The Effect of Maintenance of Diesel Engines on Particulate Generation

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ABSTRACT: Since the publication in 1988 by the United States National Institute of Occupational Safety and Health (NIOSH) of Current Intelligence Bulletin 50 (Carcinogenic Effects of Exposure to Diesel Exhaust), significant effort has been expended in developing means by which to control the generation of particulate emissions from diesel engines. The underground mining sector has conducted significant research in this area and has demonstrated that maintenance practices play a major role in controlling diesel particulate emissions. Maintenance factors affecting diesel particulate generation include intake air restrictions, exhaust gas restrictions, worn injectors, incorrect timing and fuel pump settings. In order to undertake an effective maintenance programme there is a need for simple user-friendly diagnostic tools. Researchers in the United States, Canada and Australia have developed instrumentation for the analysis of raw exhaust gaseous and particulate emissions under operating conditions. Validation of these devices in the coal and metalliferous sectors has demonstrated their effectiveness in lowering emission levels with reductions in excess of 200% achievable on some poorly maintained engines

1 INTRODUCTION

The importance of engine tune was first recognized over 100 years ago as demonstrated by the statement *"It is of particular importance that the fuel entering at the mouth should be thoroughly consumed and without the formation of soot",* made by Rudolf Diesel in an application for a US patent on 8 August 1898.

Since the rise in concern as to the potential adverse health effects of diesel particulate, greater focus on engine maintenance practices has occurred, with one major study (McGinn 2000) in the Canadian mining industry setting the benchmark for others to follow. This study was undertaken within the Canadian underground metalliferous mining industry and more recently a study in the Australian coal mining industry (Davies 2004) has also highlighted this issue.

Research in Australia (Department of Primary Industries 2004) has established the potential of surrogate instrumentation to monitor the raw exhaust of diesel engines in the underground coal mining industry. This research opens the way to assess the effectiveness of maintenance programmes at the shop floor level in the mining industry. Results to date clearly indicate that such programmes reduce employee exposure to diesel particulate.

2 HISTORICAL OVERVIEW

The first apparent reference to maintenance and emissions within the mining industry is Holz (1960) who recounts research in the United Kingdom during the early 1950's where the performance of diesel locomotives in coal mines was observed for a period of approximately two years.

Holz (1960) went on to state that at that time the US Bureau of Mines had not had the opportunity to make a detailed study of maintenance requirements for engines used in mining operations. He did however indicate that some interesting information had been accumulated, the synopsis of which is:

- Fuel injection may have an important effect on combustion. Leaking injection valves caused an increase in raw exhaust carbon monoxide and aldehyde concentrations.
- Only engine manufacturers' designed parts should be used as replacement in engines. This related to an incident where a different injector-nozzle design caused a substantial increase in raw exhaust oxide of nitrogen levels.
- A blockage of injectors or excessive wear would cause a change in fuel distribution and probably an undesirable change in the composition of exhaust gases.

By 1977 the underground mining industry had collected substantial data to better understand the effect of maintenance on emissions. A good insight into progress since 1960 is provided in the proceedings of a workshop on the use of diesel equipment in underground coal mines (NIOSH 1982) held in Morgantown WV from 19-23 September 1977.

At this symposium speakers from Australia, Canada, South Africa and the USA either raised the issue of maintenance on emission generation or referenced statutory maintenance requirements designed to control emissions. An industry “Emissions and Control Technology Work Group” also reported at the symposium and concluded that both engine and exhaust treatment are very important in emission control.

The most detailed early research on the effects of maintenance and service duration on diesel engine exhaust emissions appears to be that of Waytulonis (1985). In this study six Caterpillar 3306 PCNA and seven Deutz F6L 912W engines with varying amounts of service life were sourced from five mines. Also a new Deutz F6L 912W engine was used to determine the effects of maladjustments or faults on the production of hydrocarbons, carbon monoxide, oxides of nitrogen and particulate matter.

Waytulonis (1985) concluded that in the absence of severe faults or maladjustments, exhaust emission quality did not excessively change during the initial 4,000 hours of service life. After about 4,000 – 5,000 hours the engines examined exhibited the following trends: hydrocarbons increased, carbon monoxide increased, oxides of nitrogen decreased and particulates increased.

Waytulonis also induced a number of faults in a new Deutz F6L 912W engine and examined their effect on exhaust emissions. Waytulonis concluded that high levels of emissions could be traced to five specific maintenance activities:

1. Intake air filter changeout frequency
2. Fuel injection timing adjustment
3. Fuel rate adjustment
4. Fuel injector nozzle cleaning and/or changeout
5. Exhaust restriction monitoring

The most extensive study of the relationship between diesel engine maintenance and exhaust emissions is that reported by McGinn (2000). The key learning outcomes stressed by McGinn (2000) were:

- There is a need to have a team approach to maintenance and that the team should involve mechanics, operators, supervision, planning and management. For the team to be effective it needed to have sufficient time, tools, training and resources.

- There is a need to conduct an audit of engine maintenance at least once per year.

- There is a need to create and implement a strategy for improving existing maintenance practices to reduce diesel emissions.

- Testing of undiluted exhaust emissions is fundamental to any successful programme. There is a need to set action limits on emissions to ensure response to problems.

- Use the services of suppliers to train and update maintenance personnel.

Davies (2000), when examining the range of raw exhaust elemental carbon concentrations recorded on eight engines of the same type used in a NSW coal mine, suggested maintenance as a possible factor for the difference. Subsequent research (Davies 2004) involved the testing of the raw exhaust of 66 engines at four Australian coal mines using a modified Rupprecht & Patashnick Co Inc Series 5100 diesel particulate measurement system and a mobile gas laboratory.

Using these tools Davies (2004) identified seven engines with abnormal emission levels which in the majority of cases could be traced to maintenance issues.

Given the above, it is clear that maintenance can impact on emission levels from the exhaust of diesel engines and any process to identify key maintenance issues would be of benefit, especially in the underground mining industry.

3 FACTORS AFFECTING DIESEL EMISSIONS

The interrelationship and balance between critical performance factors has a tremendous impact on not only diesel emissions but engine power output. The raw gaseous and particulate emissions themselves provide a thumbprint of this balance of factors. Carbon monoxide (CO) for example is a critical indicator of the fuel to air ratio balance and therefore points only to problems that could exist within the air intake and charge air system or the fuel injection system. Oxides of nitrogen (NOx) on the other hand are more directly related to injection timing and intake air temperature. Diesel particulate matter (DPM) is the most critical component of emissions in terms of health effects and thus is given the highest rank of importance in terms of control. DPM is largely related to incomplete combustion and often seen in the inverse relationship to NOx. When excess oxygen is present in the exhaust NOx emissions are high and thus DPM emissions are lower. When the opposite occurs and oxygen is reduced the NOx emissions are reduced and DPM emissions go up. The incomplete combustion side of high DPM occurs when situations such as fouled injectors or intake air problems exist for example. The understanding of the components of diesel emissions is an important diagnostic tool for engine maintainers in determining where the balance lies.

In addition to understanding the source and effect of the components of emissions the critical performance factors of the engine itself must be understood and monitored. The most important points to take note of and measure on a systematic and repeatable basis are:

1. Exhaust emissions
2. Emissions control device efficiency (catalytic converter or particulate filter)
3. Engine stall speed RPM
4. Intake air restriction
5. Intake charge air (turbocharger) pressure
6. Exhaust backpressure
7. Fuel transfer pump (primary) pressure
8. Intake charge air temperature
9. Engine cooling system differential temperature (inlet vs outlet)

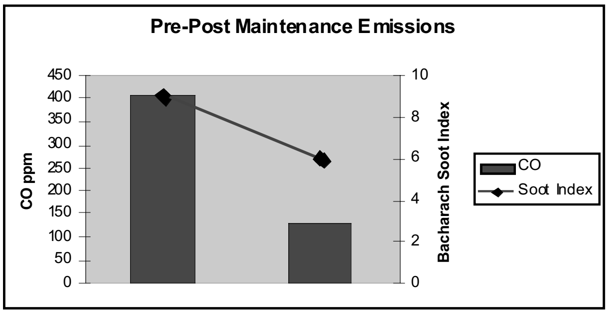
As an example of how this methodology can impact emissions and performance on a day-to-day basis, the example of an Atlas Copco ST8B LHD in a Canadian underground metalliferous mine equipped with a Detroit Diesel Series 60 electronic engine provides some insight. In the engine emissions and performance criteria shown in Table 1 & Figure 1 an engine was brought in at a 250 hour preventive maintenance interval with a note of reported low power. The mechanics performed a series of emissions and engine performance tests in a structured diagnostic process and concluded that the injectors had failed. A quick root cause failure analysis following the repair revealed that the vehicle had run out of fuel two weeks previous, which most likely caused the failure of the injectors. While this is a good example of how the combination of diagnostic tools, knowledge and a structured approach can make a significant difference in cleaner emissions and improved engine performance it is still important to consider the following:

- The problem existed for two weeks before it was reported to maintenance personnel resulting in increased emissions and worker exposure as well as reduced vehicle and engine performance.
- The engine in this case is one of the most efficient electronically injected and controlled engines used in the underground mining industry. Despite this, the problem not only existed but went undetected (no alarm codes present) and uncontrolled (emissions were high and performance was low). While electronic engines have made huge gains in efficiency and reliability they can not and do not compensate under all conditions.

Table 1. Effect of maintenance on raw exhaust emissions

Parameter	Pre (detection)	Post (correction)	Expected
Stall speed rpm	1500	1725	≥ 1700 rpm
Intake restriction	2	2	≤ 5 kPa
Intake charge pressure	110	145	≥ 138 kPa
Exhaust backpressure	5	5	≤ 7.5 kPa
Fuel pressure	448	448	≥ 413 kPa
Carbon monoxide(CO)	405	129	≤ 200 ppm
Bacharach soot index	9	6	≤ 6

Figure 1. Emission levels of an electronic engine pre and post maintenance



4 ROUTINE RAW EXHAUST MONITORING

For maintenance programmes to be effective there is a need for operations to have access to suitable raw exhaust monitoring equipment. Raw exhaust gas monitoring equipment has been available for many years and while effective only gives half the equation. The instrumentation used by Davies (2004) in the evaluation of a fleet of 66 engines is very accurate, however it is difficult to operate and not readily transportable.

Recent research Volkwein et al (2005), Department of Primary Industries (2004), has demonstrated that it is possible to measure diesel particulate in the undiluted exhaust of diesel-powered mining equipment by means of simple hand-held devices with reasonable accuracy. This research has shown that both the SKC “Diesel Detective” and the Air Quality Technologies Pty Ltd particulate monitor provide mine operators with excellent screening and diagnostic tools by which to maintain engines. The relationship of both of these devices to elemental carbon levels as measured by NIOSH Method 5040 (1994) is provided in Figures 2 & 3.

At the time of publication neither of these devices are commercially available, however this is expected to occur some time in 2005. It is anticipated that the use of such instrumentation will greatly assist mine operators to manage employee exposure to diesel particulate.

Figure 2. Comparison of SKC Diesel Detective to elemental carbon

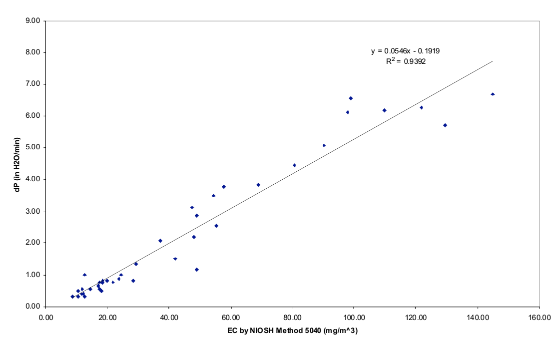
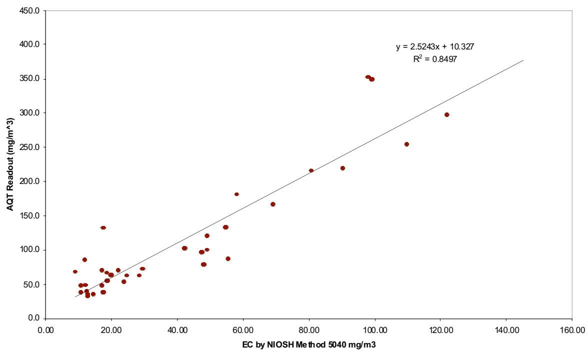


Figure 3. Comparison of AQT Pty Ltd device to elemental carbon



The benefits of having such devices available is demonstrated in the testing of operational vehicles in the field (Table 2).

Table 2. Effect of maintenance on raw exhaust EC emissions

Engine type	Raw exhaust EC (mg/m^3) Before	After	Maintenance performed
KIA 6-247	139	46	Cleaned exhaust scrubber tank
KIA 6-247	131	40	Cleaned exhaust scrubber tank
KIA 6-247	102	61	Replaced injectors, cleaned scrubber tank and intake system
MWM D916-6	159	71	Replaced injectors
KIA 6-247 (supercharged)	155	75	Replaced intake air filter
Cat 3304	166	54	Replaced injectors
Perkins 1006.6	75	44	Retarded timing, cleaned air intake system
KIA 6-247	206	80	Cleaned flame trap, reduced fuel

The data listed in Table 2 clearly indicates that basic maintenance procedures can have a major influence on raw exhaust particulate levels and thus on workplace exposures

5 CONCLUSIONS

Research conducted within the underground metalliferous and coal mining sectors has demonstrated the major impact that maintenance can have on diesel engine raw exhaust particulate levels.

While this is an established fact it is necessary to provide mine operators with suitable tools to measure raw exhaust particulate concentrations on a routine basis. Such tools have been identified and evaluated under mining conditions and will be commercially available in the near future.

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