CANMET Mining and Mineral Sciences Laboratories

MDEC - 2015

Diesel Fuel Additives for Underground Mining

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Introduction

- Like all industries in Canada, mining is actively looking to reduce GHG emissions from all sources.
- In addition, providing good air quality in the underground mine environment can be a challenge – especially with larger engines and vehicles.
- Aftermarket fuel additives claim to reduce fuel consumption and lower emissions.

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Diesel Fuel Additives

- Additive types:
  - Handling / operability
  - Combustion
- Performance testing:
  - Field vs Laboratory
  - Secondary emissions
- Strategies:
  - Evaluating needs
  - Real economic calculations

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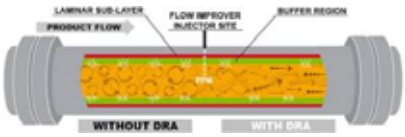
Handling and Transport

- Anti foaming agents for rapid refuelling.
- Conductivity improvers reduce static charge accumulation.
- Drag reduction agents for pipelines.



- <u>These are not aftermarket</u>. They are added by the petroleum refiner and are in the fuel already at the mine.

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Fuel Stability -Storage

- Anti-oxidants:
  - Metal deactivators (oxidation is catalyzed by metals).
  - Propanediamine compounds.
- Biocides
  - Prevent bacteria growth at high temperatures.
  - Boron compounds .

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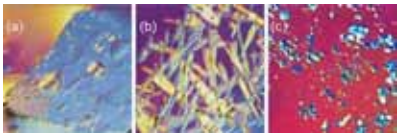
Operability - Engine

- Cold weather
  - Flow improvers – ethylene-co-vinyl acetate (EVA).
  - Wax anti-settling – acid amides



- Lubricity
  - Legislated removal of sulphur from fuel
  - Monoacids, amides, synthetic and/or non-synthetic esters.

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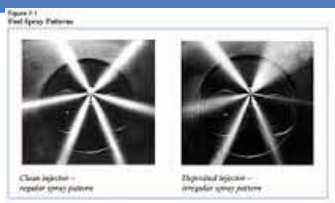
Operability



- Deposit control
  - Polymeric detergents/dispersants
  - Mainly for injector nozzle coking control

- These are usually added by the petroleum supplier at the terminal as a package.
- "Standard" and "Premium" packages are available.
- Not necessary to add your own unless there are unusual conditions.

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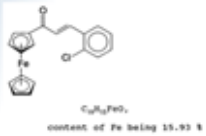
Combustion Additives

- Three major types of combustion additives:
  - Cetane number improvers
  - Flame additives for smoke suppression
  - Combustion catalysts



- Handling properties are easily evaluated.
- Combustion effects – not so easy.
- What are we trying to do and how can we measure the results?

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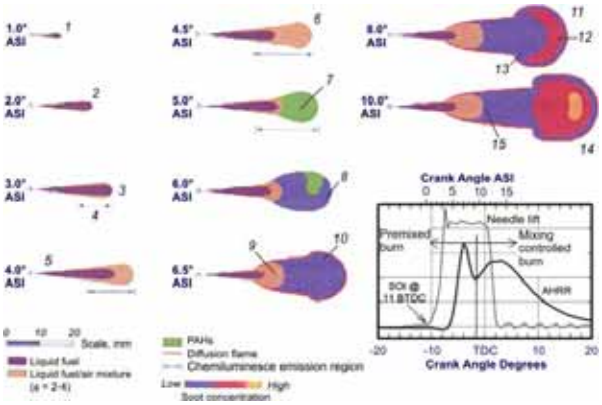
Diesel Combustion Process



- Injection of fuel and delay while fuel is mixed with air.
- Ignition of premixed fuel starts combustion.
- Once flame front is established, fuel is burned as it is injected and mixed.

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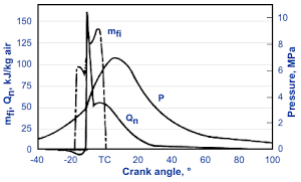
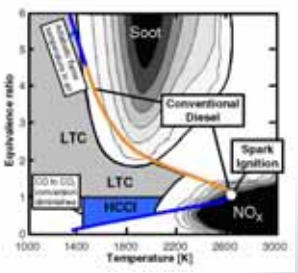
Combustion Parameters

- Lower ignition delay
  - Short delay improves starting and gets more of the fuel burned at the most favourable conditions.
  - Higher thermal efficiency.
- Improve heat release
  - Burn the fuel more completely.
  - Improve fuel efficiency.





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How do additives fit in?

- Can additives operate on the combustion process in a measureable way?

Ferrocene at 350 and 1000ppm

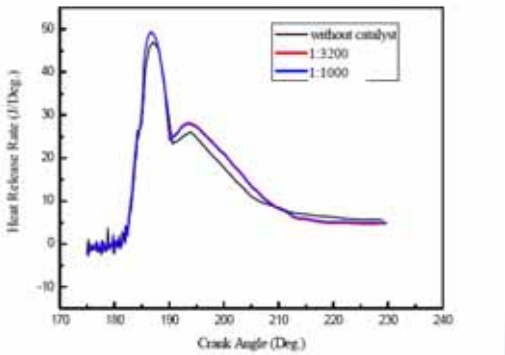

Fig.14 Heat release at engine load 6.8 Nm under engine speed 3000 rpm

- Yes, some additives can! But now we have to define the performance and dose (treatment) rate optimization.

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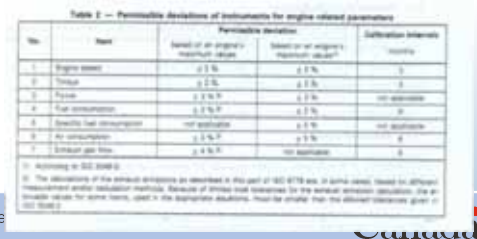
Performance Testing

- Lab testing vs. field trials
  - Field trials can be anecdotal.
  - Very difficult to control parameters.
  - Highly variable.
  - What is the statistical error? Variance?
- Laboratory testing to a recognized international standard is very important!
  - ISO8718
  - ISO17025
  - Only lab studies!



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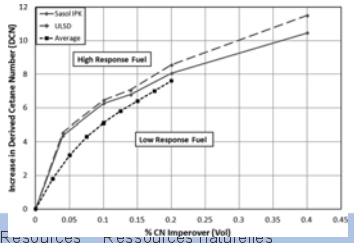
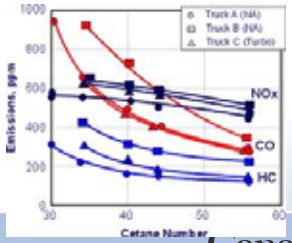
Lab studies – Cetane improvers

- 2-ethylhexyl nitrate (EHN) is the most common.
- Well established improvement in emissions at higher cetane number – but effect is limited.
- 0.05% EHN leads to a 3 point increase
- Alkyl nitrates and ethyl nitrates cheaper but not as effective.
- Do you need it? What is the cetane number of your fuel now?





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Lab studies – Smoke control

- Smoke suppression (Flame additive)
- Barium (banned due to toxicity)
- Ferrous picrate the most common
- Not too effective on newer engines where smoke is much lower
- 85-95% of the additive is carried out into the mine as ultrafine particulate.
- No statistically significant change even at 3300ppm!

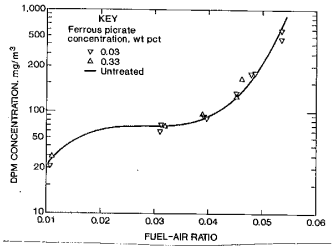

Figure 3.—Effect of ferrous picrate on DPM emissions at two concentrations of additive in fuel.

- USBM data
- Ferrous picrate at 300ppm and 3300ppm rates

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Lab studies – Fuel catalysts

- Combustion catalysts developed from organometallic compounds.
- Iron-based ferric oxide (Ferrocene) is the most common.
- Platinum and cerium are also common.

USBM data at 780ppm dose

- Incandescent metal particles are very good at promoting in-cylinder soot burn out.
- Require high dose rates to be effective.

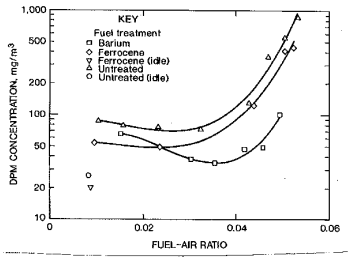

Figure 21.—Effect of barium and ferrocene on DPM. Data are averages.

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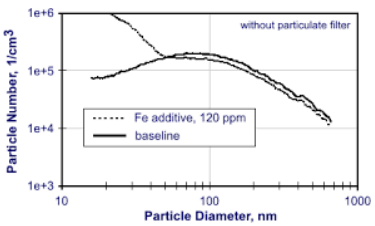
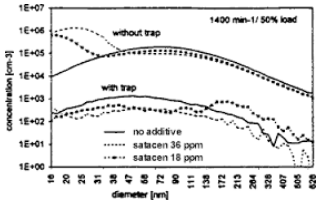
Secondary Emissions

- Fuel catalysts are not consumed in the combustion process and 85-95% are emitted as secondary particle emissions.
- Unwanted fine particles – hazardous to heath!
- In addition to fine particle lung stress, metals may have their own specific toxicity.





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Dosing rate

- Diesel fuel additives must be registered with the US EPA. You must supply test data that investigates secondary emissions health hazards. (Title 30 CFR Part 79)
- Pressure to lower dose rate to minimize secondary emissions to get on "The List".
- Note: "The List" does not apply to off-highway and mining (nor in Canada!) but would you want to use an unlisted additive???

EPA United States Environmental Protection Agency

http://www.epa.gov/otaq/fuels/registrationfuels/web-dies.htm

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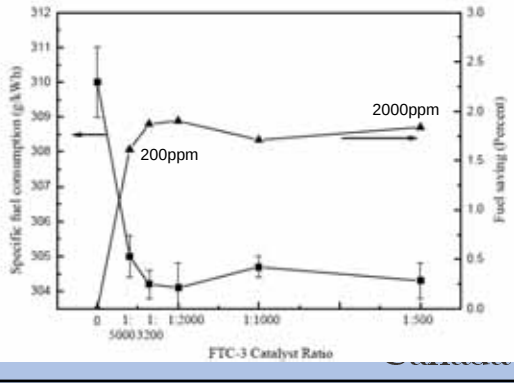
Dose rate squeeze:

- Dose rates lowered from 300 - 3000ppm in the 1990s to 15 - 30ppm today to comply with the EPA 30CFR79 registration.
- Lower dose rates are not as effective and engines have become much cleaner as well in the interim.
- At dose rates of less than 100ppm the additives are simply not effective anymore.

- At more than 100ppm there is a potential risk due to particles and secondary emissions.



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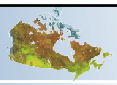

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Strategies - Plan

- (1) Evaluating the need.
  - Do you have a problem with operability or physical properties? Cold/hot extremes?
  - Long term storage before use?
  - Poor quality fuel with low natural cetane?
- (2) Develop a strategy – don't pour and go!
  - Less than 0.1% (1000ppm) so as to not affect the physical fuel properties (density, visc, etc).
  - Is the whole fleet to be dosed? Just target vehicles or problem areas?
- (3) Analyze fuel properties regularly!
  - Make sure you are in warranty compliance.
  - Watch for unintended effects: EHN vs lubricity

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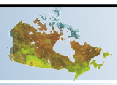

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Strategies - Legal

- Check the regulatory framework.
- Is the additive legal in Canada/US?
- At what dose rate? If the additive supplier is suggesting more than 100ppm *pay special attention*!
- Does "due diligence" and "management of change" require evaluation of hazards and health risks? How can this be done?
- Engine warranty considerations – some manufactures will not honour warranties if additives are used.

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Strategies - Costing

- Cost benefit – what's the equation?
  - The cost of the additive must be less than the fuel economy savings!
- PGM metal costs:
  - For a typical platinum additive at 0,2ppm mass dose rate around 0.17mg Pt is required per liter fuel.
  - At $1200/oz this is 0.7 cents/liter without including manufacturing and distribution!
- Higher dose rates are likely required to see more than 1-2% fuel savings….you do the math.

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- Engine Testing & RD.
  - MSHA/CSA mining certification
- Additive evaluation services.
  - Barrick
  - Vale
  - Xstrata

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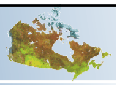

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Summary

- Remember fuel additives are like medicine!
- You should only use them if you really need to - and they should be selected and prescribed by an expert.
- Simply pouring in a random additive is unlikely to have the desired effect and may even pose a hazard.

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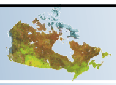

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Some Fuel Specifications

Required Fuel Property	ASTM Test	Mines LS	Low Sulphur	Biodiesel	Caterpillar	Cummins	Detroit 2-D	Deutz EN590
Flash Point (°C)	D93 / D3828	52 min	59.5	130 min	legal limit	legal limit	52 min	55 min
Kinematic Viscosity @40°C (cSt)	D445	1.30 - 4.10	1.95	1.9 - 6.0	1.40 - 20.0	1.30 - 5.80	1.9 - 4.1	2.00 - 4.50
API Gravity @ 60°F	API		35.6		30 - 40		34 - 39	
Specific Gravity			0.847				0.835 - 0.855	
Density (kg/m^3)	D1298 / D4052	850 max				816 - 876		820 - 860
Distillation Temp. (°C), 90%	D86	315 max	285	380 max	360 max		329 max	350
Distillation Temp. (°C), End Point	D86	355 max	-				355 max	370
Water & Sediment (% by volume)	D1796	0.05 max	<0.05	0.05 max	0.10 max	0.05 max	0.02 max	0.02 max
Acid Number (mg KOH/g)	D974	0.01 max	<0.01	0.80 max				
Sulphur (% by mass)	D1266 etc.	0.05 max	0.005	0.05 max	0.3 or legal	0.5 or legal	0.5 or legal	0.2 or legal
Copper Strip Corrosion (3h @ 50°C)	D130	1	1	3 max	3 max	2 max	3b max	1 max
Carbon Residue 10% Bottoms (% mass)	D4530	0.10 max	<0.10	0.05 max	0.35 max	0.35 max	0.35 max	0.30 max
Ash (% by mass)	D482	0.01 max	<0.01	0.02 max		0.02 max	0.01 max	0.01 max
Ignition Quality (Cetane Number)	D613	40 min	>46	47 min	40 min	42 min	45 min	49 min
Lubricity SLBOCLE (g)	D6078	2800 min	>2800		3100 min	3100 min	2800 min	
Lubricity HFRR (um)	D6079	460 max	<460		450 max	450 max		
Electrical Conductivity (pS/m)	D2624	25 min	>25.0					

- This chart is intended as a guide only. Please check with fuel supplier and engine manufacturer.

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