3-360A

Michael Holliday

OCCUPATIONAL HEALTH ASPECTS OF DIESEL EXHAUST EMISSIONS IN ONTARIO

by

Michael G. Holliday
John W. Sifton
F. Rainer Engelhardt
Stephen W. Langdon
Ronald A. Meng

Prepared under contract to the Standards and Programs Branch, Occupational Health and Safety Division, Ontario Ministry of Labour

November 1981

111 1/2 Beech St.
Ottawa K1S 3J9
(613) 728-9769

5. MONITORING AND CONTROL

This chapter provides an overview of the current methods and some future possibilities for monitoring and controlling diesel exhaust emissions in the workplace, based on extensive reviews and key publications. In order to inject more reality into this discussion, there will appear reported pollutant levels in a few Ontario and U.S. mines and other workplaces.

5.1 MONITORING

A wide variety of analytical techniques have been used to monitor the hundreds of components comprising diesel exhaust. Most of these techniques are too expensive and time consuming to be particularly effective in regularly measuring worker exposure. The few which might be useful for this purpose are discussed below.

5.1.1 Gases and Vapours

As can be seen in Table 5-1, there are a number of methods used to measure gas-phase atmospheric pollutants. Area monitoring may be carried out with stain tubes, optical-spectroscopic methods, electrochemical cells and chemiluminescence for a variety of different gas-phase pollutants. Electrochemical cells may also be used for personal monitoring. For example, Johnson and co-workers use non-dispersive infra-red spectroscopy for carbon monoxide and carbon dioxide measurement, chemiluminescence for nitric oxide and nitrogen dioxide measurement, and an electrochemical method for sulphur dioxide in their extensive and continuing studies of air quality in dieselized mines.[21,304,305]

5.1.1.1 Stain tubes:[306] Stain tubes, often called "Draeger tubes" after one of their major manufacturers, are commonly used to measure workplace air quality. They consist of sealed tubes which contain reagents, adsorbed on a support medium (usually silica gel), which change colour when the

TABLE 5-1 Measurement Methods for Diesel Exhaust Components[306]

Techniques	Components Measured
Stain tubes	CO, CO_2, NO, NO_x, SO_2, aldehydes
Electrochemical cells	CO, NO, NO_2, SO_2
Metal oxide detectors	CO, NO, NO_2, CH_4
Optical spectoscopy	CO, CO_2, NO, NO_2, SO_2, CH_4
Mass spectrometry	not useful for the inorganic gases, but a powerful tool, when coupled with a gas chromatograph, for organics
Gas chromatography	Organics, not often used for the inorganic gases
Chemiluminescence	NO, NO_x, SO_2

3

specific gas they are to analyze reacts with them. To use, the tube is broken open at each end and a known volume of the air being tested is drawn through. The length or intensity of the colour change along the tube gives an approximate indication of the amount of gas present.

These tubes have the advantage of low cost, simplicity of operation and almost instantaneous indication of the pollutant concentration. Their accuracy in normal use, however, is seldom better than plus or minus 25 percent, which might make them unsuitable for regulatory purposes. They are now used in Ontario mines to fulfill the monitoring requirements of the Diesel Code with respect to carbon monoxide and nitrogen dioxide.[286]

5.1.1.2 Electrochemical cells: An electrochemical cell acts as a fuel cell and generates a current proportional to the concentration of the monitored gas in an air sample. The air under test is bubbled through an electrolyte which serves as one half-cell of the galvanic cell. A membrane separates this half-cell from the reference half-cell, the nature of which depends upon the gas being measured. Carlson and Johnson used such an electrochemical cell to monitor sulphur dioxide in mine environments.[305]

As is the case with many liquid-electrolyte galvanic cells, these cells have a significant disadvantage; they are subject to changes in voltage due to polarization effects occuring at the electrodes. As a result daily calibration of the cells is often necessary. Over the longer term (three to six months) replacement usually becomes necessary because of corrosion problems.[306] Recently electrochemical solid-polymer-electrolyte (SPE) sensor cells have been developed which use no liquid electrolyte, eliminating such problems as corrosion or containment. Carbon monoxide SPE cells are now widely used in steel mills and fire departments as well as regulatory agencies. Sensors for nitric oxide and nitrogen dioxide have also recently been developed.[307]

5.1.1.3 Optical spectroscopy: Carbon monoxide and carbon dioxide have strong absorption bands in the infrared region of the spectrum, with the result that infrared sectroscopy is a convenient method for their measurement. For other gases, the ultraviolet region may be used. Nitric oxide, for example, has strong and very sharp absorption bands in the region 200 to 230 nm, while sulphur dioxide may be measured at 310 nm. Some care is necessary to assure that that sample is free of dust particles and, for infrared spectroscopy, water vapour. Carlson and Johnson, for example, measured carbon monoxide and carbon dioxide in mine atmospheres using non-dispersive infrared absorption techniques.[305]

An important advantage for some regulatory purposes is the fact that spectrometers may be used for continuous measurement of the pollutants.

5.1.1.4 Chemiluminescence: In many chemical reactions, the product molecules may be formed in an electrochemically excited state, which then relaxes to the ground electronic state with the emission of light. This process is chemiluminescence and a technique based on it has been used to measure nitric oxide and nitrogen dioxide in diesel exhaust gases.[308] Ozone is reacted with nitric oxide in the exhaust gases and electronically excited nitrogen dioxide is formed. The chemiluminescence, detected by photomultiplier, is proportional to the concentration of nitrogen dioxide formed and thus to the quantity of nitric oxide originally present. In order to measure total nitrogen oxides (including any nitrogen dioxide in the original sample) by this technique, any nitrogen dioxide present must be reduced to nitric oxide prior to its introduction into the detection chamber. Either a thermal converter or catalytic converter is ordinarily used for this reduction. The level of nitrogen dioxide is simply the difference between the two measurements (NO_x minus NO).

5

5.1.2 Diesel Particulates

Total particulates -- that is, both diesel particulates and others such as silica dust -- may be measured with a konimeter or by gravimetrically determining the particulates on a filter. In order to measure the concentration of diesel particulates in particular, the total particulate sample must be treated, either by burning off its carbonaceous portion or by extracting the diesel particluates with organic solvents to produce the soluble organic fraction, SOF.

5.1.2.1 Total particulates:[309] The konimeter is the main instrument now used to measure operational dust levels in mines. In the view of most researchers, this instrument will measure respirable dust ranging in size from 0.5 to five microns. Air (five mL) is drawn through a small orifice in the konimeter where it impinges on a glass slide coated with adhesive. The particles trapped on the slide are counted visually with a microscope or with an electronic scanner; the dust concentration is expressed as particles per cubic centimeter of air, ppc. The slide is heated in air to remove combustible material and then the particles on it are recounted. The difference between the two particle counts constitutes an estimate of the proportion of diesel particulates in the original sample. The konimeter uses a grab or random spot sample approach and provides no information on a miner's time-weighted-average exposure.

A gravimetric method of measurement may be more useful for personal monitoring. With this technique air is drawn through a pre-weighted filter paper, silver membrane or glass-fibre filters; the dust concentration is then determined gravimetrically. With silver membrane or glass-fibre filters, the weight of the sample may be determined before and after combustion and an estimate of the diesel-derived particulates made.

The filters used to trap total particulates do not differentiate between respirable and non-respirable fractions of airborne dust. There are,

6

however, size-specific collection devices which are basically miniature cyclone collectors. These operate on the principle that, for a given velocity of air passing through the cyclone, only particles greater than a certain size will be collected; smaller particles will pass right through. By using a train of cyclone collectors and carefully adjusting the air flow through them, it is possible to assure that the final collector will trap most (say 95 percent) of the respirable particles but not the larger, non-respirable ones. The collected respirable particles may then be determined gravimetrically and the combustion technique described above may then be used to estimate the amount of diesel particulates. Cyclone collectors are being introduced for measurement of silica dust in silica regulations dealing with mine environments.[310]

All diesel particulate measurement methods relying on combustion will be somewhat inaccurate because diesel soot is not the only component of total particulates affected by combustion. Weight losses after combustion may also reflect the loss of water of crystallization from mineral particles, oil and fuel trapped during sampling and any combustible ore dust present in the atmosphere. In a dieselized mine, diesel particulates represent an estimated 80 percent of the total combustible, respirable dust.

5.1.2.2 Soluble organic fraction (SOF): The major health concern is, of course, the organic molecules adsorbed on soot particles. These may be measured in a gross way by extracting the particulates trapped on a filter (or collected in a cyclone) with organic solvents, evaporating the solvent and then weighing the residue. Such solvents as hexane and dichloromethane are used for this purpose. Measurement of the SOF is used, for example, to determine the effectiveness of various engines and emission control options in reducing levels of the more toxic pollutants in diesel exhaust.[5]

5.1.2.3 Analysis of polynuclear aromatic hydrocarbons (PAHs): Polynuclear aromatic hydrocarbons are the component of the soluble organic

7

fraction that have raised the greatest concern with respect to the health effects of diesel exhaust. They also pose a complex monitoring problem because:

> The PAH pollution found ... consists of an extremely complex mixture of individual PAH compounds. In some cases more than 100 compounds have been identified in the particulate matter from workplace environments. This means that, for a complete characterization of the potential hazardous compounds in some of these workplace environments, analytical techniques with very high resolving power, high sensitivity and good reproducibility for quantitative measurements are necessary.[311]

Gas chromatography,[311,312] high pressure liquid chromatography[312,313] and thin layer chromatography[314,315] are the techniques used to measure PAHs in environmental samples. For details on these techniques, the reader is referred to a comprehensive review contained in the Ontario Ministry of the Environment's report, Polynuclear Aromatic Hydrocarbons.[313] These techniques have been used, for example, to measure PAHs in diesel exhaust,[316] the air of Ontario cities,[314] and Ontario mine atmospheres[315] as well as for studies intended to identify the contribution of diesel vehicles to the total PAH levels in the vicinity of highways.[317]

5.1.3 Carbon Dioxide as a Surrogate Measure of Diesel Exhaust Levels

About 99 percent of the carbon from the combustion of diesel fuels is expelled as carbon dioxide. Extensive work by Johnson and co-workers has demonstrated linear relationships between carbon dioxide levels and carbon monoxide, nitrogen oxides, and diesel particulates measured in working mine environments.[9] This finding led Johnson to propose using carbon dioxide as a surrogate measure of air quality in dieselized mining environments.

The approach has a number of attractions. Carbon dioxide levels are far higher than those of other exhaust pollutants (fractions of a percent, compared to ppm quantities). Relatively robust instruments are available

(using non-dispersive infrared absorption techniques) and these may be located in mines or even mounted on mine vehicles to provide a continuous monitor of carbon dioxide levels in the vicinity of the vehicle operator. Carbon dioxide measurement can also provide a ready check on the efficiency with which the ventilation system is removing diesel exhaust.

This monitoring option is not universally accepted. It has been argued that it does not measure what would be considered a harmful substance; that the variations in the toxic pollutants with engine type, engine load and fuel are not reflected in carbon dioxide levels. Others have stated that the attachment of monitoring devices to mine vehicles would be an unnecessary expense and mean additional maintenance, as well as unwarranted anxiety among workers.

5.2 POLLUTANT LEVELS FOUND IN OCCUPATIONAL ENVIRONMENTS

The potential magnitude of the problem posed by diesel exhaust may be seen through a brief examination of actual pollutant levels reported in dieselized workplaces. The data presented here are far from comprehensive, however, because such a data-collection effort would be beyond the scope of this project.

5.2.1 Underground Mining

Table 5-2 presents pollutant levels found during the late 1970s in four mines, two located in the United States and two in Ontario. All four mines are trackless operations. White Pine is a copper mine; Bushey Creek, a lead mine; Ojibway, a salt mine; and Dennison, a uranium mine. Interestingly the pollutant levels are similar in all four mines, perhaps because they are fairly representative of trackless mining in general. More important, the actual levels for gaseous pollutants are all considerably below the current TLVs.

exhaust levels may become uncomfortably high at times (after all, there may be 200 buses starting and warming up in one enclosed space), this work practice reduces the eight-hour time-weighted-average exposure. All storage areas have carbon monoxide monitors set to sound an alarm if the carbon monoxide level exceeds 35 ppm.

Each bus must pass a daily inspection, which includes visual inspection of exhaust smoke. Any bus emitting excessive smoke is withdrawn from service for correction of the problem. In addition, the buses undergo regular 32,000-mile services.

5.3.3 Loading Docks

Well designed docks can substantially reduce exposure to diesel exhaust of employees working in them. One loading dock facility, seen during a visit to a manufacturing plant, was enclosed and ventilated, while dual bays were separated by floor to ceiling partitions. A tractor-trailer delivering a load backs up to the dock and the rear of the trailer fits into a seal on the warehouse door. This prevents air passing from the dock into the warehouse. Unloading of the trailer can then take place without exposing workers to exhaust fumes, even if the tractor's engine is running. In winter, the tractor-trailer area can be closed by a roller-blind outside the door. These control techniques, besides coping adequately with worker exposure to exhaust, reduce heat losses from the warehouse area.

The same company, which had continual deliveries and shipments, has a practice of unhooking the tractor from the trailer once the trailer is in position. The tractor is then free to pick up an unloaded trailer from another bay and drive off for another load while the warehouse crew unloads the delivered trailer.

The NIOSH survey at a Massachusetts factory already referred to above outlines some generally applicable approaches used to improve air quality in

an enclosed loading dock.[302] Vehicles that had to keep their engines running during unloading (because of the need to power auxiliary equipment or starting problems in cold weather) were hooked up to a flexible exhaust hose vented to the outside by an extractor fan. This control measure was simple to install and reduced exhaust levels considerably, both in the loading area and in the surrounding offices. The NIOSH report also stated that the company had introduced regulations governing the maximum time a vehicle would be allowed to run its engine while waiting to unload.

5.3.4 Diesel Repair Shops

The same approaches to diesel exhaust emissions are followed in both independent repair shops (i.e., those establishments whose income is generated by the service and repair of diesel vehicles) and "captive" shops (i.e., in-house operations which maintain and repair diesel vehicles, and indeed railroad locomotives, for their organizations). There is, however, a wide variation in the quality of control measures used in different establishments; larger enterprises and "captive" shops tend to be more stringent than smaller operations.

5.3.4.1 Ventilation: The most effective ventilation regime is individual ventilation hoses on vehicle exhausts complemented by general-area ventilation.

General-area ventilation practices range from installed ventilation ducts (which vent shop-air to the outside) to the simple use of ceiling fans, to merely opening the garage doors when the fumes get too bad.

Installed diesel exhaust extraction systems (DEES) are usually designed to fit vehicles with vertical exhaust stacks (the common configuration in heavy- and medium-goods vehicles). Problems arise when the shop has to repair vehicles with under-slung exhausts as the DEES hoses may not be long enough to accommodate under-vehicle exhausts. To be effective, the DEES should have an extraction fan of sufficient capacity to remove exhaust