Diesel Engine Exhaust

Updated: April 2016

Diesel and gasoline engines are the major sources of power used in motor vehicles. Both are internal combustion engines, but differ fundamentally in terms of their fuel-air mixture preparation and ignition and in the fuels they use. Diesel fuel is composed of petroleum fractions with a higher boiling range than those of gasoline.

Exhaust emissions from combustion engines comprise a complex and varied mixture. These include:

- Gases - Carbon monoxide and nitrogen oxides
- Particles - Elemental and organic carbon, ash, sulfate and metals
- Volatile organic compounds – Benzene
- Semi-volatile organic compounds
- Polycyclic aromatic hydrocarbons (PAHs) - Oxygenated and nitrated PAH derivatives

The exact qualitative and quantitative composition of the exhaust depends on the fuel used, the type and age of the engine, the use of an emission control system, the tuning of the engine, its state of maintenance, and its pattern of use, load, and acceleration.

The following table represents some compounds and classes of compounds in vehicle engine exhaust [IARC].

Gas Phase	Particulate Phase
Acrolein	Heterocyclics and derivatives[a]
Ammonia	Hydrocarbons (C_{14}-C_{35}) and derivatives[a]
Benzene	Inorganic sulfates and nitrates
1,3-Butadiene Formaldehyde	Metals (e.g. lead and platinum)
Formic acid	Polycyclic aromatic hydrocarbons and derivatives[a]

Gas Phase	Particulate Phase
Heterocyclics and derivatives[a]	Heterocyclics and derivatives[a]
Hydrocarbons (C_1-C_{18}) and derivatives[a]	
Hydrogen cyanide	
Hydrogen sulfide Methane	
Methanol	
Nitric acid	
Nitrous acid Oxides of nitrogen	
Polycyclic aromatic hydrocarbons and derivatives[a]	
Sulfur dioxide	
Toluene	

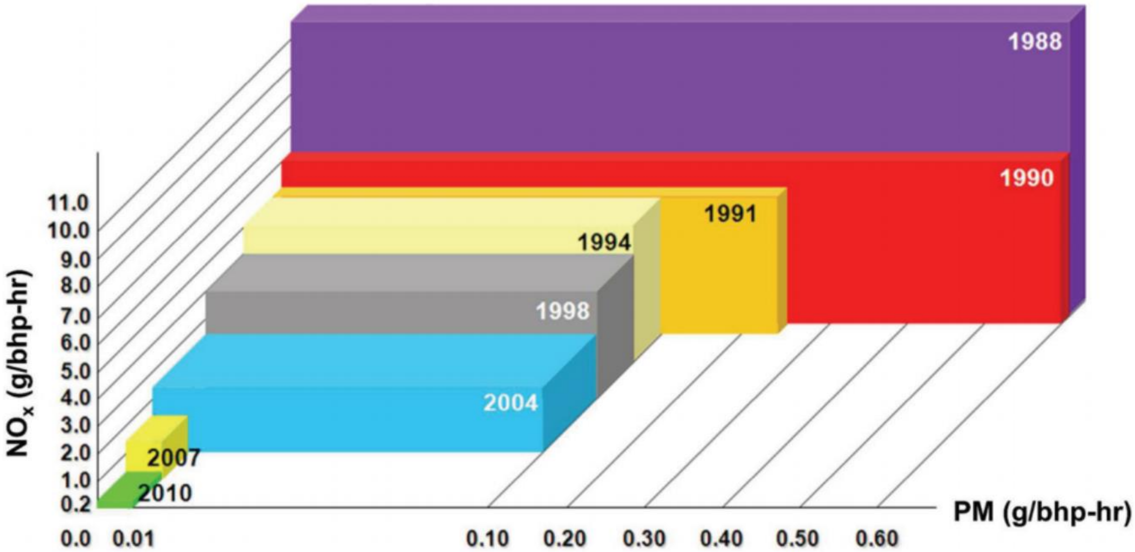
[a] Derivatives include acids, alcohols, aldehydes, anhydrides, esters, ketones, nitriles, quinones, sulfonates, halogenated and nitrated compounds, and multifunctional derivatives.

The emission of particulate matter in the earliest diesel engines was not controlled. Consequently, their exhaust contained large amounts of particulate matter, while gasoline engine exhaust contained higher levels of certain gases such as carbon monoxide [IARC]. As engines developed and improved transitional models were produced with progressively advancing technology and lower emissions of particulates, nitrogen oxides, and hydrocarbons. Modern engine models are characterized by the integration of wall-flow diesel particulate filters and diesel oxidation catalysts, and use of ultra-low sulfur fuel. Concurrently, the quality of diesel fuel has been improved in most parts of the world. New-technology diesel engines have only recently been introduced onto the roads in the USA and Europe [IARC].

New standards and technology have significantly influenced exposure to engine exhaust gases and particles. There is a strong link between emission standards and engine technology in which standards give impetus to new technology and technology enables more stringent standards.

Dramatic changes in diesel engine technology in the past few decades have resulted in > 99% reduction in particulate matter. Since 1998 the unregulated traditional diesel engines or TDE that existed before 1988 have given way to current new technology diesel engines (NTDE)s.

The following illustration presents the evolution of US heavy-duty diesel engines on-road emissions standards, expressed as grams PM or NOx emitted per brake-horsepowerhour (g/bhp-hr) [Hesterberg, 2012].



The changed PM emissions from today's NTDE resemble the PM emissions in contemporary gasoline engine exhaust and compressed natural gas engine exhaust more than those in the older TDE [Hesterberg].

In addition, the quality of fuel has improved with the introduction of new types of fuels such as gas, ultra-low sulfur fuel, and biodiesel – a fatty acids methyl ester made by reacting vegetable oils or animal fats with methanol, usually used in a blend with petroleum diesel.

Usage and Exposure

Combustion engines are used in a variety of off-road vehicles and equipment in different industrial sectors, such as mining, construction and transport. Diesel engines are generally used to power heavy-duty equipment such as bulldozers and forklift trucks, whereas both gasoline and diesel engines are used in lighter vehicles.

Exposure to diesel engine exhaust occurs in many different occupational settings, such as the mining, railroad, construction and transport industries. The main factors that determine the degree of exposure are the size and number of diesel engines in use, the working environment (indoor or outdoor), and the degree of ventilation [IARC].

The most widely used forklifts have an internal combustion engine powered by gasoline, diesel fuel, or compressed natural gas. If the engine is not combusting fuel properly, the exhaust may contain high levels of carbon monoxide. The most dangerous situations occur when forklifts are used in enclosed areas. Newer forklifts with internal combustion engines have on-board sensors that monitor and adjust emissions and have catalytic converters that help reduce emissions [OSHA].

Exposure of the general population to traffic emissions depends upon their proximity to traffic, the volume and characteristics of the traffic, and the presence of previous traffic emissions in regional pollutants [IARC].

Tsai et al. studied cell toxicity of fuels and found that cell mortality from exposure to biodiesel exhaust was “effectively reduced” in comparison to pure diesel fuel exhaust [Tsai].

Another study conducted by Kisin et al. showed that the particles from biodiesel exhaust have a higher mutagenic potency than those of ultra-low-sulfur diesel fuel exhaust [Kisin].

There are few studies on the health effects of NTDE and new fuels and there is limited information about their health effects, but it is clear that occupational exposure and the general pollution from engine exhaust has been reduced or will be dramatically reduced.

Routes of Exposure

Inhalation is the main route of exposure to diesel engine exhaust.

Target organs

Lungs, urinary bladder

Health hazards

Acute effects

Self-asphyxiation using car exhaust was previously a common method of suicide. However, the introduction of catalytic converters in the early 1990s resulted in lower toxicity of car exhaust, particularly carbon monoxide, and there has been a decline in the number of suicide incidents since then [Amos].

Information is limited regarding the potential health effects associated with acute or short-term exposure to engine exhaust. However, available human and animal evidence reveals that acute or short-term episodic exposure to diesel exhaust can cause acute eye, throat, and bronchial irritation, neurophysiological symptoms such as lightheadedness and nausea, and respiratory symptoms such as coughing and phlegm. There is also evidence of an immunologic effect – the exacerbation of allergenic responses to known allergens and asthma-like symptoms [EPA].

Chronic Effects

Information from the available human studies is inadequate for a definitive evaluation of possible non-cancer health effects from chronic exposure to diesel exhaust. However, on the basis of extensive animal evidence, diesel exhaust poses a chronic respiratory hazard to humans. Animal inhalation studies involving chronic exposure show a spectrum of dose-dependent inflammation and histopathological changes in the lungs in several animal species including rats, mice, hamsters, and monkeys [EPA].

Carcinogenicity

Combustion by-products of diesel and gasoline engines represent thousands of chemical components present in the gas and particulate phases. Some of them also have carcinogenic properties. Some chemicals and metals found in diesel and gasoline engine exhaust and their carcinogenicity evaluation are shown in the following table [IARC].

Agent	CAS no.	IARC Evaluation
Metals		
Antimony compounds	1309-64-4 (Trioxide)	2B
Arsenic and inorganic arsenic compounds	007440-38-2	1
Beryllium and beryllium compounds	007440-41-7	1
Cadmium and cadmium compounds	007440-43-9	1
Chromium (VI)	018540-29-9	1
Cobalt and cobalt compounds	007440-48-4	2B
Lead compounds	Inorganic/organic	2A/3
Nickel	Metallic/compounds	2B/1
Organic chemicals		
1,3-Butadiene	106-99-0	1
Acetaldehyde	75-07-0	2B
Benzene	71-43-2	1
Bis(ethylhexyl)phthalate	117-81-7	2B
Ethylbenzene	100-41-4	2B

Agent	CAS no.	IARC Evaluation
Formaldehyde	50-00-0	1
Propylene oxide	75-56-9	2B
Halogenated and other chemicals		
Dioxin/dibenzofurans	1746-01-6 (TCDD)*	1
Polycyclic aromatic hydrocarbons		
Benz[*a*]anthracene	56-55-3	2B
Benzo[*b*]fluoranthene	205-99-2	2B
Benzo[*k*]fluoranthene	207-08-9	2B
Benzo[*a*]pyrene	5-32-8	1
Chrysene	218-01-9	2B
Dibenz[*a,h*]anthracene	53-70-3	2A
3,7-Dinitrofluoranthene	105735-71-5	2B
3,9-Dinitrofluoranthene	22506-53-2	2B
1,3-Dinitropyrene	75321-20-9	2B
1,6-Dinitropyrene	42397-64-8	2B
1,8-Dinitropyrene	42397-64-9	2B
Indeno[*1,2,3-cd*]pyrene	193-39-5	2B
Naphthalene	91-20-3	2B
3-Nitrobenzanthrone	17 117-34-9	2B
6-Nitrochrysene	7496-02-8	2A
2-Nitrofluorene	607-57-8	2B
1-Nitropyrene	5522-43-0	2A
4-Nitropyrene	57835-92-4	2B
Styrene	100-42-5	2B

*TCDD, 2,3,7,8-tetrachlorodibenzodioxin

The NTDE introduced in recent years will influence the pattern of exposure to engine exhaust, but they do not yet dominate on the roads.

In 1988 the International Agency for Research on Cancer (IARC) classified diesel exhaust as probably carcinogenic to humans (Group 2A). An Advisory Group which reviews and recommends future priorities for the IARC Monographs Program has recommended diesel exhaust as a high priority for re-evaluation since 1998 [IARC Press release].

In 2012 IARC concluded that there is currently sufficient evidence for the carcinogenicity of diesel engine exhaust. Diesel engine exhaust causes lung cancer. Positive associations have also been observed between exposure to diesel engine exhaust and cancer of the urinary bladder.

Diesel engine exhaust is *carcinogenic to humans (Group 1)*.

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