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How to reduce black smoke and carbon emissions from diesel engines

GenCat Diesel Particulate Filters

GenCat Engineering Department

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Introduction

Diesel exhaust soot is the visible cloud of black carbon-containing smoke that appears on engine start-up and during normal diesel engine operation. Black carbon is hazardous to health and presents a range of other issues, including visible product contamination and soiling. It is also believed that black carbon is a contributory factor in climate change. This technical paper aims to clarify the issues surrounding exhaust soot and presents information designed to assist in the decision-making process of how best to reduce black carbon emissions from diesel exhausts.

Un-burnt carbon particles, engine oils, debris, soot and ash particulates are known as particulate matter (PM).

What is Particulate Matter (PM)?

In a theoretically perfect combustion, carbon dioxide, water and nitrogen are the end products. In reality, the incomplete combustion of diesel fuel results in emissions that include oxides of nitrogen (NOx), carbon monoxide (CO), carbon dioxide (CO_2), water (H_2O) and unburned hydrocarbons (HC). There are also un-burnt carbon particles, as well as engine oils, debris, soot and ash particulates, which are known as *particulate matter (PM)*.

PM10 are particles from 2.5 microns to 10 microns, PM2.5 are particles less than 2.5 microns.

This *diesel particulate matter (DPM)* is the visible cloud of black smoke that appears from engine start-up and continues to appear when the engine is running. DPMs can be categorised into two groups:

- PM10 - Particles of 2.5 microns to 10 microns, and
- PM2.5 - Particles of less than 2.5 microns in size.

Although most Diesel Particulates are very small, more than 99% are in the sub-micrometre range.

What are the concerns associated with DPM?

Climate change is something that directly affects us all and is just one of the concerns associated with diesel exhaust emissions. The main issues surrounding black carbon soot being:

Long-term exposure can lead to chronic, more serious health problems such as cardiovascular disease and lung cancer.

- **Health** DPM has been identified by health experts as contributing to a variety of lung related illnesses. Exposure to DPM has been linked to acute short-term symptoms such as headaches, nausea, and irritation of the eyes, nose and throat. Long-term exposure can lead to chronic and more serious health problems such as cardiovascular disease and lung cancer.

- **Inhalation** The smallest particles have the worst health implications because of their ability to penetrate deep into lung tissue. They easily bind with other toxins in the environment, thereby increasing the hazards of particle inhalation.

- **Confined Spaces** Machinery operating in confined or enclosed spaces – for example in tunnels, mines, and quarries, or in factories and warehouses where ventilation is limited – pose a greater health risk to operatives and anyone in the vicinity of that equipment.

Diesel exhaust contributes to ozone formation, acid rain, and global climate change.

- **Air Quality** In addition to the health concerns mentioned above, the pollution emitted by diesel engines contributes greatly to air quality problems such as haze and smog, both of which restrict visibility and can cause irritation of the eyes, nose and throat. Furthermore, diesel exhaust fumes contribute to ozone formation, acid rain, and climate change.

- **Contamination** DPM can also contaminate products and packaging in factories and warehouses where DPMs are present in the atmosphere. In the wider environment DPM contaminates foliage and soils buildings, an all too common sight in urban areas.

How can the black smoke be reduced?

Diesel Particulate Filters are designed specifically to reduce particulate emissions.

The industry has been developing innovative ideas to reduce exhaust emissions for many years. A number of solutions are available and these range from Exhaust Gas Recirculation (EGR) to Dual Fuel conversions. The most effective solutions are designed specifically to deal with particulates and can reduce the DPM emissions in the exhaust by up to 99%, from startup. These systems are known as *Diesel Particulate Filters* or Soot Filters.

What is a diesel particulate filter (DPF)?

***Diesel particulate filters** collect the particulate matter in the exhaust stream by means of physical filtration.*

A Diesel Particulate Filter is a device that traps the exhaust stream particulate matter by means of physical filtration. This process is an established, efficient and effective way of removing DPM from the exhaust stream. Once captured, the accumulated DPM must then be dealt with in a safe and secure manner.

All types of filters have a finite capacity. DPFs are no different and must be cleared of the accumulated DPM, either at regular intervals, or during operation. Failure to do so will eventually cause the filter to block. This can damage or destroy the filter and may also damage the engine due to increased backpressure.

There are two solutions to this problem. One is to remove and replace the filter with a fresh one; the second method is to regenerate the filter so it can be reused:

A Non-Regenerative filter, once blocked, must be replaced.

- **Non-Regenerative** Generally constructed from fibre matting in which materials such as steel wool and fibreglass are used. Housed in a steel canister or similar, the DPM is trapped within the fibre matting. When full, the element must be replaced with a clean one. These types of filter have a life of around 300 working hours. Therefore they are suited to low usage applications such as standby generator sets, or on equipment that is used for short periods of time. Systems can also be bypassed so that they are only used when required (e.g. operating in confined spaces such as tunnels or warehouses).

A regenerative filter collects the DPM, the carbon deposits are then burnt away.

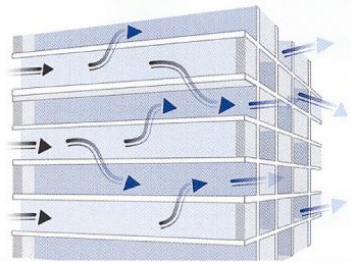

Figure i

- **Regenerative** Commonly produced from ceramic materials such as cordierite or silicon carbide. Constructed as a honeycomb monolith, channels are blocked at alternate ends **(figure i)** forcing the exhaust gasses to flow through the walls between the channels, known as ‘wall-flow’. The particulate matter cannot pass through the walls and is deposited within the channels. As DPM is collected in the filter the carbon deposits are burnt away. This is known as ‘regeneration’. Due to the high temperatures involved in regeneration, these filters are suited to high-usage applications where the exhaust gas temperature (EGT) is high (e.g. prime power generators or high usage materials handling equipment).

Both Non-Regenerative and Regenerative solutions are effective at cold temperatures and capable of trapping up to 99% of DPM. The addition of either type of system will dramatically reduce black smoke at start-up, as well as during normal operation.

Passive and Active regenerative systems

The DPM collected in a regenerative system burns at approximately 600°C, which is a temperature rarely reached in a diesel exhaust system. There are two main solutions to this problem, namely 'active' or ‘passive’ regeneration.

A passive system requires no additional energy inputs and works by lowering the temperature at which the DPM will combust. An example of this is a fuel-borne catalyst, which reduces the combustion temperature to around 280˚C.

An active system uses electric heating or a fuel burning system to increase the temperature in the filter when required and allows regeneration of the filter to occur.

DPF Applications

Diesel Particulate Filters can be fitted to almost any piece of machinery that has a diesel engine.

Diesel Particulate Filters can be fitted to almost any piece of machinery or vehicle, for on or off-road use, that uses a diesel engine, such as:

- **Materials handling equipment**
  Forklift trucks, side loaders and telescopic handlers.

- **Power generation equipment**
  Standby or prime power generators.

- **Construction equipment & non-road mobile machinery (NRMM)**
  Excavators, dumpers and earth moving equipment.

- **On-road vehicles**
  On-road vehicles such as buses, coaches and HGVs.

The table below indicates which types of filters are recommended, based on engine usage and the type of emissions reduction required:

	Standby/ Low usage	Prime/ High usage
PM	Non-regenerative	Regenerative
CO	Catalytic Converter	Catalytic Converter
HC	Catalytic Converter	Catalytic Converter
PM, CO + HC	Non-regenerative + Catalytic Converter	Regenerative + Catalytic Converter

As each application is unique, the above table is for guidance only. GenCat engineers are happy to assist in the selection of appropriate Diesel Particulate Filters or Catalytic Convertors tailored to your specific requirements.

For more information please contact info@gencat.co.uk, or visit our web site at: www.gencat.co.uk

Catalytic Converters

Catalytic converters reduce carbon monoxide (CO), unburned hydrocarbons (HC) and aldehydes.

Catalytic converters are separate systems that reduce carbon monoxide (CO), unburned hydrocarbons (HC) and aldehydes. These exhaust emissions are generally associated with contributing significantly to atmospheric pollution problems and are responsible for irritation to the eyes and respiratory system. They can also cause nausea, headaches and tiredness. These effects are further compounded in enclosed spaces such as warehouses, tunnels and mines. For further information regarding catalytic converters contact info@gencat.co.uk or visit our web site at: www.gencat.co.uk/catalysts

Further Reading

…details the use of diesel exhaust gas after treatment systems such as catalytic converters and diesel soot particulate traps to remove particulate matter.

Health and Safety Guidance 187 HS(G)187

This guide, provides practical advice to employers on how to control exposure to diesel engine exhaust emissions (DEEE's) in the workplace, and so protects the health of employees and others who may be exposed. The guidance also details the use of diesel exhaust gas after treatment systems such as catalytic converters and diesel soot particulate traps to remove particulate matter. ISBN: 0-7176-1662-2. *www.hse.gov.uk*

The Health and Safety Executive (HSE)

The *Diesel Engine Exhaust Emissions* guidelines have recommendations for health protection against exposure to diesel fumes. *www.hse.gov.uk*

Control of Substances Hazardous to Health Regulations 1994 (COSHH)

Employers should make a suitable and sufficient assessment of the risks to the health of employees if they are exposed to diesel fumes. *www.hse.gov.uk/coshh*

Low Emissions Zone (LEZ)

To reduce the pollution into London's air from vehicle exhausts, vehicles such as HGVs, vans, coaches and buses will have to be adapted to meet tightening standards or pay to drive through the capital. In force from February 2008. *www.tfl.gov.uk/roadusers/lez*

Best Practice Guide (BPG)

Fitting particulate filters to non-road mobile machinery (NRMM) reduces particulate emissions.

Outlines guidance for the control of dust and emissions from construction sites, paying particular attention to off-road machinery and plant. The guide also suggests fitting particulate filters to non-road mobile machinery (NRMM) to reduce particulate emissions. *www.alg.gov.uk*

Department for Transport

The *Emission Standards for Non-Road Mobile Machinery* is dedicated to reducing emissions from NRMM is part of the EU's strategy to reduce air pollution. These legislations tighten emissions from diesel engines. Directive 97/68/EC, 2002/88/EC & 2004/26/EC. *www.dft.gov.uk*

Further Information

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GenCat engineers are happy to assist in providing specific information regarding our range of effective Diesel Particulate Filters and Catalytic Converters, and can advise or provide quotations for any of your specific requirements or applications.

Please contact us by email at info@gencat.co.uk, or by telephone on +44 (0) 20 7998 7702. Further information can also be found on our web site at www.gencat.co.uk

Thank you for you interest in this paper, we hope it has proved useful in increasing your understanding of the issues surrounding DPFs, and the solutions available to address those issues. We welcome any comments, feedback or suggestions you may have.