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# Diesel engine emission deterioration

## *a preliminary study*

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### ABSTRACT

The objective of this study was to find a parameter in diesel and oil analysis of underground mining vehicles that can be correlated with personal diesel particulate matter (DPM) exposure and used as part of an engine maintenance programme.

A number of engines were monitored over a period of a few months. Diesel and oil samples were taken from selected engines and the personal DPM exposures of the operators were measured. Eight oil contaminants were chosen and compared with the DPM exposure results. It was found that as the oil contaminant concentrations increased, the DPM exposure of the machine operators increased. When remedial actions were taken on an engine during maintenance, the DPM exposure of the operator reduced.

The preliminary study results show that the oil and diesel parameters can be used as an indicator of how the DPM emitted by the engine deteriorates (i.e. worsens) over time. This information can be used to enforce better maintenance regimes to reduce mine employee exposure to DPM.

### INTRODUCTION

Diesel particulate matter (DPM) forms due to the uncontrolled combustion of fuel. Proper engine maintenance by qualified personnel has been shown to have a considerable impact on the control of DPM (Waytulonis, 1992), among other available solutions.

Uncontrolled combustion is the result of, but not limited to, a few factors:

- Poor spray pattern caused by blocked injector tips (dirt, wear debris) or burnt injector tips from excessive combustion heat;
- A too-high cetane index, which causes combustion too close to the injector tips and not in the combustion chamber. This also causes damage to the injector tips; and
- Filter blockages due to dirt or microbiological growth (Robinson, 2005).

Against this background, this study aimed to evaluate diesel and oil test results over a period of seven months to establish the resulting DPM values.

### OBJECTIVE

The objective of this study was to find a parameter in diesel and oil analysis results that can be correlated with DPM exposure and used as part of an engine maintenance programme.

### METHODOLOGY

At the start of the study, ten diesel powered engines were chosen for this project. Over time, some engines became unavailable over the full study period (e.g. breakdowns). In the end, two Tier 2 Load Haul Dump (LHD) vehicles were selected from two underground platinum mines. These engines were chosen because they had undergone a major service or had been refurbished. The original plan was to conduct this exercise over a period of 12 months. However, a delay caused by unplanned labour unrest in the platinum industry meant that this fieldwork was reduced to six months.

Once a month, personal DPM exposure measurements of the LHD operators of the selected engines were taken. The operators of the engines were fitted with a personal sampling train to measure DPM exposure for the duration of their shift. The sampling train consisted of a real-time DPM instrument (Airtec™, FLIR, USA), size-selective cyclone (GS1, SKC, USA) with impactor and a three-piece cassette with a tissue-quartz filter inside the instrument.

The flow-rate was set at 1.7 L/min. The filters were analysed with a Sunset DPM Analyser according to the NIOSH 5040 test method. The results obtained were for elemental carbon (EC), organic carbon (OC) and total carbon (TC).

Diesel and oil samples were taken from the LHD diesel tanks. The oil and diesel samples were taken in the middle of the shift when the engine had operated for a while and the oil had had a chance to circulate through the engine. The wear materials and contaminants were captured in the oil and detected during the analysis. Oil is usually replaced after a period of time and is representative of the cumulative condition of the engine.

Samples were also taken intermittently over the study period from the oil and diesel bays from which the machine operators would refuel or replenish the engines. At the start of each shift, the operator would fill the engine tank with diesel. The diesel samples that were taken once a month would largely be representative of the condition of the diesel on that day and would have minimal representation of the historical, cumulative condition.

The oil and diesel samples were sent to Wearcheck Africa for analysis. Wearcheck Africa is an ISO 17025-accredited laboratory and carries out diagnostic interpretation of analytical parameters of diesel and oil. The diesel samples were tested for conformance with the SANS 342:2006 standard for diesel.

The oil analysis parameters that were considered for the monthly evaluation are presented in Table 1. The source or cause of the parameter is specified in the table.

The diesel properties that were considered during this study are set out in Table 2. These properties are required to conform to the SANS 342:2006 national standard for diesel. If any of these

Table 1. Oil parameters associated with uncontrolled combustion

Parameter	Source
Iron	Wear on cylinder inners, gears, shafts; rust.
Chromium	Wear on cylinder inners, gears, shafts.
Aluminium	Wear on pistons, plain bearings.
Copper	Wear on bearings, bushes, any bronze part.
Particle Quantifier Index (PQI)	Ferrous debris; presence of large particles.
Silicon	Dust.
Soot Value	Caught during lubrication; forms during incomplete combustion.
Sulphate	Caught during lubrication; forms during incomplete combustion
Combustion Efficiency	Total Base Number (TBN) is also a useful tool in assessing engine combustion efficiency, if rapid depletion is observed. If an engine's combustion is inefficient, unburned diesel will enter the oil as blowby, forming acids and using up TBN reserves. Exhaust emissions will often be visible as excessive smoke, which in extreme cases will form 'wet' soot with large soot particles on the exhaust, which will have a detrimental effect on engine wear. This base reserve is called the Total Base Number.

Source: Wearcheck Africa report interpretation training manual

properties differs from the specification, there could be an increase in DPM in the exhaust emissions.

At the start of the study, both of the study mines used 500 ppm sulphur diesel. However, during the period in which the engines were monitored, the mines changed to 50 ppm sulphur diesel. The mines reported that the diesel deliveries were not always consistent in this regard.

## LIMITATIONS TO THE STUDY

Measurements of machine operator exposure along with oil and diesel samples were taken once a month. Detailed records of services that were conducted during the month were not obtained.

Some engines did not operate for the full shift on the day of the sampling due to a breakdown. In this instance, only diesel and oil samples could be taken and left a full-shift DPM personal exposure sample incomplete.

## RESULTS

At the start of the study ten engines were chosen for this project. As mentioned in the methodology section above, some engines became unavailable over the full period of the study. The diesel, oil and personal exposure results reported here are based on the two machines that had more than three months of consecutive results. The two machines were from two different mines.

### Engine 1

Figure 1 presents a comparison of the engine oil contaminants that were evaluated for Engine 1 over a period of seven months. This engine was refurbished three months prior to the start of the study and had received a general service one week prior to the first

Table 2. Diesel properties monitored for all the engines

Property	Units	Criteria	Comment
Density@20°C	kg/L	0.800 min	Energy content. Denser, more energy.
Viscosity@40°C	cSt	2.2-5.3	< 2.2 possibly diluted; > 5.3 possibly oil present.
Flashpoint	°C	55 min	< 55: adulteration / dilution with petrol / paraffin.
Water Content	%	0.05 max	Does not lubricate, but wears parts; causes corrosion; micro growth.
90% Recovery Temp.	°C	362 max	This measures the temperature range over which a fuel volatilises or turns to a vapour. This provides an indication of whether there are any additives in the oil.
Total contamination	mg/kg	24 max	Debris/particulates in the system due to leaks, wear and corrosion debris, filter media, bacteria and fungi. Large number of small particles. Causes damage to injector tips.
Sulphur	ppm	500 max	Natural lubricity (protects fuel pumps and injectors). Forms H <sub>2</sub> SO <sub>4</sub> , which results in corrosion; neutralised by lubricant; thus, oil needs replacement. Forms particulate matter.
Residue	%		Debris
Cetane Index		45-50	Indicates ignition quality. Too high, ignites too close to the injector, resulting in incomplete combustion and soot. Too low, loss of power.

Source: Wearcheck Africa report interpretation training manual

measurement. Notice that all the contaminants follow a similar trend: there is an increase in the concentrations of all the parameters until month five when the combustion efficiency is at its highest (1 = good; 5 = poor). The diagnostic comment from the oil analysis report was that "ring and cylinder/liner wear rates are higher than normal" and that an inspection must be carried out to ensure that the blow-by (i.e. when a small amount of unburned fuel is forced past the piston rings into the crankcase) is not excessive. At month six Figure 1 shows that the parameters are back to normal (combustion efficiency is 1), indicating that remedial measures had been taken. However, at month seven the combustion efficiency and all the parameters have increased and are very similar to the results for month five.

The corresponding personal DPM exposure results followed the same trend. In the first month, the operator's exposure was 0.304 mg/m<sup>3</sup> EC; in month five, the exposure increased to 0.526 mg/m<sup>3</sup> EC and, after remedial measures had been taken (details unknown), the DPM dropped to 0.265 mg/m<sup>3</sup> EC in month six. The remedial measures resulted in an approximately 49% reduction in EC and approximately 23% reduction in the personal TC exposure of the operator.

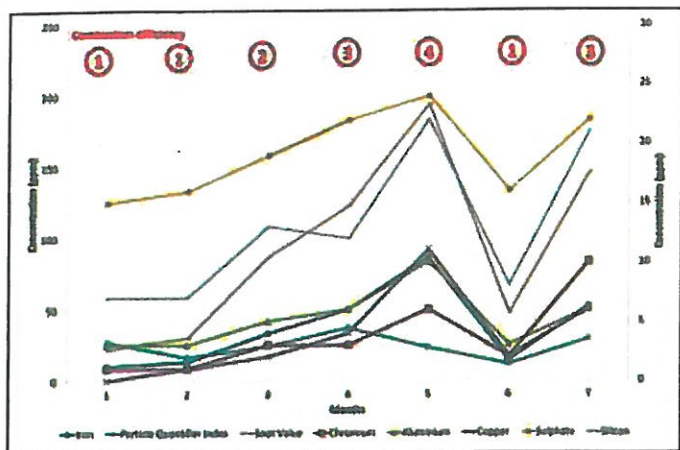


Figure 1. Oil contaminants (ppm) for Engine 1 over a period of seven months, with the combustion efficiency for each month

The diesel properties remained consistent over the entire period for Engine 1. The only exception was the low sulphur (S) content of the diesel in month six, which was 20 ppm S. In the months prior to month six, higher sulphur diesel was used (300 - 400 ppm S). It cannot be confirmed that the low S diesel in month six resulted in the improved results.

### Engine 2

Engine 2 had a newly refurbished engine, which had been in operation for only one hour. Despite the new engine, the personal DPM exposure after four hours was 0.146 mg/m<sup>3</sup>. Over the study period, the personal EC exposure ranged between 0.146 and 0.364 mg/m<sup>3</sup> (with the latter being the highest exposure in the last month).

Oil and diesel samples were taken after the first test drive. Figure 2 shows the oil parameters for Engine 2. The combustion efficiencies for every month were good and the diagnostic interpretation from the oil analysis report was that the wear was normal. No gradual increase in the oil contaminants took place over the period of five months. Compared to Engine 1, the iron, silicon and soot values are much lower. The PQI value was high (66) for month two and, because the total contaminants were above the limit value of 24, the diesel did not comply with the SANS 342:2006 standard for diesel. The cetane index for months three and five was higher than 50 (i.e. potential heat damage to

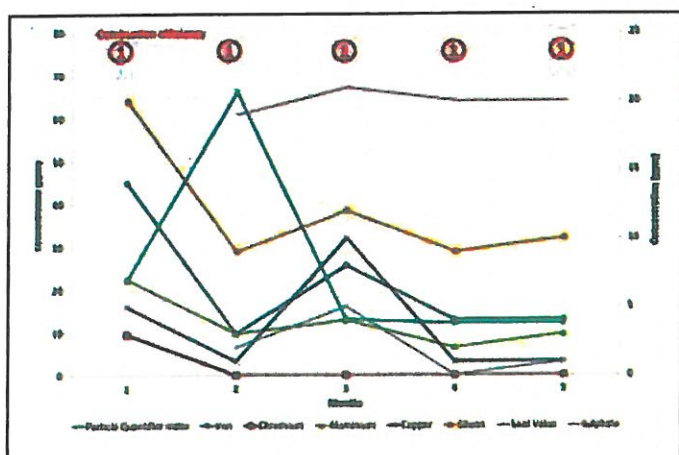


Figure 2. Oil contaminants (ppm) for Engine 2 over a period of five months, with the combustion efficiency for each month

injector tips). The other properties for diesel were relatively consistent over the period. At the start of the study, Engine 2's mine was buying 500 ppm S diesel and was planning to change over to 50 ppm S. The sulphur content for all the diesel samples (engine and diesel bay) taken over the five-month period varied between 23 and 380 ppm. For diesel taken from Engine 2, the S content varied between 30 (in month two) and 146 (month six) ppm S.

### DISCUSSION

This preliminary study shows a relationship between the personal exposure of the LHD operators and the oil and diesel contaminants over the period of the study. As the oil and diesel contaminants for Engine 1 increased, the personal DPM exposure increased as well. When interventions were taken and the oil and diesel contaminants decreased, the personal DPM exposure decreased. This outcome confirmed findings from other studies that maintenance is the most effective means of reducing DPM exposure (Stachulak & Conard, 1997; Waytulonis, 1992 a&b).

It is not clear whether the improvements on Engine 1 in month six were as a result of a general service of the engine or whether they were related to the low sulphur content of the diesel taken from the engine.

Lower sulphur diesel is known to reduce the DPM in exhaust emissions and is most effective on Tier 2 engine technology and higher.

Although Engine 2 started with a newly refurbished engine and the oil and diesel properties were relatively consistent over the study period, the DPM exposure concentrations of the operator still increased over time. This could indicate that even though regular inspections and general maintenance were carried out over the period, the problem of incomplete combustion (i.e. higher DPM formation) was not addressed properly.

### CONCLUSION

Evaluating the results of the analysis of diesel and oil from diesel-powered engines can be a useful tool for managing DPM. The engine oil provides a great deal of historical information about the engine because it lubricates many areas in the engine. The oil and diesel parameters can be used as an indicator of how the DPM emitted by the engine deteriorates (i.e. worsens) over time.

The oil parameters that were investigated are all useful for estimating DPM concentrations. To isolate a few, the iron content, soot value and silica are indicative of leaks and severe wear to engine parts.

These parameters have a detrimental effect on an engine's performance. When the spray pattern is negatively affected, uncontrolled combustion occurs and this in turn results in an increase in DPM formation.

The control of DPM can be achieved through proper, engine-specific maintenance as engines are at different stages in their maintenance cycle and problems differ between engines. The implementation of oil and diesel diagnostic tests and proper evaluation of their results can provide a very useful tool as part of the maintenance programme.

## RECOMMENDATIONS

This preliminary study shows that diesel and oil diagnostic information can be used to control DPM emitted by diesel-powered engines.

The transport, handling and storage of diesel can have a negative effect on its quality and integrity. It is recommended that samples are taken from the diesel transport tankers when diesel is delivered and from the diesel bays and machine tanks and that these samples are tested for conformance to the national standard for diesel, SANS 342:2006. If water, particulate or liquid contamination has occurred during transport and storage, it can be addressed before the diesel is used in the engines.

Analysis of the engine diesel will shed light on engine-related contaminants.

The same applies to the testing of engine oil. The oil diagnostic report provides enough information to address specific problems that cause uncontrolled combustion.

It is highly recommended that maintenance regimes are re-evaluated. Improvements can be implemented immediately and the effect on personal DPM exposure can be monitored continuously. In many cases maintenance is conducted according to a schedule and a standard checklist. Because of production pressures, sufficient time is not spent on the engine. The result is that the root causes of problems are not addressed effectively and the engine performance is only good for a short time.

Engine inspections before a shift can pre-empt problems. For example, untreated oil leaks allow dirt to enter the system, which can block injector tips. This can have a negative effect on the spray pattern, which results in uncontrolled combustion; i.e. an

increase in DPM emission.

A recommendation associated with the above is to consult with the engine manufacturer regarding specific inspections that can be conducted with a focus on lowering DPM in exhaust emissions. When the DPM is lower (because of improved combustion), the engine will perform better and will be in a "healthier" condition.

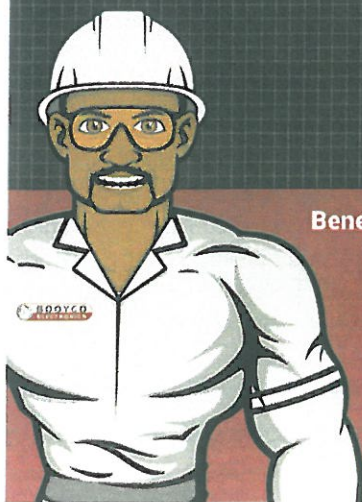
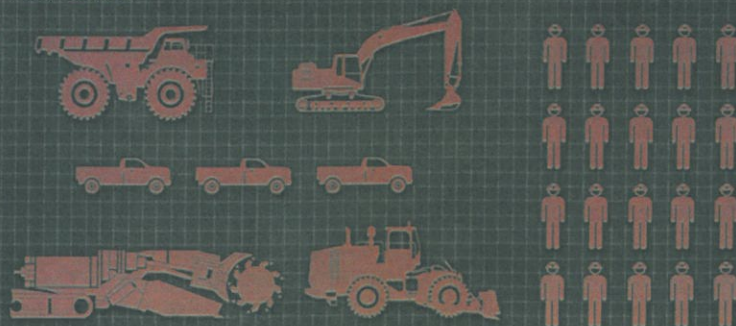
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