

# Diesel Vehicle Research at BHP Collieries

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## ABSTRACT

Research into the control of diesel particulates (DP) has been conducted by BHP Coal for more than 7 years. Personal monitoring of employee exposures (n = 480 full shift samples) conducted at nine underground coal mines has indicated that the exposure of the workforce ranges from less than 0.1 to 2.2 mg/m<sup>3</sup> of DP dependent on job type and mining operation. Approximately 50% of the mass of DP captured is elemental carbon (EC) which is the species currently being considered by some international regulatory authorities as the exposure standard. Five technologies for controlling DP were investigated in a combination of studies conducted in an above ground simulated tunnel, in a special controlled section of underground mine roadway and validated by application in standard coal mining operations at Tower Colliery. Tests conducted under controlled conditions indicate that dependent on the type of fuel in use, the introduction of low sulphur fuels can reduce DP levels in return airways by up to 50% and in actual mining situations a reduction of 20% can be achieved in exposure of the workforce. In addition, subjective responses from the workforce indicate that exhaust emissions from low sulphur fuels provide lower irritation and a more pleasant aroma. The use of water filled scrubber tanks reduces the level of DP emissions by 25%. Chemical decoking of engines resulted in a reduction of 20% in DP in return airways. A commercially available non-flammable disposable dry exhaust filter constructed from synthetic organic fibres with an operational lifetime in excess of 20 hours was found to reduce DP exhaust emissions by 80%. Investigations have indicated that the use of increased ventilation to control DP levels particularly in multiple vehicle situations does not follow a simple dilution factor and in some instances compliance with current regulatory requirements may not produce the required reduced exposure levels. The results from single component control strategies provide considerable reduction in exposure to DP, however the most efficient and cost effective control methodology is the use of a combination of individual systems modelled to operations conducted at each mine.

## INTRODUCTION

For more than forty years diesel powered equipment has been used extensively in Australian underground coal mines and for much of that period colliery employees have expressed concern over direct health effects such as unpleasant aroma, eye and respiratory tract irritation, and to potential adverse health effects such as lung cancer arising from exposure to diesel exhaust emissions (NIOSH, 1988). In May 1990 BHP Collieries commenced a major research project with the aim of investigating and reducing exposure to diesel exhaust emissions. The interdisciplinary team consisted of mine management, mining engineers, diesel mechanics, occupational hygienists and workforce representatives.

The NSW Coal Mines Regulations require that each piece of diesel machinery is subject on a monthly basis to underground checking by the operator for the compliance of raw engine exhaust gas concentrations (using detector tubes) for CO (maximum 1500 ppm) and oxides of nitrogen ( maximum 750 ppm ) and in addition every six months a comprehensive analysis is required to be carried out by an accredited laboratory that is approved by the Mines Department (NSW, 1984). A minimum fresh air ventilation of 0.06 M<sup>3</sup> /second/kilowatt of power is required to provide adequate dilution of exhaust gases for each machine. Although control of gaseous emissions indirectly controls soot emissions there is no engine emission standard for DP and no occupational exposure standard for DP in Australia.

Initial investigations conducted by the team indicate that raw diesel emissions consist of a complex mixture of toxic and noxious gases, vapours and particulate matter (soot). The soot or diesel particulate (DP) is almost entirely respirable, with about 90% by mass having an equivalent aerodynamic diameter of less than 1.0 micrometer which are readily deposited in

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the alveolar region of the lung (Rogers, Davies and Conaty, 1993). The surface characteristics and the graphitic nature of the carbon core allows ready absorbence of organics such as polycyclic aromatic hydrocarbons that have been generated in the combustion process (UN, 1994)

Given the increasing dependence of Australian underground coal mining operations on diesel equipment, the research team set out to investigate through a number of sub-projects the following technical aspects:

1. Suitable monitoring methods to capture, separate and quantify diesel particulates;
2. The relative influence on DP emissions and driver exposure to known major variables such as work routines, engine type and condition, ventilation rates, fuel quality and various scrubber control technologies (both above ground simulated testing and underground controlled section mine roadway testing)
3. Spplication of the findings to actual underground mining situations at Tower Colliery so as to determine the extent of influence in a mixed factor environment.
4. To determine the usage of diesel equipment, extent of DP exposure of the workforce and the extent of variables such as fuel quality at both large and small underground coal mines in all mining districts within NSW.
5. Monitoring of overseas developments in measurement, advances in control technology and legislative trends for diesel particulates.

## **TEST METHODS**

### **Diesel particulate capture and measurement**

Diesel particulate (DP) by definition is the mass of sub-micron aerosol particulates found in diesel exhaust. The sampling device used in our project was developed by the University of Minnesota /US Bureau of Mines to measure diluted diesel exhaust as found in general mine atmospheres via a combination of a cyclone and impaction plate to separate the submicron fraction of aerosols which is subsequently gravimetrically determined (Cantrell and Rubow, 1992). Transmission electron microscopy studies indicated that for mine atmosphere samples, more than 85% of the DP was captured using this technique, with the remainder being excluded since it is attached to larger dust particles. Quantitative Analytical scanning electron microscopy indicated that the amount of positive interference from submicron non diesel particulates such as coal dust was less than 10% provided that the respirable dust levels are kept below the statutory limit of 3.0 mg/M<sup>3</sup> (Rogers, Davies and Conaty, 1993) As a result of overseas changes in methodology, supplementary studies were introduced later to measured the elemental carbon (EC) content of the DP (Rogers and Whelan, 1996).

### **Relative effect of variables and the application to controlling exposures**

#### *Above ground simulated tunnel testing*

Initial test work was carried out in a pit top test tunnel (45 m long, 5 m wide and 2.5 m high) designed to simulate a section of mine roadway ( Pratt et al, 1993). An auxiliary fan was fitted at one end to provide ventilation inside the tunnel in accordance with the NSW Coal Mines Regulation Act. The test vehicle chosen was a Domino Minesmobile fitted with a Perkins 242 direct injection engine. A stringent driving schedule incorporating loaded and unloaded cycles was used that represented as much as possible the normal driving cycle of the vehicle if it were being used underground (total time for the cycle was five hours). Personal DP samples were collected on the driver during the various test regimes. The raw exhaust gases (carbon monoxide, oxides of nitrogen and carbon dioxide) were continually sampled using a probe inserted into the exhaust manifold with flexible tubing connected to direct - reading instruments with data stored directly onto a portable computer. This above ground system allowed the use of test equipment that did not meet the underground intrinsic safety requirements of the Coal Mines Regulations.

### *Controlled section underground mine roadway testing*

After the satisfactory completion of the above ground tests, a suitable section of mine roadway approximately 110 m long was identified and pneumatically operated steel doors were installed at one end to provide variable control of ventilation to deliver the exact legislative ventilation requirements for various types of machinery. To reduce undue influences with respect to extraneous airborne dust, a large section of the rib was meshed and sprayed with concrete while the floor was graded and filled with road ballast. A Noyes Multi Purpose Vehicle (MPV) was selected as the most appropriate vehicle for testing because of the number of these vehicles in the colliery fleet and previous research which had demonstrated that these vehicles produced diesel aerosol particulates at a level that minimised the analytical errors associated with the selected sampling device. A driving schedule including various load cycles was developed that reflected as much as possible the normal activities of this type of vehicle in transporting supplies around the colliery over a normal shift. The vehicle was driven backwards and forwards along the test section of roadway for a number of shifts. Diesel aerosol particulate samplers were placed on the MPV operator; the machine itself adjacent to the driver's cabin; inbye of the MPV between the vehicle stopping barrier and the ventilation doors; and outbye of the MPV near the entrance to the test station roadway.

### *Mining operations at tower*

At the completion of various stages of the above ground and underground test tunnel studies, depending on the results obtained under controlled conditions, individual control technologies were introduced to actual mining operations at Tower Colliery and their efficacy tested. Tower is typical of contemporary operations in underground coal mining in NSW. With a workforce of 409 operating a long wall over three production shifts, it achieves an annual production of over 2 million tonnes of high grade coking coal which is used both domestically and for export. Extensive methane drainage is used to supplement ventilation control of gaseous coal seam emissions. Thirty three trackless rubber tyred diesel powered units are used throughout the mine mainly for transport of manpower and materials (70 kilowatt) with heavy duty diesel powered equipment (120 kilowatt) being used for longwall moves.

### **Results of above-ground, simulated tunnel and real mine operation testing**

#### *Fuel quality*

The above ground tunnel testing of 3 commercially available diesel fuels that are commonly used in the mining industry, one commercial low emission fuel and one experimental low emission fuel indicated that both aromatic hydrocarbon and sulphur content affected DP exposures with increased sulphur content in particular indicating a linear increase in driver exposure to both DP, carbon monoxide and oxides of nitrogen. Sulphur has a major influence resulting in the creation of fine particulate sulphates during combustion which catalyses the formation and agglomeration of increased levels of carbon nuclei.

Operational field trials were conducted by introducing the low emission test fuel into a small underground lead/zinc mine that traditionally used high sulphur imported fuel (Pratt et al, 1993). A 40 to 50% reduction in DP measurements was found in the general work areas and return airways in this mine which was similar to the results predicted in the above ground tunnel tests. Trials conducted at Tower Colliery where commercial diesel fuel that complied with the coal mines regulations was substituted with the experimental fuel, resulted in reductions in DP exposure to the workforce of around 10-15%.. In both mines the workforce commented favourably on the use of the low emission fuels, reporting an immediate reduction in irritation and an improvement in the aroma of the emissions. The low emission test fuel has now been incorporated into all BHP underground coal mines in NSW. A fuel specification designed to meet low emission standards also needs to take into consideration other parameters in addition to sulphur including cetane number (which effects cold start, emissions and diesel knock), density (which effects power and hence emission levels), cloud point (which creates problems in cold climates) flash point (which indicates flammability) and distillation range (which indicates higher ends that result in the creation of additional DP) (NSW Mineral Council, 1996).

#### *Scrubber tank cleanliness*

A series of tunnel runs were conducted separately on two machines with the raw exhaust scrubber tank was trialed dry, wet and after extensive cleaning using chemical agents and a high pressure water jet. The NSW legislative requirements are

that this trap be filled with water so as to act as a flame trap but it was also found that water in the scrubber tank acts as an effective impaction barrier for DP resulted in a reduction of 20 -30% to workforce exposures. The presence of water is the major influence in achieving the levels of reductions observed with vehicles fitted with scrubber tanks, however it was found that the additional degree of cleaning instigated in the tests did not increase efficiency of capture above that of normal routine flushing procedures.

### *Engine chemical decoking*

Short - term tests previously conducted at Tower Colliery has shown a significant reduction in the generation of diesel particulates after chemical decoking using commercially available systems. Further tests were conducted to determine the long - term effectiveness of procedures for the chemical decoking of engines and to evaluate the effects on component wear. A Noyes MPV was tested under controlled conditions for a number of days, then removed to the underground workshop and chemically decoked. After decoking, the vehicle was returned to the test station and retested over a number of successive days until the diesel particulates indicated a downward trend. The vehicle was returned to the vehicle fleet to resume normal duties from which it was extracted at regular intervals over a nine month period for retesting. A significant downward trend of diesel particulate levels was obtained soon after treatment and maintained over the nine month period of sampling. Apart from routine maintenance, no other work has been performed on the engine over the sampling period and no adverse mechanical effects were noted up to the present.

The decoking process releases considerable quantities of soot through the vehicle exhaust and water filled scrubber tank which continues for a number of hours. This release of built-up carbon requires the careful management of exhaust emissions to ensure workers are not inadvertently exposed to a range of noxious products.

Other machines have been similarly treated and tested and decreased DP emissions were also found although the amount of reduction was found to be dependent on the condition of the engine prior to the decoking.

### *Disposable exhaust filter*

Considerable work has been undertaken in the USA to develop a disposable exhaust filter system (Ambs and Hillman, 1992). These filter types have a proven record in the USA of reducing DP exposures in underground vehicles, but unfortunately a number of incidents have been recorded where hot exhaust has carbonised and even ignited the paper filters making them unacceptable for use in Australian coal mines. Our research developed a filter constructed from polypropylene filter material which has enhanced flame resistant characteristics, good filtration characteristics, is not adversely effected by water mist and is commercially available obtainable at reasonable cost (Pratt et al, 1995).

A P. J. Berriman Pty Ltd Power Tram fitted with and without filters to the scrubber tank exhaust was tested under full power load in the underground test tunnel for durations up to four shifts. Back pressure was monitored to ensure that engine performance and exhaust emission levels were not adversely effected. Significant reductions in diesel aerosol particulates were recorded using the filter for periods in excess of three consecutive shifts even though backpressure increased to 20 kPa no effect was detected on engine performance. Without the filter, visibility in the heading was poor with significant levels of water vapour and soot present while with the filter, visibility was improved significantly. A number of other diesel machines types at Tower have been fitted with the filter units and this has been successful in reducing DP exposures in the mine.

The exhaust filter devices are now commercially available although not all equipment have filter kits which are approved. This system however provides the best short - term means of controlling diesel particulates from low - use heavy haulage vehicles in the underground coal mining industry. It is necessary that appropriate safety systems be installed with the unit to ensure that the filters are never exposed to temperatures above their design characteristics and that they are changed out on a regular basis (e.g. after each 24 hours of use).

### *Mine ventilation*

A linear decrease in operator DP levels was found for increased airflow when machines were operating alone. When machines were used in combination, the actual results were different from the calculated additive values, being lesser in the low flow conditions and higher in the air flows greater than 12 m<sup>3</sup>/s. Thermal stratification in the tunnel was observed

only at flow rates less than 6 m<sup>3</sup>/s. The reason for the difference in additive effects of multiple machinery remains unclear. At some flow rates thermal stratification may result in higher exposures to some members of the workforce.

In situations where multiple vehicle use occurs in some headings, high DP levels have been reported. A tag system has been implemented at Tower to prevent the use of machines in areas where the ventilation requirements may be exceeded.

#### *Routine underground diesel test bay*

The underground research test bay has been developed into a routine test procedure for all machines. Each operator once per week drives their machine into the test bay and enters the machine number into the computer which indicates the statutory air flow requirements. The operator adjusts the air flow then runs the machine under an idle and short load cycle. In-bay gas sensors record the exhaust emissions and indicate the status of compliance to the driver, the information is automatically recorded in the mine computer records. The driver must obtain a satisfactory printout for the machine before continuing further into the mine, failed machinery is immediately returned to the service bay. This system has been found to be very successful in preventing poorly tuned engines from entering work areas and in predicting early deterioration of machinery so that maintenance measures can be taken prior to it failing the statutory gas testing.

Currently a system is being researched that may facilitate gas testing as well as testing of DP levels under the same test bay conditions.

#### *Employee exposure profile*

During the research project some 203 personal DP samples were collected over a 18 month period to profile the exposures for all job types at Tower Colliery. In normal operating conditions, exposures ranged from 0.05 to 0.4 mg/M<sup>3</sup>. This increased during extreme load conditions such as long wall change to between 0.4 and 0.6 mg/M<sup>3</sup>. For tasks linked to diesel engine activity a linear relationship was found between exposure and number of hours of driving (Pratt, 1995). Overall a reduction of DP exposures at Tower has been observed as various control technologies have been introduced.

The DP monitoring program was extended to a number of operations within the NSW underground coal mining industry, with diesel activities sufficiently different to that of Tower Colliery. Railtrack and diesel locomotive haulage were identified as two such areas that needed to be monitored. A group of eight mines was selected that met the required criteria. Each colliery was contacted seeking their assistance and followed up with a site visit by the Project Co-ordinator in order to outline the research and to seek their commitment to the project. During this pre-sampling site visit, considerable time was allocated to the selection of those activities which would provide the most useful data in terms of differences to Tower Colliery. At least one operation similar to that at Tower Colliery was included in the tasks to be sampled as a control. Sampling was then undertaken at the eight collieries in the period July to December 1994, with the aim of obtaining a minimum of six full shifts of sampling per mine per specific activity. All samples collected were on a full shift personal basis with a minimum of four hours sampling duration. In all 134 personal samples were collected at the eight collieries.

While direct comparisons between exposures found at individual collieries is not possible because of varying ventilation and duty cycle requirements, Colliery C appeared to have consistently lower results relative to other operations, including Tower Colliery. Discussions with colliery management indicated the use of a low sulphur diesel fuel, good road conditions throughout the mine which minimised engine revving, an intensive scheduled maintenance program, a system for limiting the number of vehicles in ventilation splits, a computerised weekly exhaust emission testing program, and a policy of replacement of "older" design engines had lead to the improved conditions.

#### **Future exposure standards and legislative requirements for diesel particulates**

A proposed occupational exposure standard (TLV's) for diesel particulates have been published in 1995 and 1997 by the American Conference of Governmental Industrial Hygienists (ACGIH, 1995). Worksafe Australia has commenced viewing these standards and presumably they will flow on to the Australian coal industry. MSHA in the USA has indicated that they are close to releasing mechanisms by which a diesel particulate exposure standard would be set. MSHA have also released a "toolbox" consisting of mechanisms by which DP levels can be reduced in coal mines.

Monitoring data from USA suggests that most coal mines would have difficulty in meeting the proposed standard of 150 micrograms/M<sup>3</sup> (elemental carbon) unless they introduce control technologies similar to that currently being implemented in BHP mines which has been adopted into Guidelines by the NSW Mineral Council (1996).

A survey funded by an existing Joint Coal Board Health and Safety Trust research grant is being conducted in NSW and Queensland coal mines using modern sampling and analytical methods designed to specifically capture and analyse this sub micron fraction of DP and to measure elemental carbon content. The aim is to determine the suitability of these monitoring systems for the Australian coal industry and for applicability to any future exposure standards.

#### **4 Wheel drive project**

An ACARP funded research has just commenced on reviewing the current design criteria for underground light duty diesel vehicles in terms of safety and practicability with the view of developing a commercially available four wheel drive vehicle design for use in the non-hazardous zone of NSW underground coal mines. The more efficient electronically controlled engines may provide an alternate and future approach to control of diesel particulates. A successful outcome of the project will also provide substantial benefits to the to the workforce in respect of vehicle comfort plus significant reductions in the initial purchase price of diesel equipment for personnel transportation.

### **CONCLUSIONS**

The research conducted at Tower Colliery has added significantly to the knowledge of the extent employee exposure to DP and to the methods by which exposures can be controlled. The traditional control strategies such as engine and scrubber tank maintenance, regular gaseous emission testing and the requirement of minimum ventilation rates provide considerable control of workforce exposures. Additional controls such as correct fuel quality, regular engine tuning and engine decoking provide further significant overall reductions in DP exposures as well as creating a more pleasant smelling atmosphere in which to work. For specific tasks which emit high diesel particulate levels, particularly under heavy load conditions, additional controls in the form of disposable filters fitted to the exhaust outlet appear to provide the most effective method of control at this stage. The most efficient and short - term cost effective overall control strategy is to use a combination of individual systems modelled to suit equipment and operations conducted at each specific mine.

Users of diesel equipment in underground mines are rapidly reaching a situation where they will need to comply with regulations that specifically limit the extent of employee exposure to diesel particulates. The control strategies tested in research described in this paper are now being successfully incorporated into the regular mining activities at Tower Colliery, the four other BHP mines as well as being adopted as a Code of Practice for all mining operations in NSW and hence will assist the industry in meeting future legislative requirements as well as improving the working conditions of the miners. Research which is in progress will move the industry to a new level of competitiveness in the future.

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