NO₂ Generation at Goderich Mine

Background
- Mining Operation entirely under Lake Huron
- Surface Facilities situated on peninsula totaling about 6 Hectares
- Intake and exhaust shafts less than 100m apart
- Approximately 750,000 CFM enters the mine through two 16’ diameter shafts
- Air exhausts through one 22’ diameter shaft
- Air travels ~17 km from intake to exhaust
NO$_2$ Generation at the Goderich Mine
Mining Operation
• 3 sizes of headings:
  – Conventional (60’ wide by 43’ High)
  – Development (60’ wide by 12’ High)
  – Bench (60’ wide by 48’ High, ultimate height: 60’)
• Air velocities range from 10’/min. to 700’/min.

Ventilation Studies
• CANMET – 1997
  – Tracer gas, barometric psychometric to determine maximum capacity of intake and exhaust shafts
• CANMET – 1999
  – Tracer gas to determine retention time and total time air is in the mine
NO$_2$ Generation at the Goderich Mine

Results of Studies

- Ventilation system capable of supplying up to 800,000 CFM
- Air can be in the mine for over 40 hours
- Using Fine’s equation, 61% of original NO generation converts to NO$_2$
- Typical NO:NO$_2$ ratios in multi-level mines are 10 : 1. Goderich mine ratio is 1 : 1
Introduction

- Oxides of nitrogen (NOx) are significant pollutants in the underground mine environment.
- Health hazards include:
  - Central nervous system effects (NO)
  - Lung irritation (NO₂)
- Provincial regulations limit the level of NO and NO₂ in ambient air quality.
- Significant efforts are being made to reduce the levels of NOx emissions at the source.

Diesel Engines and NOx

- Diesel exhaust is an oxidizing environment (lean fuel/air ratio means O₂ is left over).
- Not possible to reduce NOx without an additional reductant.
- Selective catalytic reduction (SCR) uses urea-based agent to permit control of NOx emissions in diesel exhaust.
- SCR provides 60%-80% NOx reduction.
SCR for NOx Control

- Urea liquid is hydrolyzed to ammonia upon injection into the exhaust.
- \(6\text{NO} + 4\text{NH}_3 \rightarrow 5\text{N}_2 + 6\text{H}_2\text{O}\)
- \(4\text{NO} + 4\text{NH}_3 + \text{O}_2 \rightarrow 4\text{N}_2 + 6\text{H}_2\text{O}\)
- \(6\text{NO}_2 + 8\text{NH}_3 \rightarrow 7\text{N}_2 + 12\text{H}_2\text{O}\)
- \(2\text{NO}_2 + 4\text{NH}_3 + \text{O}_2 \rightarrow 3\text{N}_2 + 6\text{H}_2\text{O}\)

SCR System Concept
Practical SCR System

SCR Experience

- Approximately two thirds of all HD highway trucks in Europe are equipped with urea SCR mandated by Euro 4 NOx limits.
- SCR is the technology of choice where fuel economy is the major driving factor, as with heavy-duty diesel.
- Off-highway mobile equipment is a new market for SCR, but trials are promising.
- Industrial stationary power generation has used SCR for decades!
- This project is the first underground mining application for SCR retrofit technology in North America.
SCR Project Objectives

- Conduct a demonstration project at the Compass Minerals Sifto Salt Mine.
- Help mine plan for effective SCR technology implementation.
- Perform a two vehicle pilot study of SCR technology.
- Real-time underground emissions test.
  - Determine the SCR emission reductions possible.
  - Look at system long-term durability.

Compass Minerals

- Compass Minerals Sifto Salt (Goderich).
- Words largest salt mine.
- Over 22,000hp diesel fleet underground.
- Large single unit vehicles over 600hp.
Demonstration Project

- In-mine pilot study using two vehicles.
  - Caterpillar 775D truck
  - Caterpillar 990G loader

- SCR systems:
  - NETT Technologies (sensor feedback)
  - BASF Tenneco (engine map-based)
  - Portable emissions measurement system.
    - SEMTECH-DS
  - Vehicle emissions sampling over actual production duty cycles during regular shift operation.

Pilot Test Vehicles

- Caterpillar 775D
- Caterpillar 990G

Both use C27 engine at 725hp (truck) and 675hp (loader)
Portable Emissions Measurement System

- SEMTECH-DS

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SCR Pilot Systems (Truck)

- NETT Technologies
- Sensor Feedback
- Custom fit
SCR Pilot Systems (Loader)

• BASF Tenneco consortium
• Map-based
• Dual bank

Truck / Loader Cycle

• Loaded at face and tram to pile.
Results: Cycle NOx - Truck

• Significant reduction in steady state and cycle NOx.
• Good transient control

Caterpillar 775D Truck #41 NOx Emissions Baseline and With NETT SCR System.

65% Overall Cycle Reduction

80% Reduction at Steady-state

Cycle NOx - Loader

• Good cycle NOx control but long idle periods.
• Left bank performance not as good (only 50%)
Idle Emissions and NO₂

- SCR systems do not inject urea at idle due to low exhaust temperatures. The SCR catalyst is not active and the urea would pass through the system into the mine.
- Compounding this, the pre-catalyst is designed to make NO₂ for a favorable SCR reaction and may be active at low temperatures.
- There is a risk of NO₂ passing through the system unaffected at idle.

$$\text{NO} + \text{NO}_2 + 2\text{NH}_3 \rightarrow 2\text{N}_2 + 3\text{H}_2\text{O}$$

NO₂ Formation and Slip

- This effect was seen with both SCR systems at Sifto and will have to be addressed in the production units.
- Limiting potential NOx reductions for cycles with long idling.
- Minimize cycle idle time for best performance.
Other issues

- Good acceptance from operators and mechanics.
- Minimal maintenance issues once initial installation problems overcome.
- Recording urea consumption important for diagnostics.
- Electronic control system calibration optimization important for best performance.
  - Especially for map-based system.

Routine Tailpipe Testing

- SCR systems can be tested by mechanics at the mine using standard portable gas analyzers.
- Loaded (stall) test.
SCR and Diesel Fleet

- Significant reduction in vehicle NOx emissions without affecting engine fuel economy and performance.
- Can be retrofitted to HD vehicles to affect mine-wide ambient NOx levels.

Conclusions

- Initial SCR system performance very good! 60-65% cycle NOx reduction.
- Potential for significant reductions of NOx emissions. DPM emissions reduction similar to simple DOC catalyst (25%)
- Good acceptance of the technology at the mine.
Conclusions

- First underground application of SCR technology to mobile equipment.
- SCR specifically targets NOx, which has been an issue for large mines.
- Commonality of 990x and 775x vehicles allows for economies of scale and mine-wide air quality improvement.

Biodiesel & SCR?

- Potential for biodiesel to increase NOx, or at least be NOx neutral.
- SCR can clean-up any extra NOx generated.
- Biodiesel has inherently low sulphur, which is advantageous for SCR operation.
- Combined to take advantage of GHG / carbon reductions of biodiesel without suffering NOx penalty.
Next Steps

- Model projected mine-wide effects from implementation on target vehicles.
- Considerations for ventilation reduction and certification air volumes.
- Retrofit of target fleet vehicles with production SCR systems.
- Look at combined SCR and Biodiesel.

Questions?