in the Cripple Creek Mining District since 1976. Current reserves are only amiable to surface mining since previous underground mining has depleted near surface ore rich veins.

Over the past ten (10) years or so, the Cripple Creek & Victor Mining operation used a 50/50 Heavy ANFO Bulk Blasting Agent as the main explosive charge for its ore and overburden blasting operations. At the time of its introduction it was the leading Heavy ANFO bulk explosive and loading technology available. In 2012, considering the age and the millions of pounds of explosive that bulk loading equipment had loaded, the blasting operation at the mine was faced with the decision to either directly replace the bulk loading equipment with new replacements and continue on with the same Heavy ANFO bulk explosive and loading technology or evaluate a more advanced bulk explosive technology and loading system to stay on leading edge into another 10 years of mining.

This paper presents, as a case study, the 4 month project undertaken to evaluate the advanced bulk explosive and loading system at the CCV Mine. The case study presents: the baseline and performance testing methodology, the production metrics used to evaluate performance improvements as well as the results and conclusions of the study.

The primary goals of the project were to determine if the advanced bulk explosive and loading system technology could: improve operational efficiencies and reduce operating costs in both ore and overburden; as well as, reduce NOx after blast fumes. Important criteria for the project was that it not interfere with daily or monthly mine production requirements and that testing encompassed the various geologies encountered in the operating pits.

The evaluation study concluded that the advanced bulk explosive and loading system technology could make measurable and significant contributions to improving mine productivity and reducing mining costs in both ore and overburden through: a reduction in powder factor; increased shovel productivity; reduction in stemming material; elimination of drill hole dewatering; and reduction of NOx after blast fume events.

CCV decided to complete the conversion and upgrade their equipment.
Introduction
AngloGold Ashanti Limited is a global gold mining company with 21 operations on four continents. It was formed in 2004 by the merger of AngloGold and the Ashanti Goldfields Corporation. AngloGold Ashanti and its subsidiaries hold a 100% interest in Cripple Creek & Victor (CC&V) Gold Mining Company.

CC&V operates the largest surface gold mine operation in Colorado and is located west of Colorado Springs in Teller County between the towns of Cripple Creek and Victor. Gold was first discovered in the Cripple Creek mining district in the 1890’s. CC&V has been conducting gold mining and precious metal extraction operations in the Cripple Creek Mining District since 1976. Current reserves are only amiable to surface mining since previous underground mining has depleted near surface ore rich veins. The surface mine operation provides ore to a crusher and valley leach facility, one of the largest in the world.

Over the past ten (10) years or so, the CC&V operation used a gassed and augered 50/50 Heavy ANFO Bulk Blasting Agent (Dyno Nobel Titan 2050G) as the main explosive charge for its ore and overburden blasting operations. At the time of its introduction it was one of the most advanced Heavy ANFO bulk explosive and loading technologies available. In 2012, considering the age and the millions of pounds of explosive that bulk loading equipment had loaded, the blasting operation at the mine was faced with the decision to either directly replace the bulk loading equipment with new replacements and continue on with the same Heavy ANFO bulk explosive and loading technology or evaluate a more advanced bulk explosive technology and loading system to stay on the leading edge into at least another 10 years of mining.

On May 14, 2012, AngloGold Ashanti Cripple Creek & Victor Gold Mining Company, Buckley Powder Co. and Dyno Nobel Inc. mutually agreed to sponsor a project to evaluate the performance of Dyno Nobel’s Titan XL1000 bulk repumpable emulsion blasting agent (100% emulsion) and Differential Energy ($\Delta E$) bulk loading technology in the blasting applications at the CC&V operation. The overall objective of the project was to determine what benefits this high performance bulk explosive product and advanced explosive loading technology would provide to drill/blasting performance and overall productivity to the mining process at CC&V beyond current practice.

The Mine Operation
Cripple Creek & Victor Gold Mining Co. operates a large low grade open pit gold mine which historically has utilized heap leaching to process ore. Current reserves are permitted with approximately seven square miles and are scheduled to be mined through the year 2026. Geologically, CC&V is hosted in a diatremal breccia which has been intruded by porphyritic phonolite stocks and/or sills. The deposit contains steeply dipping structures with phonolite and lampophyre dikes. The deposit has structurally encountered some argillic, sericitic, and potassium feldspar pyrite alterations. This geologic structure results in the deposit being vertically controlled in terms of grade. Most of the operation does not encounter ground water as a result of drainage tunnels below the district which were constructed to dewater the historic mining operations.

As current operations gain in depth from the surface the deposit is transitioning from oxide ores to sulfide rich ores. To take advantage of increased recoveries, the operation is currently constructing a mill to increase the recovery of gold in the sulfide zones.
The primary down the hole hammer drill fleet consists of 6 – Drilltech D55SP, 1 – Sandvik D25 drill, and 1 – Ingersoll Rand DM45E drill. The primary drill fleet is supported by 1 – Sandvik DI600 drill and 1 – Sandvik DX800 drill for the presplitting operation. Production drill holes are typically 40 feet deep (including 5 feet of subdrill) and are 6 ¾ inch diameter. Burden and spacing are varied depending upon geology; however typical burden is between 15 and 16 feet with spacing between 17 and 19 feet. Overburden rock is crushed periodically at the primary crusher to produce stemming material for blastholes.

Drill holes containing minimal amounts of water were dewatered and loaded with augured chemically gassed 50/50 Heavy ANFO blend while drill holes containing significant amounts of water were pumped with a 70/30 repumpable emulsion/ANFO blasting agent. On average CC&V blasts 2,375 holes per week between Mondays and Fridays.

CC&V’s operations utilize a traditional hydraulic truck/shovel mining method. The fleet consists of three (3) 36 yard class hydraulic shovels, one (1) 20 yard hydraulic shovel, one (1) 34 yard large wheel loader, and a primary haul truck fleet with twenty two (22) 240 ton class haul trucks.

All ore is processed through a primary gyratory crusher (Fuller Taylor/Smith 60x80) before being sized and going through secondary cone crushers if appropriate (P80 - ¾ inch). From the processing circuit, the haul truck fleet hauls the ore to the leach pad for placement and gold recovery. Final processing is conducted at an adsorption/ desorption/ recovery plant to produce dore which is sent offsite for refinement.

CC&V operates 24 hours a day with two mining shifts 365 days per year. Annual gold production in 2012 was approximately 247,000 ounces from 22.5 million short tons of processed ore. Overburden mined in 2012 totaled approximately 41 million short tons. CC&V employs 515 miners to achieve this production with future numbers increasing to operate the mill.

**Experimental Design**

To expedite completion of the performance evaluation and rather than using historical blast and mining data to establish a baseline for performance to be measured against, it was decided that both baseline and performance testing be done concurrently through the project.

So that the baseline and performance blasts were as directly comparable as possible, they were planned to be at best side by side, as similar as possible in size and shape and in as similar or same geology. Short and Mid Term mine planning engineers identified the blasts using these criteria.

Blast designs (drill pattern and blast hole initiation sequence) in the performance and baseline blasts were not altered during the project. Only one primer (1 lb cast primer with detonator properly attached) was used in blastholes. It was located at grade level near the bottom of the blast hole. All blasts, except for one performance blast, were initiated using a programmable electronic initiation system.
In addition to performance testing conducted with baseline, it was decided that the advanced bulk emulsion explosive and loading system be used without baseline in the worst of or special blast applications. That is in select areas of blast patterns or entire blast patterns where excessive water was present in the geology: in areas of softer ground where NOx afterblast fumes normally resulted and in a few “rind” blasts (blasts to final wall).

Blast results, shovel productivity, and crusher idle time reports were monitored for each. Blast tonnage used for baseline and performance blast calculations were to be those supplied by ore control survey.

Shovel productivity was measured and tracked using Modular and recorded by the mine’s Mine Management and Reporting System (MMRS). All effort was made to utilize the same excavation equipment for baseline and performance blasts. Production rates were sorted and compared relative to Shovel and/or Loader unit # and material classification type. (ORE 1 or 2; OVB 1 or 2; MWT 1 or 2).

No fragmentation analysis was conducted. As hydraulic shovels were used at CC&V and their necessity to work very near to the muck pile slope, neither a safe or practical way to manually or automatically collect data was available. The authors were aware of an automated photoanalysis system that was useable with rope shovels but not aware of any for hydraulic. Temporary set up of a automated photoanalysis system at the primary crusher dump was not cost effective.

Crusher productivity was measured using dispatch info and crusher operator logs/idle time reports. Throughput for ore from both baseline and performance blasts was compared to the production target of 2,900 tons/hr. Due to mine production requirements, more often than not ore from different blasts was hauled to the crusher in the course of a day. For this reason, it was necessary to sort data to isolate productivity over periods while crushing ore from a single blast and periods while crushing ore from multiple blasts.

Blast vibrations were monitored using Instantel MiniMate Plus seismographs @ Goldfield City Hall; Flowershop; Ajax; Timmons; and the DuBois residence.

Generation of NO\textsubscript{x} afterblast fumes was rated on a visual/time scale based on personal observation and/or video recordings.

Project must not interfere with daily or monthly mine production requirements.

**Blast Hole Loading**

The typical blast hole load used for ore and overburden blasting is shown in Figure 1. The Heavy ANFO blasting agent is “chemically gassed” (The International Society of Explosives Engineers, 2011) so the weight of the product on itself in the blast hole causes its density to be highest at the bottom and gradually lower toward the top of the column. Also shown in Figure 1 is the powder column density profile resulting with the repumpable emulsion blasting agent when loaded using ΔE technology. As shown there are three (3) segments of differing densities. Using ΔE, the repumpable emulsion blasting agent is also “chemically gassed”.
The goal for the ∆E blast hole loading approach was to load the same charge weight, as was used with 50/50 Heavy ANFO, into each hole and optimize the explosive distribution. This was achieved by loading a heavier density in bottom 9 ft, a density equivalent to the 50/50 Heavy ANFO mid column and a lighter density in the top 10 ft. The loading approach allowed a reduction to amount of stemming required and also because of the high detonation velocity of the repumpable emulsion blasting agent (5,200 m/sec) provided a 40% increase to detonation pressure in the rock mass.

Detonation pressures were calculated using Equation 1. An equation commonly used by explosive manufacturers. (The International Society of Explosives Engineers, 2011)

$$p_d = 2.5 \times p_e \times c_d^2 \times 10^6$$

**Equation 1**

Where,

- $p_d$ = Detonation pressure (kilobars). 1 kilobar = 0.1 gigapascal.
- $p_e$ = Explosive density (grams /centimeter$^3$)
- $c_d$ = Detonation velocity (meters/second)

Both wet and dry holes were loaded using the same blast hole loading profile. In dry holes, the hose was placed 10 feet past the collar of the hole and then loaded. In wet holes, the hose was run to the bottom of the hole and then auto-retracted as the hole was loaded. Wet holes were not dewatered. The 40,000 lb capacity ∆E bulk truck is shown in Figure 2.
Figure 2. Jumbo RC Loading Truck with ΔE technology

Results

From May 23 to September 25, twelve (12) Baseline and Performance blasts were taken in typical blast applications in the CRESSON (8) and WHEX (4) pits. Over the course of the project period, the differentially loaded repumpable emulsion Blasting Agent was also loaded, as part of normal production loading, in blast applications outside of the project plan (43% out of plan). In these cases the ΔE product was used in very wet holes and in soft unconsolidated geology where NO\textsubscript{x} afterblast fumes had been a problem. A total of 1,288,580 lbs was loaded during the project period.

Table 1 shows a summary of the blast details for the Baseline and Performance blasts.

Table 1. Summary of Blast Details for Baseline and Performance Blasts.

<table>
<thead>
<tr>
<th>Heavy ANFO (50/50) Baseline</th>
<th>Pit</th>
<th>Blast #</th>
<th>Blast Date</th>
<th>Rock</th>
<th>Total Blast Holes</th>
<th>Total Bulk Explosive</th>
<th>Percent ANFO</th>
<th>Total Tonnage Tons</th>
<th>Powder Factor lbs/ton</th>
<th>Approximate Performance lbs/hole</th>
<th>Performance PF Reduction</th>
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<tbody>
<tr>
<td>Cresson 9585-78</td>
<td>5/22/2012</td>
<td>Breccia</td>
<td>223</td>
<td>146,646</td>
<td>50.6%</td>
<td>135,600</td>
<td>1.081</td>
<td>658</td>
<td>40.5%</td>
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<td>WHEX 10145-119</td>
<td>6/20/2012</td>
<td>Precambrian</td>
<td>247</td>
<td>136,625</td>
<td>50.8%</td>
<td>171,900</td>
<td>0.795</td>
<td>513</td>
<td>21.6%</td>
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<td></td>
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<tr>
<td>Cresson 9550-54</td>
<td>7/9/2012</td>
<td>Phonolite</td>
<td>253</td>
<td>141,562</td>
<td>51.6%</td>
<td>187,700</td>
<td>0.752</td>
<td>558</td>
<td>23.5%</td>
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<td></td>
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<tr>
<td>Cresson 9550-66</td>
<td>7/27/2012</td>
<td>Breccia</td>
<td>305</td>
<td>173,558</td>
<td>50.4%</td>
<td>252,800</td>
<td>0.686</td>
<td>569</td>
<td>2.4%</td>
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<tr>
<td>Cresson 9550-73</td>
<td>8/7/2012</td>
<td>Breccia</td>
<td>208</td>
<td>130,981</td>
<td>54.1%</td>
<td>133,200</td>
<td>0.833</td>
<td>534</td>
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<tr>
<td>WHEX 10145-130</td>
<td>9/4/2012</td>
<td>Breccia</td>
<td>394</td>
<td>207,266</td>
<td>50.5%</td>
<td>241,800</td>
<td>0.857</td>
<td>526</td>
<td>8.0%</td>
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<td></td>
<td>1,680</td>
<td>946,216</td>
<td>1,123,000</td>
<td>0.566</td>
<td>566</td>
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<td></td>
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</table>

<table>
<thead>
<tr>
<th>Repump Emulsion (100%) Performance</th>
<th>Pit</th>
<th>Blast #</th>
<th>Blast Date</th>
<th>Rock</th>
<th>Total Blast Holes</th>
<th>Total Bulk Explosive</th>
<th>Percent ANFO</th>
<th>Total Tonnage Tons</th>
<th>Powder Factor lbs/ton</th>
<th>Approximate Performance lbs/hole</th>
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<tr>
<td>Cresson 9585-79</td>
<td>5/24/2012</td>
<td>Breccia</td>
<td>144</td>
<td>60,178</td>
<td>0.0%</td>
<td>93,500</td>
<td>0.644</td>
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<tr>
<td>WHEX 10145-118</td>
<td>6/5/2012</td>
<td>Precambrian</td>
<td>319</td>
<td>145,047</td>
<td>1.1%</td>
<td>232,900</td>
<td>0.623</td>
<td>455</td>
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<td>Cresson 9550-55</td>
<td>7/11/2012</td>
<td>Phonolite</td>
<td>204</td>
<td>93,182</td>
<td>0.0%</td>
<td>157,900</td>
<td>0.590</td>
<td>407</td>
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<tr>
<td>Cresson 9550-67</td>
<td>8/1/2012</td>
<td>Breccia</td>
<td>240</td>
<td>120,749</td>
<td>0.0%</td>
<td>180,300</td>
<td>0.670</td>
<td>503</td>
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<td></td>
</tr>
<tr>
<td>Cresson 9550-72</td>
<td>8/3/2012</td>
<td>Breccia</td>
<td>174</td>
<td>88,625</td>
<td>0.0%</td>
<td>146,700</td>
<td>0.604</td>
<td>509</td>
<td></td>
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<tr>
<td>WHEX 10145-131</td>
<td>9/6/2012</td>
<td>Precambrian</td>
<td>396</td>
<td>205,040</td>
<td>0.0%</td>
<td>260,100</td>
<td>0.788</td>
<td>518</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td>1,477</td>
<td>752,881</td>
<td>1,071,400</td>
<td>0.477</td>
<td>90</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Difference | 90 lbs |


It was discovered that although the strategy was to match total charge weight in holes that in fact 18% less explosives were loaded in the case of the performance blasts. It is felt that the difference was attributable primarily to the viscosity difference between the two (2) blasting agent products, the thicker limiting loss into cracks or fissures, and secondarily to the reduced amount of coating of upper collars and spillage between holes. Figure 3 shows the difference in appearance around the collars of loaded holes.

Figure 3. (L-R) Heavy ANFO collar after loading. Repumpable Emulsion collar after loading.

Table 2 summarizes the blast details of those blasts, outside of plan, in which varying amounts of product was loaded to address wet hole and unconsolidated ground conditions. A total of 380,000 lbs was loaded in these applications. This data was useful in confirming the charge weight differences found with the baseline and performance blast testing. (505 lbs/hole vs 441 lbs/hole)

Table 2. Summary of Blast Details for loading outside of plan.
Shovel productivity was monitored for over 90% of the total 2.2 million tons of material blasted in baseline and performance blasts. Overall between the four (4) hydraulic shovels and one (1) wheel loader monitored and considering all material types excavated, shovel/loader productivity increased on average 7.9%.

Of the total ore blasted in the baseline and performance blasts, 40% was monitored through the primary crusher unmixed. That is the ore monitored was only from a single blast. In this study, crusher throughput was increased 2.4% for ore from Cresson pit and 3.5% for ore from WHEX pit. Of the 60% of ore blasted in the baseline and performance blasts that was monitored as it was run through the primary crusher mixed with ore from other blasts, crusher throughput decreased no matter the source pit, -2% in the case of Cresson and -2.9% in the case of WHEX. Even though overall there was a 1% increase in primary crusher throughput, considering the small change and the discrepancy found between mixed and unmixed ore, crusher throughput was considered unchanged through the evaluation.

There were no extraordinary blast vibration levels measured for any baseline or performance blasts and no neighbor complaints.

Zero (0) visible NOx events were recorded in all performance blasts or either two (2) 100% wet blast patterns that were taken out of plan, a WHEX Production blast and a WHEX “trim” blast. Figure 4 shows examples of after blast fumes recorded during the evaluation.

![Figure 4. (L-R) Baseline blast fumes. Repumpable Emulsion Performance blast fumes](image)

Measured results confirmed that significant value in productivity, cost and blast performance were delivered. The mine reduced its overall powder factor, realized an increase in shovel productivity in overburden, and ore. In the case of ore, there also was no change in primary crusher throughput. Additionally, NOx after blast fumes incidents were nearly eliminated in even the wettest areas of the pits.

**Conclusion and Future Work**

The evaluation study concluded that the advanced bulk explosive and ΔE loading system technology made measurable and significant contributions to improving mine productivity and reducing mining costs in both ore, and overburden.
Reduction in powder factor.

Overall powder factor was reduced from 0.82 to 0.67 lbs/ton, without reducing productivity. This was done in large part by putting the energy and detonation pressure where it was needed. Limiting higher explosive energy and detonation pressure to the bottom of the blast hole helped fragment rock at grade level. Changing to a lighter density/lower explosive energy yet still high detonation pressure in mid and upper portion of the blast hole, improved explosive distribution throughout the rock bench.

Increased Productivity

Dewatering was eliminated. Reduced equipment, removed maintenance and operating costs. Reduced need for Bulk Explosive delivery trucks by one, single product for wet or dry applications. Bulk Explosive Truck turnaround time was shortened and 9 more holes loaded per truck. There was 17% reduction in overall stemming used, reduced the time to stem holes. Shovel productivity in overburden, and ore as measured in tons/hr increased overall by 7.9%. There was no change in the crusher throughput (tons/hr).

Minimized NOx

After blast NOx fumes that were readily apparent when the mine’s normal chemically gassed 50/50 Heavy ANFO blend was used in areas of the mine where rock was damp, wet and/or unconsolidated material were visually absent under all conditions tested.

Reduce opportunity for Nitrate Dissolution

The excellent water resistance of the repumpable emulsion blasting agent dramatically reduced the opportunity for Nitrate dissolution into runoff and ground water. Delivery of the repumpable blasting agent product by hose into the drill hole put the product down the hole, not around the hole. There was obvious visible difference when 50/50 Heavy ANFO was augered into the drill holes. Roughly 6% of the powder was visible in the open cracks of crevices in the broken collar zones, coating the upper unloaded walls of the drill holes, at and around the collars, and in-between blast holes on the blast pattern. Bulk explosive material in these areas is less likely to react in the blast and allows for the Nitrate they contain to be available for dissolution afterwards.

In addition to these contributions, it was recognized that implementation of the advanced bulk emulsion explosive and loading system at CC&V would position AngloGold Ashanti with the explosive tools to: further maximize productivity into the next 10 to 15 yrs.; provide superior adaptability to future and possible changing needs of the drill and blast operations; and support sustainment of compliance with current and future environmental regulations.

In January 2013, CC&V decided to upgrade the bulk explosive delivery equipment to the new technology and convert their blasting applications to the advanced bulk emulsion explosive. In May 2013 the conversion was complete. Periodic auditing of blasting practices since the conversion indicate that powder factors and production efficiencies continue to be sustained at project levels.
Acknowledgements

The authors are pleased to acknowledge the efforts of the following individuals without whom this project could not have been successful.

Aaron Kash, Josh Imm, Mohameden Abouby, Ryan Meany and all the CC&V powder crew
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Wes Jepson, David Moulton and Gary Knight – Dyno Nobel Inc.

References
