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Controlling and monitoring exposure to diesel engine exhaust emissions in non-coal mines

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Controlling and monitoring exposure to diesel engine exhaust emissions in non-coal mines

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Most non-coal mines use diesel powered vehicles and equipment underground and consequently, in the confined spaces of a mine, the potential for worker exposure to diesel engine exhaust emissions (DEEEs) is high.

This document provides practical advice on how to control exposure to diesel engine exhaust emissions in non-coal mines and so protect the health of employees. It details a simple on-site method which allows mines to measure for themselves general body or personal exposures to DEEEs and so confirm that any controls in place are still effective and that exposures are being kept to a minimum in line with the Control of Substances Hazardous to Health (COSHH) requirements.

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EXECUTIVE SUMMARY

Most non-coal mines use diesel powered vehicles and equipment underground and consequently, in the confined spaces of a mine, the potential for worker exposure to diesel engine exhaust emissions (DEEEs) is high.

This document provides practical advice on how to control exposure to diesel engine exhaust emissions in non-coal mines and so protect the health of employees. It details a simple on-site method which allows mines to measure for themselves general body or personal exposures to DEEEs and so confirm that any controls in place are still effective and that exposures are being kept to a minimum in line with the Control of Substances Hazardous to Health (COSHH) requirements.

1 INTRODUCTION

This document provides practical advice on how to control and measure exposure to diesel engine exhaust emissions (DEEEs) in non-coal mines, and so protect the health of employees and others who may be exposed.

This document is not suitable for coal mines because the background of coal dust necessitates a different sampling method for measuring exposure to DEEEs and not the method outlined here.

2 DIESEL ENGINE EXHAUST EMISSIONS

Diesel Engine Exhaust Emissions (DEEEs) contain a complex mixture of gases, vapours, liquid aerosols and particulates. These substances are the products of combustion and the major constituents are listed below:

- Nitrogen (N_2)
- Carbon Dioxide (CO_2)
- Water (H_2O)
- Carbon Monoxide (CO)
- Oxides of nitrogen e.g. Nitric Oxide (NO) & Nitrogen Dioxide (NO_2)
- Oxides of sulphur e.g. Sulphur Dioxide (SO_2)
- Various hydrocarbons
- Alcohols, Aldehydes, Ketones
- Particulates (soot)
- Polycyclic aromatic hydrocarbons (PAHs)

Exhaust emissions from diesel engines are usually more visible than those emitted from petrol engines because they contain over ten times more soot particles. In general diesel engines produce less carbon monoxide than petrol engines but more oxides of nitrogen, oxides of sulphur (although very little with modern low sulphur fuels), aldehydes and particulate matter.

The soot particles associated with diesel engine exhaust are extremely fine with diameters less than 1 micrometre. They consist of an elemental carbon (EC) core comprising 40 – 80% of the particle mass onto which are adsorbed hundreds of organic substances, referred to as organic carbon (OC), some of which are potentially harmful to health.

The quantity and composition of DEEEs depend mainly on:

- The type of engine e.g. direct or indirect injection, turbocharged or non-turbocharged;

- Whether the engine has been regularly maintained and tuned;

- The specification and type of fuel used;

- The workload demand on the engine, e.g. whether the engine is required to work near to its capacity;

- The engine temperature, e.g. starting from cold.

3 HEALTH EFFECTS

There are essentially two health issues associated with exposure to DEEEs. In the short term, exposure to high concentrations of DEEEs will cause irritation of the eyes and respiratory tract. Nitrogen oxides, sulphur oxides and aldehydes are all respiratory irritants and are present in DEEEs. It is probable that they all contribute to the overall problem and the ultrafine soot particles may also be a contributory factor.

In the long term there is some evidence to indicate that sustained exposure to DEEEs may slightly increase the risk of lung cancer. Research has shown that this is due to the fine, often ultrafine, soot particles associated with DEEEs and the substances absorbed onto them.

4 LEGISLATION

The HSE believes there is insufficient evidence for DEEEs to be classed as a carcinogen and at present in the UK there are no occupational exposure limits for DEEEs. However, under the Control of Substances Hazardous to Health Regulations[1], DEEEs are classed as a substance hazardous to health. As such these require that exposure be prevented or, where this is not reasonably practicable, adequately controlled. To achieve this the law requires that employers make a suitable and sufficient assessment of the risks to health which arise from exposure to hazardous substances, such as DEEEs, and that the necessary steps are taken to prevent or adequately control exposure.

[1] Control of Substances Hazardous to Health Regulations, 2002. SI 2002/2677 The Stationery Office ISBN 011 042919 2

5 WORKPLACE EXPOSURE

The potential for exposure to DEEEs in mines is greater than in surface industries. With large diesel powered equipment operating in confined spaces it is inevitable workers, especially drivers and those working close to or down ventilation of the equipment, will be exposed to DEEEs. It is important that this exposure is kept to a minimum.

6 MEASURING EXPOSURE TO DEEES

6.1 INTRODUCTION

As outlined DEEEs consist of a complex mixture of gases, vapours and particulates and deciding which component or components to monitor to provide a representative measure of exposure to DEEEs is difficult. However, one method which is thought by many to be the best is to collect, using a respirable cyclone sampler, a sample of airborne diesel particulate onto a quartz filter and to analyse the exposed filter for carbon; both the organic carbon (OC) associated with the adsorbed organic substances and elemental carbon (EC) from the soot cores themselves. All the evidence shows that the diesel particulate EC concentration provides a good surrogate measure of exposure to DEEEs and a number of countries now have occupational exposure limits based on EC. There are distinct advantages in measuring EC as follows:

- ***Specific*** In most workplaces (with the exception of coalmines and factories using carbon black) the only airborne EC is from DEEEs and consequently measuring airborne EC is very specific to diesel particulate. Also, the analysis is very specific for carbon and so any other dusts collected during sampling will not affect the EC result.

- ***Appropriate*** It is now thought that the ultrafine EC associated with diesel particulate is the primary cause of the health problems associated with long term exposure to DEEEs and so measuring EC is an appropriate surrogate measure of exposure.

- ***Representative*** Diesel particulate is extremely fine with very little mass. Once airborne it behaves very much like a gas and stays airborne for a long time. Consequently, measuring diesel particulate EC is fairly representative of the other gases and vapours associated with DEEEs. If the EC concentration is high then it is likely the concentration of other exhaust gases will also be high. However, it must be understood that there is no direct correlation between particulate EC with carbon monoxide and nitrogen oxides and therefore the concentration of these gases must be determined independently using other methods.

7 GUIDANCE LIMITS

HSE carried out a technical development survey (TDS) of surface operations where workers over the working day were exposed to DEEEs. With respect to diesel particulate EC the report indicated that:

- Fork-lift truck drivers were the highest exposed group with personal exposures up to 403 µg/m³ EC with a median value of 75 µg/m³ EC.

- For the purposes of control 200 µg/m³ EC should be considered high exposure.

Research work carried out in non-coal mines produced diesel particulate EC exposures ranging from 17 to 430 µg/m³ EC with an average exposure of 153 µg/m³ EC.

Although in the UK there are no occupational exposure limits for DEEEs, all mines should aim to reduce exposures to below 150 µg/m³ EC. To make it possible for mines to monitor their own EC exposure levels the HSE/HSL has developed an on-site method.

8 ON-SITE METHOD FOR MEASURING EC EXPOSURES

8.1 RESEARCH

Over recent years HM Inspectorate of Mines have commissioned a number of research projects with the Health and Safety Laboratory (HSL) to provide information on the exposure of mineworkers to DEEEs and some of this research is mentioned in the section on 'Ways to Control Exposure'. However, one primary objective of this research was to develop an inexpensive and simple on-site method for measuring EC exposure, which would allow mines to determine personal or general body EC exposure measurements themselves without the need for laboratory analysis. The following sections detail an on-site method for non-coal mines and provides information on how this is achieved and the equipment required.

8.2 BACKGROUND TO THE ON-SITE METHOD

Normally, diesel particulate samples are collected onto quartz glass fibre filters using a respirable cyclone sampler[1] operating at 2.2 litres/min and the samples analysed for organic and elemental carbon using laboratory based equipment. From the mass of EC on the filter and the volume of air sampled the diesel particulate EC concentration is determined. This is used as a measure of exposure as outlined previously.

However, there exists a strong correlation between the 'blackness' of a diesel particulate filter sample and the amount of EC present on the filter, and a relationship equating 'blackness' and EC can be determined[2]. This relationship may differ slightly from mine to mine dependant on the 'blackness' of the mineral being mined and other dust collected on the filter. But once the relationship is determined it makes it possible to estimate how much EC is present on a filter by simply measuring the 'blackness' of the filter without the need for laboratory methods.
This simple on-site approach makes it possible for a mine to regularly monitor EC exposures and to keep records that will demonstrate that exposure to DEEEs is being kept to a minimum in line with the COSHH requirement.

Notes:

(1) Cyclone samplers are used because they are particle size selective and eliminate much of the larger background dust and only collect the much finer respirable diesel particulate. In dusty areas this type of sampler can prevent the filter being overloaded with unwanted dust that may interfere with the 'blackness' method.

(2) There are limits to the relationship and once the filter is totally black then it cannot get any blacker and it breaks down. This can be a problem in areas where exposures are high. In these areas the sampling time is reduced to prevent overload.

8.3 BOSCH SMOKE EVALUATOR UNIT

One device designed to measure the 'blackness' of filters is the Bosch Smokemeter Evaluator Unit that is mentioned in Section 9.2 and is detailed in Appendix A. This device is normally used in conjunction with the Bosch Smokemeter Sampling Pump to measure the 'blackness' of tailpipe particulate samples collected using the pump. However, it can be used to measure general body or personal diesel particulate samples collected with a respirable cyclone sampler provided a relationship equating filter 'blackness' (Bosch No.) and the EC mass on the filter has been determined.

All mines are encouraged to use a device such as the Bosch Smokemeter to regularly monitor tailpipe emissions and, using cyclone samplers, determine personal and general body EC exposures. Regular monitoring to ensure controls are still effective is important if exposures are to be kept to a minimum. A more detailed guide to setting up the on-site method is given in section 10.

9 WAYS TO CONTROL EXPOSURE

There are many factors that will influence the concentration of DEEEs in the general body air of the mine and the consequent exposure of workers. These are:

9.1 ENGINE DESIGN

Manufacturers are improving the design of diesel engines all the time and modern engines are cleaner and produce far less exhaust emissions than older engines. To reduce worker's exposure mines should try to upgrade old equipment sooner rather than later. It only takes one dirty engine to raise the general body DEEEs concentration to unacceptable levels.

9.2 VEHICLE MAINTENANCE

Poorly serviced and/or badly tuned engines produce far more exhaust emissions than well maintained engines. For example a partially blocked air filter can greatly increase the exhaust emissions, especially particulates.

A program to regularly monitor the tailpipe particulate emissions from vehicles under a standard condition of operation will provide useful information about the operating condition of the engine. Regular measurements on each vehicle will soon provide a baseline result for that vehicle or engine such that any deviations from the norm can be quickly spotted and addressed.

One simple and relatively inexpensive piece of equipment for monitoring tailpipe particulate emissions is the BOSCH Smokemeter (see Appendix A for details). This device consists of two parts; a sampling pump which can be inserted into the exhaust pipe and which draws a defined quantity of exhaust through a filter disc: And a smoke meter evaluating unit which photoelectronically measures the 'blackness' of the sampled filter disc and provides a reading (Bosch No.) of between 0.0 (white) and 9.9 (intense black). The more soot particles present in the exhaust emissions the 'blacker' the filter and the higher the Bosch No.

Some engines will naturally produce more particulate than others and consequently it will be necessary to determine baseline norms and have specific action levels for each vehicle. In the longer term consideration should be given to replacing the 'dirty' engines with more modern and cleaner versions.

9.3 FUEL

Diesel fuels are being improved all the time to make them cleaner burning and so reduce emissions. One major improvement has been the reduction in the sulphur content of diesel fuel which, over the last 5 years or so, has been reduced by a factor of ten and ultra low sulphur fuels are now the norm. Low sulphur fuels produce less particulate and sulphur dioxide (SO_2), a toxic gas and potent respiratory irritant, has been virtually eliminated.

Other fuels which can directly replace standard diesel can also be considered. One such example is biodiesel a diesel fuel derived from natural plant oils (e.g. in Europe rape seed oil is used and in the USA soya bean oil). Research carried out by HSE and HSL has shown that emissions are greatly reduced using biodiesel, especially particulates where reductions greater than 90% were measured and a 30% blend of biodiesel with standard diesel saw reductions in particulates greater than 40%.

At the present time in the UK the availability of biodiesel and the cost are possibly prohibitive. But this is changing and the government is looking more favourably on alternative fuels and it is likely biodiesel will become more readily available over the coming years and tax incentives could make it cost effective. For use underground biodiesel has much to offer in reducing exposure to DEEEs.

Note: Only diesel fuels approved by HSE can be used in mines.

9.4 FILTERS

There are now available catalytic diesel exhaust filters that can both trap the particulate and, when exhaust temperature conditions are catalytically favourable, oxidise the particulate to carbon dioxide. Manufacturer's claim that particulate reductions in excess of 90% are possible and research carried out by HSE/HSL has confirmed this. For the filters to operate properly they do require certain exhaust temperature conditions and some engines may not meet these requirements and this needs to be discussed with the filter supplier. But for engines that do meet the requirements these filters have much to offer in reducing DEEEs especially particulates.

9.5 VENTILATION

Good ventilation to dilute and disperse the exhaust emissions is possibly the most important factor for ensuring exposure is kept to a minimum. In coal mines where ventilation velocities are much higher than in non-coal mines research has shown that exposure to DEEEs is much lower and this is directly attributable to the ventilation. Therefore, every effort must be taken to ensure ventilation losses and leakages are kept to a minimum and that the maximum amount of air possible is passing through the areas where the diesel engines are operating and personnel are working.

9.6 NUMBER OF ENGINES

The more engines operating in the mine the more exhaust emissions. Only operate engines that are necessary and switch off engines not in use. Do not leave engines idling.

9.7 ELECTROSTATIC FILTER MASKS

Some dust masks offer little or no protection against diesel exhaust particulate. Only masks rated to FFP1, FFP2 or FFP3 provide protection against diesel particulate exposure with greater than 90% of diesel particles being trapped by the filter mask. Research carried out at HSE/HSL has shown that FFP2 type masks are the most efficient but there is an increased resistance to breathing with this type of mask. The FFP1 masks offer good protection coupled with relative ease of breathing.

Workers who are working in close proximity to diesel engines should be encouraged to wear an FFP1 electrostatic face mask. These simple and relatively inexpensive devices will help to reduce exposure to diesel exhaust particulate.

9.8 POSITION OF PERSONNEL

The closer personnel are to diesel powered equipment the higher their exposure to DEEEs, especially if they are working downwind of the exhaust. Therefore, keep to a minimum the number of people working in close proximity to diesel engines and where possible arrange it such that they are upwind of the exhaust fume. In certain situations higher exposure may be unavoidable. If this is the case then try and limit the time a worker is exposed by swapping their duties with a less exposed worker mid way through the shift.

10 STEP BY STEP GUIDE TO SETTING UP THE ON-SITE METHOD AND HOW TO MEASURE EXPOSURE

Note: The following is a suggested guide and there may be other suitable methods. However, the method described has been used in the HSE/HSL research previously mentioned and has been tried and tested on several occasions.

10.1 PRELIMINARY SAMPLING TO DETERMINE THE BOSCH NO. TO EC RELATIONSHIP

Before the simple on-site method to measure EC exposure can be used, a relationship equating Bosch No. and EC has to be determined for each mine. For this trained personnel will collect a number of diesel particulate samples covering a range of exposures and take these away for laboratory analysis. For each sample the Bosch No. 'blackness' and the EC mass is determined and from these data a relationship equating Bosch No. and EC produced. Using this relationship a simple look up table is produced and an example is shown in Appendix B.

The on-site preliminary sampling will provide an opportunity for the trained personnel to go through all the different aspects of the method and the practicalities of collecting samples and how to determine exposure. The person/s whose task it will be to carry out the exposure monitoring can also be shown in detail exactly what to do and how to collect samples.

10.2 COLLECTING DIESEL PARTICULATE SAMPLES

10.2.1 Equipment

A list of the equipment required to carry out diesel particulate sampling and a number of suggested suppliers is shown in Appendix C. There has been no attempt to recommend one supplier over another and all provide perfectly good equipment. The list is not exhaustive and there are other suppliers but the ones mentioned here are established recognised suppliers of airborne monitoring equipment and would be able to give advice if necessary.

10.2.2 Setting up Samplers

Diesel particulate samples are collected using a respirable cyclone sampler loaded with a 25 mm diameter glass fibre filter. The filter is loaded into the cyclone sampler and the sampler is connected via flexible plastic tubing to a sampling pump. Before sampling commences a rotameter is connected in series with the pump and cyclone and the sampling pump adjusted to provide a sampling flow rate of 2.2 litres/minute through the cyclone, see Figure 1. The initial flow rate is recorded onto a result sheet, an example of which is shown in Appendix D.

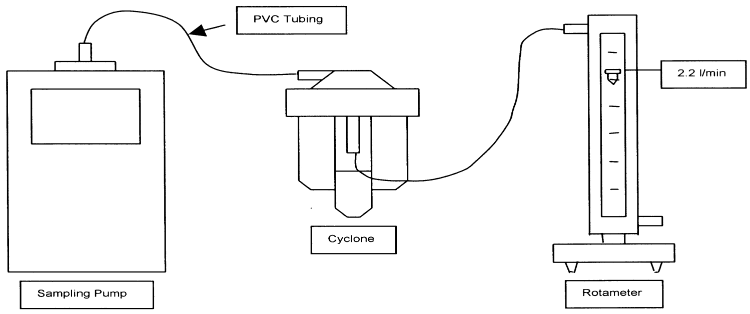

Figure 1. Using a Rotameter to Set the Flowrate Through the Cyclone

Once the flowrate is set the pump is switched off and the rotameter removed. The sampler is then either attached to a worker to monitor personal exposure or positioned at a fixed point in the mine to determine background general body exposure concentrations. Once positioned the pump is switched on and the start time, sampling location, date and any other relevant information recorded on the result sheet.

Sampling should be for as long as possible to provide a representative time weighted average (TWA) concentration. However, with the 'blackness' method it is important the filter is not overloaded and therefore this limits to some degree the sampling time. With experience the optimum sampling time soon becomes apparent but 1 to 4 hours is typical. At the end of sampling record the end time and using the rotameter measure and record the final flowrate.

Using the result sheet column headings in Appendix D for guidance and the example given, determine the mean flow rate and the total sampling time in minutes and calculate the sample volume in cubic metres (m^3).

Remove the filter and measure the 'blackness' using the Bosch Smoke Evaluator Unit as per the manufacturer's instruction and obtain a Bosch No. reading for the sample and record the result on the results sheet. From the Bosch No. v EC look up table determine the mass of EC equivalent to the Bosch No. result and record this on the result sheet. An example is shown in Appendix D but it must be remembered the look up table used in this example will be different to the one specifically determined for your mine.

Determine the EC exposure concentration by dividing the Mass of EC by the sample volume to give a TWA result in micrograms per metre cubed ($\mu g/m^3$).

10.2.3 Comments

The simplicity and low cost of the on-site method make it possible for non-coal mines to regularly monitor general body and/or personal exposure to DEEEs and to have a measure of exposure that can be recorded. In this way a mine can compile a database of exposure information such that any unusual high exposure events can be identified and the cause remedied. By doing this the mine will be demonstrating that, in line with the COSHH regulations, the exposure of workers to DEEEs is being kept to a minimum and that the health of workers is of primary importance and not being compromised by over exposure to DEEEs.

11 APPENDICES

Appendix A - BOSCH Smoke Meter

The Bosch Smoke Meter consists of two parts: (1) A sampling pump which is inserted into the exhaust pipe and which draws a defined quantity of exhaust through a filter disc and this is shown in the foreground of the photograph. (2) A smokemeter evaluating unit which photoelectronically measures the 'blackness' of the sampled filter disc using a 'light pen' to provide a Bosch No. result between 0.0 (white) to 9.9 (intense black), and this is shown at the rear of the photograph.

Appendix B - An example of a look-up table relating Bosch No. to EC

Bosch No.	**EC (µg)**	**Bosch No.**	**EC (µg)**
3	8.3	**6.1**	12.1
3.1	8.2	**6.2**	12.5
3.2	8.1	**6.3**	13.0
3.3	8.1	**6.4**	13.6
3.4	8.0	**6.5**	14.2
3.5	7.9	**6.6**	14.8
3.6	7.9	**6.7**	15.5
3.7	7.9	**6.8**	16.3
3.8	7.9	**6.9**	17.1
3.9	7.9	**7**	18.0
4	7.9	**7.1**	19.0
4.1	7.9	**7.2**	20.0
4.2	8.0	**7.3**	21.2
4.3	8.0	**7.4**	22.4
4.4	8.1	**7.5**	23.8
4.5	8.2	**7.6**	25.3
4.6	8.3	**7.7**	26.9
4.7	8.4	**7.8**	28.7
4.8	8.5	**7.9**	30.6
4.9	8.7	**8**	32.7
5	8.9	**8.1**	35.1
5.1	9.0	**8.2**	37.6
5.2	9.2	**8.3**	40.4
5.3	9.4	**8.4**	43.5
5.4	9.7	**8.5**	46.9
5.5	9.9	**8.6**	50.7
5.6	10.2	**8.7**	54.8
5.7	10.5	**8.8**	59.4
5.8	10.9	**8.9**	64.4
5.9	11.2	**9**	70.0
6	11.6	**9.1**	76.2

$$EC = \text{Exp}\{3.24 - (0.6169 \times \text{Bosch No.}) + (0.081 \times [\text{Bosch No.}]^2)\}$$

Note: Above Bosch No. 9.1 the relationship between the Bosch No. to EC starts to break down and this defines the upper limit. The sampling time must be arranged such that the Bosch No. is below 9.1.

Appendix C - Equipment and suggested suppliers

EQUIPMENT	SUPPLIER
Bosch Smokemeter - Sampling pump ETD 020.00 - Diesel smoke evaluator ETD 020.50	**Robert BOSCH Ltd** PO Box 98, Broadwater Park North Orbital Road Denham, Uxbridge Middx., UB9 5HJ Tel: 01895 834466 Fax: 01895 838388
Personal Sampling Pump Capable of 2.2 litres/minute **(a,b,c)** **Respirable Cyclone** With 25 mm cassette **(a,b)** **Glass Rotameter** To measure up to 2.5 litres/min **(a,b)** **25 mm GFA Glass Fibre filters** **(b,d)**	**a) SKC Ltd.** Unit 11, Sunrise Park, Higher Shaftesbury Road Blandford Forum Dorset, DT11 8ST. Tel: 01258 480 188 Fax: 01258 480 184 **b) Casella CEL** Regent House, Wolseley Road Kempston Bedford, MK42 7JY. Tel: 01234 844100 Fax: 01234 841490 **c) Shawcity Ltd.** Pioneer Road, Faringdon Oxfordshire, SN7 7BU. Tel: 01367 241675 Fax: 01367 242491 **d) The Labsales Co.** Over Industrial Park, Norman Way Over, Cambridge, CB4 5GR. Tel: 01954 233190 Fax: 01954 233195

Appendix D - Result sheet with a worked example

Date/Location	Cyclone Number	Flow Rate (l/min) Initial	Flow Rate (l/min) Final	Flow Rate (l/min) Mean (A)	Sampling Time	Total Time (B) (mins)	Sample Vol. (A) x (B) = (C) litres	Sample Vol. (C) / 1000 = (D) m^3	BOSCH No.	EC (From look up table) (E) µg	EC Conc. (E) / (D) $\mu g/m^3$
30/10/03 Workshops	CY1	2.2	2.15	2.175	**Start:** 10.00 **End:** 11.30	90	196.2	0.196	7.3	21.2	**108.2**
					Start: **End:**						
					Start: **End:**						
					Start: **End:**						
					Start: **End:**						
					Start: **End:**						
					Start: **End:**						
					Start: **End:**						

Note: For the sake of the worked example here the EC mass has been determined using the look up table in Appendix B. In normal use the EC mass will be determined from a look up table which is specific to each mine.

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