Science.
Applied to Life.™

Technical Bulletin

Release 1, November 2017
#253

Diesel Particulate Matter and Respiratory Protection

Introduction

The US Occupational Safety and Health Administration (OSHA) has provided the following summary information regarding diesel exhaust (DE) and diesel particulate matter (DPM):

"Diesel engines provide power to many types of equipment used in a large number of industries, including transportation, mining, construction, agriculture, as well as many manufacturing operations. Occupations with potential exposure to DE/DPM include miners, construction workers, heavy equipment operators, bridge and tunnel workers, railroad workers, oil and gas workers, loading dock workers, truck drivers, material handling operators, farmworkers, long-shoring workers, and auto, truck and bus maintenance garage workers.

Diesel exhaust is a mixture of gases and particulates produced during the combustion of diesel fuel. The very small particles are known as diesel particulate matter (DPM), which consists primarily of solid elemental carbon (EC) cores with organic carbon (OC) compounds adhered to the surfaces. The organic carbon includes polycyclic aromatic hydrocarbons (PAH), some of which cause cancer when tested in animals. Workers exposed to diesel exhaust face the risk of health effects ranging from irritation of the eyes and nose, headaches and nausea, to respiratory disease and lung cancer." [1]

"Short term exposure to high concentrations of DE/DPM can cause headache, dizziness, and irritation of the eye, nose and throat severe enough to distract or disable miners and other workers. Prolonged DE/DPM exposure can increase the risk of cardiovascular, cardiopulmonary and respiratory disease and lung cancer. In June, 2012, the International Agency for Cancer Research (IARC) classified DE (including DPM) as a known human carcinogen (Group 1)." [2]

Exposure Limits

US OSHA doesn't currently have an exposure limit for DPM for general industry, agriculture, construction and maritime industries. However, OSHA does have exposure limits for other components of DE such as carbon monoxide, nitric oxide and nitrogen dioxide. "Monitoring for these gases can provide an indication of the presence of DE, and can be of help in evaluating the effectiveness of engineering and administrative controls implemented to minimize the potential for exposure to DE when working with or around diesel-powered equipment."[2]

In contrast, the US Mine Safety and Health Administration (MSHA) does have DPM exposure limits. For underground metal/nonmetal mines, the 8 hour time weighted average (TWA) permissible exposure limit for each worker is 160 $\mu g/m^3$, measured as total carbon. For underground coal mines, DPM emissions from diesel-powered engines are limited according to laboratory tests on the engine exhaust; 2.5 or 5 g/hr, or according to EPA standards.

Australian New South Wales Department of Mineral Resources has an 8 hour TWA permissible exposure limit of 0.1 mg/m^3, measured as submicron elemental carbon.

Exposure Control

Engineering and administrative controls must be the first step to reduce DE and DPM exposure. This includes, but is not limited to, properly maintaining diesel engines, engine exhaust filters, diesel oxidation catalysts, low sulfur fuel, ventilation, minimizing traffic congestion and idling, and limiting diesel engine operating areas. Rotation of miners to comply with the exposure limit is prohibited by MSHA.

Respirators may only be used when engineering and administrative controls are not feasible or are inadequate. For underground mines, US MSHA requires particulate respirator filters used for DPM to be either NIOSH certified as:

1. High-efficiency particulate air (HEPA) filter for powered air purifying respirators, or
2. 100 level (99.97% efficient) particulate filter for negative pressure respirators. R or P class filters (R100, P100) are required due to the presence of oily mist.[3]

For surface mines, US MSHA simply requires NIOSH approved respirators "which are applicable and suitable for the purpose intended". [4]

Performance of Respirators Against DPM

A number of studies have been conducted to characterize the performance of different respirators and filters against DPM. These studies are all designed to address the question of what happens to filtration performance as DPM particles accumulate on the filter. This may be relevant for electrostatically charged filter media used in many current particulate filters and respirators. Oil-containing particles from the DPM that are deposited on the fibers in the filter could theoretically mask their electrical charge, thereby reducing their effectiveness at capturing particles.

An early study of the performance of NIOSH-approved filters against DPM was published by Janssen and Bidwell.[5] In that study, two products from two manufacturers (identified as X and Y) were evaluated. The NIOSH-approved products included an N95 filter from each manufacturer, a P95 filter from Manufacturer X, and an R95 filter from Manufacturer Y. N class filters are tested by NIOSH against sodium chloride (NaCl), and are not for use against oily mists. R and P class filters are tested by NIOSH against dioctyl phthalate (DOP), and may be used against particles including oily mist such as may be present with DPM.

All of the filters were replaceable filters of the type that are used in pairs on elastomeric (reusable) respirators. The initial efficiency of each filter was measured by exposing it briefly to either NaCl or DOP aerosol of the appropriate particle size in accordance with the filter's approval type (N, R, or P) at a flow of 42.5 L/min (equivalent to 85 L/min for a pair of filters). Then the filters were subsequently loaded with various levels of DPM at a flow of 25 L/min (total flow of 50 L/min for a pair of filters which corresponds to a medium to heavy breathing rate[6]). During loading with DPM, NIOSH Test Method 5040[7] was used to measure the mass concentration of elemental carbon downstream of each filter and in the test chamber, permitting calculation of EC penetration for each filter. Afterwards, the final (instantaneous) filter efficiency was again measured with either NaCl or DOP under conditions similar to the NIOSH respirator certification test under 42 CFR 84. That is, essentially all of the loading on the filter consisted of DPM; NaCl and DOP were only used to measure the initial and final penetrations of the filters.

The results of the study showed that the average penetration of elemental carbon was below 5% for all the filters using method 5040 for DPM. But when subsequently tested with NaCl similar to NIOSH 42 CFR 84 conditions, the N95 filters from Manufacturer Y yielded average instantaneous penetrations greater than 10%. Similarly, after 8 hours of continuous or intermittent exposure to DPM, Manufacturer Y's R95 filters yielded average instantaneous DOP penetrations greater than 5%. For Manufacturer X, after loading with DPM the average NaCl penetration for the N95 filters and the average DOP penetration for the P95 filters were still below 5%. The authors noted that the DPM loading values were much higher than would be anticipated in any work environment but nevertheless, insofar as NIOSH N class filters and respirators are not approved for use against oil-containing dusts and mists, they should not be used for protection against DPM. Janssen and Bidwell attribute the difference in penetration values to several factors, most notably the difference in flow rate (25 vs 45 l/min) and the use of nanoparticles in the 42 CFR 84 test methods. The net result is that the NIOSH respirator test methods are more stringent than mass-based measurements such as NIOSH method 5040, which measure worker exposure to DPM.

A study by Leung, et al.[8] evaluated the effect of DPM on filter material obtained from an N95 respirator. In this study the researchers measured the penetration of DPM of specific particle sizes (50, 70, 100, 200, 300 nm) at regular time intervals over the course of a 6 hour loading test. Rather than using a mass-based method for measuring penetration of DPM (as done by Janssen and Bidwell), they used a particle counting-based method, which tends to give higher penetration values. This method also tends to give higher penetration values than the NIOSH test method specified in 42 CFR 84. The maximum penetrations measured were as high as 30% for 50 nm diameter particles at the start of the test (i.e., before any DPM had accumulated on the filter). Such a high penetration for a new (unloaded) filter is unexpected. In two separate studies of five different models of N95 respirators published by NIOSH[9, 10] using the same count-based measurement method but with monodisperse salt (NaCl) and silver (Ag) particles in the size range of 4 to 400 nm, the highest reported penetrations were 5% or less for all particle sizes. The limited amount of data presented in the study by Leung and the high penetration values reported (compared to other studies) raise doubts about the reproducibility of the work.

A study by Penconek and co-workers[11,12] used a mass-based method of their own design to assess the performance of CE-approved FFP2 and FFP3 respirators loaded with one of three different types of diesel fuel (petroleum diesel, ecodiesel, and biodiesel). In this study the air flow through the respirators was held constant at 30 l/min and the samples were loaded with DPM for 40 minutes. The engine used in this study was old (1982) and the exhaust was not diluted, so the emission concentration was rather high (>10 mg/m^3). Under these conditions, the average penetration through the FFP2 filters ranged from 10.6% for ecodiesel up to 15.7% for biodiesel. The average penetration through the FFP3 filters ranged from 13.3% for ecodiesel up to 24.9% for biodiesel. The European certification test for FFP2 respirators specifies separate loading tests with NaCl and paraffin oil and maximum penetration levels below 6% for each test agent. The maximum allowed penetration for FFP3 filters is 1%.

The results of this study are also questionable. First, considering the age of the engine used, the emissions obtained from it may not reflect modern diesel engine design. Second, the concentration of DPM obtained was far higher than would be observed in a typical work environment. The third, and more important question with regard to these results is related to the method of measuring the mass of DPM penetrating through the respirators. The authors used polypropylene (PP) fibrous filters to collect the samples and gravimetric analysis to determine mass concentrations. The use of PP filters may not be appropriate for DPM measurements because adsorption of low-volatility gases that are ubiquitous in diesel exhaust has been shown to be a concern in measurement of DPM with other filter materials.[13,14] The mass of gas-phase components adsorbed by the PP filters would have the effect of increasing the apparent weight of particles captured on the filter, thereby increasing the apparent penetration of DPM through the respirators. A recently published study[15] confirms that gas absorption by PP filters yields substantial bias in calculated mass penetrations of DPM. It is not known how susceptible the quartz filters used in NIOSH Method 5040[7], the method used by Janssen and Bidwell, are to this bias; however the low DPM penetration values they reported would suggest that it is not significant. In short, the high penetrations reported by this study are more likely artifacts of the method used rather than accurate reflections of the respirator performance.

The most recent study of respirator performance against DPM was published by Burton16 and coworkers in 2016. The objective of the study was to investigate whether the standard methodology for filter penetration testing in AS/NZS 1716 is adequate to ensure DPM is effectively filtered. They evaluated three different products (3M 9923V, Dräger X-plore 1320V, and Sundström SR510) in two studies using different diesel engines. The approval types and levels are summarized in the table below. Comparing the certification tests between NIOSH 42 CFR 84, AS1716, EN143, and EN149, the 3M 9923V is similar to a NIOSH N95 respirator (because the AS1716 certification test uses a NaCl aerosol). The 1320V, which is tested against both NaCl and paraffin for EN approval, is similar to a NIOSH R95. The SR510 is most similar to a NIOSH P100 filter because it is tested with both NaCl and paraffin and has a higher rated filtration efficiency.

Respirator/Filter Model	Approval	NIOSH Equivalent*
3M 9923V	AS1716 P2	N95
Dräger X-plore 1320V	AS1716 P2 / EN149:2001 FFP2 NR D	R95
Sundström SR510	AS1716 P3/ EN143:2000 P3 R	P100

*Approximate equivalent approval level

In the two studies described by Burton et al. (labeled Study 1 and Study 2 in their publication), multiple respirator samples were exposed to DPM at a constant flow of 95 l/min for a total period of 60 minutes. The reported concentrations were measured according to NIOSH Method 5040, from which the penetration was calculated (See Figure 1 on page 4). In both studies, the mean penetration over 60 minutes was below 6% for all of the products tested; however in Study 1 there was significant variability in the data. This is reflected in the confidence intervals, which exceed 6% for the 9923V as shown in the chart below.

The calculated penetrations for 9932V and 1320V were significantly lower in Study 2, as was the variability. The lower penetration values may reflect differences in the DPM size and concentration (as a consequence of using a different diesel engine), differences in the source of diesel fuel between the two studies, or simply a reflection of improvements in sample handling technique between the studies.

The results for the 1320V (which has an EN FFP2 approval) contradict the results of Penconek et al. [10,11], especially given the higher flow rate and longer test duration (60 minutes at 95 l/min vs 40 minutes at 30 l/min). However, the DPM penetration for the SR510 filter, which has an EN P3 approval, is much higher than the allowable penetration of NaCl and paraffin for such a filter (0.5% vs 0.05%). The results for this filter appear to be an anomaly given that the SR510 filter is made of fiberglass filter media (also known as “mechanical media”) that is much less susceptible to degradation by exposure to oil-containing aerosols than electrostatically charged filters. The unexpectedly high DPM penetration for the SR510 raises questions about the results for that filter. By comparison, Janssen and Bidwell reported that DPM penetration through P95-approved (oil resistant) filters was below the limit of detection for the NIOSH Method 5040. On that basis, one would expect similar low penetration for the SR510. Further testing on this filter is required before these results can be accepted as representative of the filter's performance.

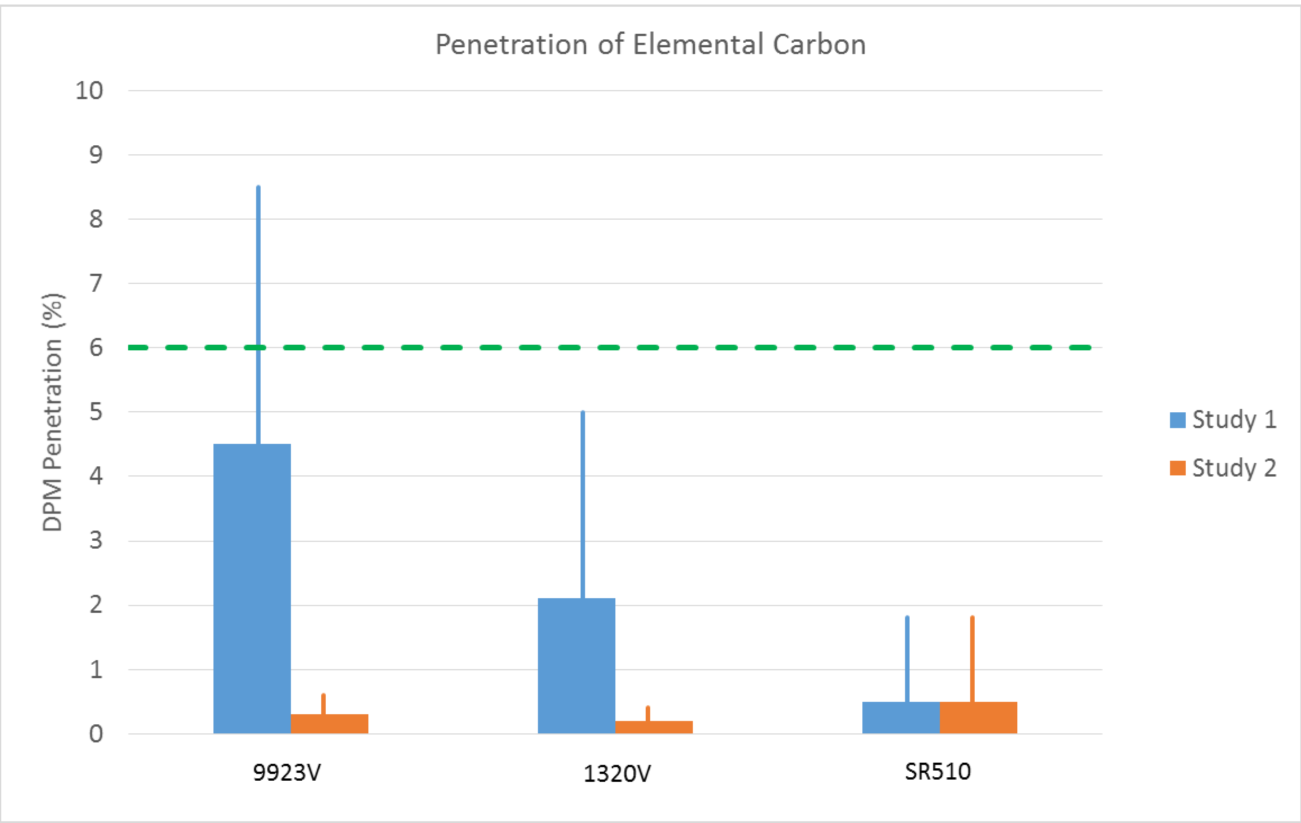

Figure 1. Adapted from Burton and coworkers[16].

Summary

Questions about the performance of respirators and filters against DPM have prompted several studies and more are underway. Differences in the study designs (flow rate, test duration, engine size and operating conditions, diesel source, DPM measurement technique, etc.) make it difficult to make direct comparisons between them. DPM loaded onto filters and respirators may increase filter penetration in subsequent laboratory measurements, which may or may not reflect workplace performance. The fact that gaseous components in diesel exhaust can affect gravimetric results highlights the need for a validated test method. In the two studies that use a standard method for measuring DPM (Janssen and Bidwell, and Burton), the penetration of elemental carbon through NIOSH 95-level filters and EN FFP2 respirators is below the penetration allowed according to the relevant regulatory test methods. However, the results for the SR510 P3 filter raise questions about either the method or the filter.

Both in Janssen and Bidwell and in Burton's Study 2, the penetration of elemental carbon through all filters/respirators was less than 5%. In contrast, the protection factor in many countries for half mask respirators is 10. This means that when used in accordance with a respirator protection program that meets local regulations (proper selection, use, maintenance, fit testing, etc.), it will reduce inhalation exposure by a factor of 10 (or 90%). However, this also implies up to 10% penetration through either the filter or from face seal leakage during use. Therefore, DPM filter penetration may not be as significant when compared to the importance of ensuring that respirators are properly fitted and worn during the entire time of exposure. Although not specifically evaluated in these studies, particle filters with a thin layer of carbon for low levels of organic vapors may be desirable to help filter PAHs commonly associated with DPM.[17, 18]

References

1. https://www.osha.gov/SLTC/dieselexhaust/index.html
2. https://www.osha.gov/dts/hazardalerts/diesel_exhaust_hazard_alert.html
3. 30 CFR 56.5060 MSHA "Limit on exposure to diesel particulate matter, underground only"
4. 30 CFR 56.5005 MSHA "Control of exposure to airborne contaminants"
5. Janssen, L.L. and J.O. Bidwell, "Performance of Four Class 95 Electret Filters Against Diesel Particulate Matter", J. Int. Soc. Resp. Prot., Vol 23, No. I, 2006.
6. Nelson, G.O. and Correia, A.N., "Respirator Cartridge Efficiency Studies VIII. Summary and Conclusions", Am. Ind. Hyg. Assoc. J. 36:514-525, 1976.
7. National Institute for Occupational Safety and Health: NIOSH Manual of Analytical Methods (NMAM), Fifth Edition. K. Ashley and P.F. O'Connor Eds. https://www.cdc.gov/niosh/docs/2014-151/pdfs/methods/5040.pdf, Accessed May 12, 2017.
8. Leung, W.W., J. Chung, C. Tsang, and C. Hung, "N95 Face Mask Under Increasing Solids Loading and Moisture", Filtration, Vol 8, No. 2, 2008.
9. Rengasamy, S, W.P. King, B.C. Eimer, and R.E. Shaffer, "Filtration Performance of NIOSH-Approved N95 and P100 Filtering Facepiece Respirators Against 4 to 30 Nanometer-Size Nanoparticles", J. Occ. Env. Health, 5: 556–564, 2008.
10. Rengasamy, S., A. Miller, and B.C. Eimer, "Evaluation of the Filtration Performance of NIOSH-Approved N95 Filtering Facepiece Respirators by Photometric and Number-Based Test Methods", J. Occ. Env. Health, 8: 23–30, 2011.
11. Penconek, A., P. Drążyk, and A.Moskal, "Penetration of Diesel Exhaust Particles Through Commercially Available Dust Half Masks", Ann. Occup. Hyg. 3:360-373, 2013
12. Penconek, A., A. Jackiewicz, and A.Moskal, "Penetration of Diesel Exhaust Particles (DEPs) through Fibrous Filters Produced Using Melt-Blown Technology", KONA, 32:184-195, 2015.
13. Chase, R. E., G. J. Duszkiewicz, J. F. O. Rickert, D. Lewis, M. M. Maricq and X. Zing. "PM Measurement Artifact: Organic Vapor Deposition on Different Filter Media," SAE paper 2004-01-0967, 2004.
14. Swanson JJ, Kittelson DB. "Factors Influencing Mass Collected During 2007 Diesel PM Filter Sampling." SAE Int J Fuels Lubr; 2(1):718-729, 2009.
15. Satish, S., Swanson, J.J., Xiao, K., Viner, A.S., Kittelson, D.B., and Pui, D.Y.H., "Gravimetric measurements of filtering facepiece respirators challenged with Diesel exhaust", Ann Work Expo Health (2017) 61 (6): 737-747.
16. Burton, K.A, J.L. Whitelaw, A.L. Jones, and B. Davies, "Efficiency of Respirator Filter Media against Diesel Particulate Matter: A Comparison Study Using Two Diesel Particulate Sources", Ann. Occup. Hyg., 60(6), pp. 771-779, 2016.
17. Kvikstad, J.A. "Dust/Mist Respirators in Coke Oven Environments". 3M Job Health Highlights 10(1). 1992.
18. Rozi, T., J. Snyder, D. Novak, "Pilot Study of Aromatic Hydrocarbon Adsorption Characteristics of Disposable Filtering Facepiece Respirators that Contain Activated Carbon." J. Occup. Environ. Hyg. 9:624-629. 2012.

WARNING

This respirator helps reduce exposures to certain airborne contaminants. Before use, the wearer must read and understand the *User Instructions* provided as a part of the product packaging. Follow all local regulations. In the U.S., a written respiratory protection program must be implemented meeting all the requirements of OSHA1910.134, including training, fit testing and medical evaluation. In Canada, CSA standard Z94.4 requirements must be met and /or requirements of the applicable jurisdiction, as appropriate.
Misuse may result in sickness or death. For correct use, consult supervisor and *User Instructions*, or call 3M PSD Technical Service in USA at 1-800-243-4630 and in Canada at 1-800-267-4414.

Personal Safety Division
3M Center, Building 235-2W-70
St. Paul, MN 55144-1000

3M PSD products are occupational use only.

In United States of America
Technical Service: 1-800-243-4630
Customer Service: 1-800-328-1667
3M.com/workersafety
In Canada
Technical Service: 1-800-267-4414
Customer Service: 1-800-364-3577
3M.ca/Safety