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S-Series Catalytic Diesel Particulate Filters



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Introduction

Diesel particulate matter (DPM) is probably the most troublesome emission from the diesel engine. Due to its sub-micron particle size, DPM is almost totally respirable. Elevated concentrations of DPM, which may accumulate in the ambient air, present a serious health concern and are the subject of increasingly more stringent environmental and occupational health regulations worldwide.

Nett Technologies designed the S-Series particulate filters to effectively control DPM emissions from heavy-duty engines in such applications as mining, tunneling, ports and rail yards, buses, trucks, and municipal vehicles. The filters utilize ceramic wall-flow monoliths which physically capture the particulates. The monoliths are coated with a catalyst which lowers the soot combustion temperature and facilitates self-regeneration of the filter under elevated exhaust temperatures. The exhaust temperatures needed for proper filter operation are typically encountered in most heavy-duty diesel engine applications. Nett S-Series soot filters typically provide an over 90% reduction in DPM emissions and total elimination of the black smoke.

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What is Diesel Particulate Matter?

Diesel particulate matter, as defined by the US EPA regulations and sampling procedures, is a complex aggregate of solid and liquid material. Its origin is carbonaceous particles generated in the engine cylinder during combustion. The primary carbon particles form larger agglomerates and combine with several other, both organic and inorganic, components of diesel exhaust. Generally, DPM is divided into three basic fractions:

- Solids - dry carbon particles, commonly known as soot,
- SOF - heavy hydrocarbons adsorbed and condensed on the carbon particles, called Soluble Organic Fraction,
- SO₄ - sulfate fraction, hydrated sulfuric acid.

The actual composition of DPM will depend on the particular engine and its load and speed conditions. “Wet” particulates can contain up to 60% of the hydrocarbon fraction (SOF), while “dry” particulates are comprised mostly of dry carbon. The amount of sulfates is directly related to the sulfur content of the diesel fuel.

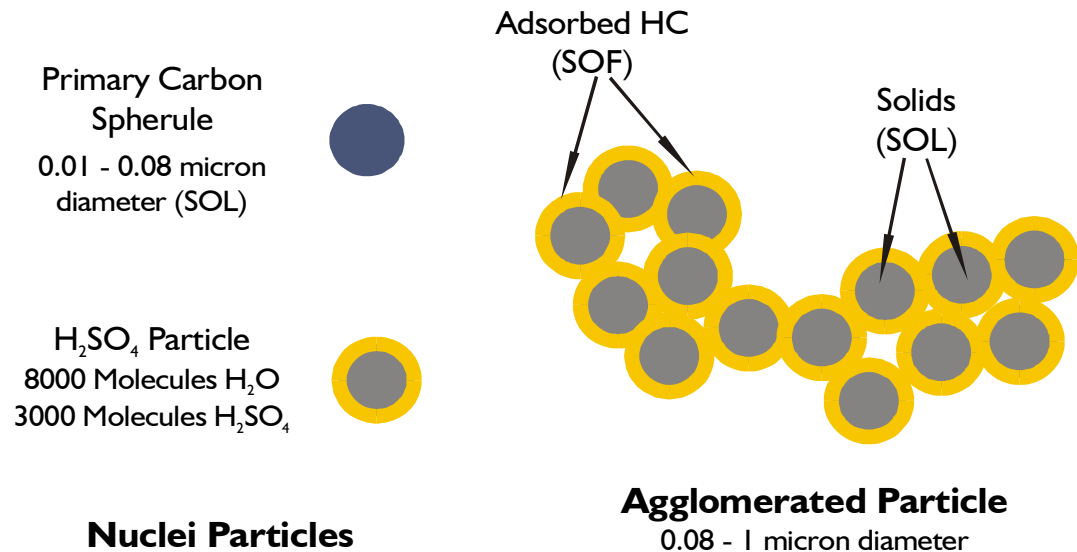


Figure 1. Schematic Composition of Diesel Particulate Matter

Diesel particulates are very fine. The primary (nuclei) carbon particles have a diameter of 0.01 - 0.08 microns, while the agglomerated particles diameter is in the range of a few microns. As such, diesel particulate matter is almost totally respirable and has a significant health impact on humans. It has been classified by several government agencies as either “human carcinogen” or “probable human carcinogen”. It is also known to increase the risk of heart and respiratory diseases.



How the Filter Works

Nett[®] S-Series diesel filters utilize cordierite or silicon carbide wall-flow monoliths to trap the soot produced by heavy-duty diesel engines. The cylindrical filter element consists of many square parallel channels running in the axial direction, separated by thin porous walls, as shown in Figure 2.

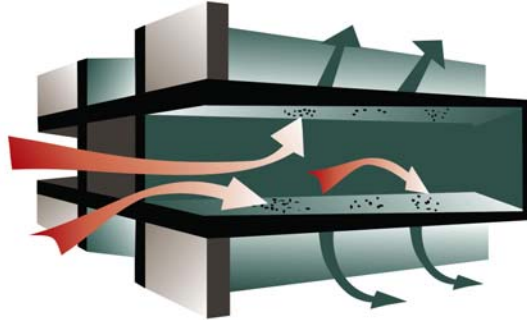


Figure 2. Gas Flow in the Filter Monolith

The channels are open at one end and plugged at the other, which forces the particle laden exhaust gases to flow through the walls. Gas is able to escape through the pores in the wall material. Particulates, however, are too large to escape and are trapped in the filter walls and in the inlet channels.

A proprietary noble metal catalyst is coated onto the inside surface of the filter monolith. The catalyst lowers the soot combustion temperature allowing the filter to regenerate. The accumulated soot is oxidized in the filter during regular operation of the engine. For about 25-30% of the engine operating time, the exhaust temperatures must be at least 275-300°C (530-575°F) for proper filter regeneration when ULSD (ultra-low sulfur diesel) fuel is used. The exact temperature requirements change with engine technology, with installations on older, dirty engines requiring higher exhaust temperatures for regeneration. For example, filters installed on older off-highway engines with high DPM emissions (e.g., ≥ 0.30 g/bhp-hr) may require temperatures of 325-400°C (615-750°F). The regeneration also depends on other factors, such as the vehicle duty cycle, filter sizing and type of diesel fuel used. ULSD fuel (S < 15 ppm wt.) is now widely available and should be used whenever possible with any diesel particulate filter.

Usually, a recording of the engine exhaust gas temperature is taken before the installation of an S-Series filter. In applications where the exhaust temperatures are too low or high temperatures are seen only for very short periods, the filter may cause excessive engine back pressure. In extreme cases, clogging of the unit may occur.

The catalyzed filter monolith is wrapped in a fiber mat and packaged into a stainless steel housing, which is installed in the vehicle's exhaust system.



Filtration Efficiency and Pressure Drop

The soot filtration efficiency of the Nett[®] S-Series catalytic diesel filter increases with the soot loading in the unit. Even at low soot loads the filter efficiency exceeds 90% (blue line in Figure 3). The visible smoke is completely eliminated by the filter, resulting in a dramatic improvement of smoke opacity readings.

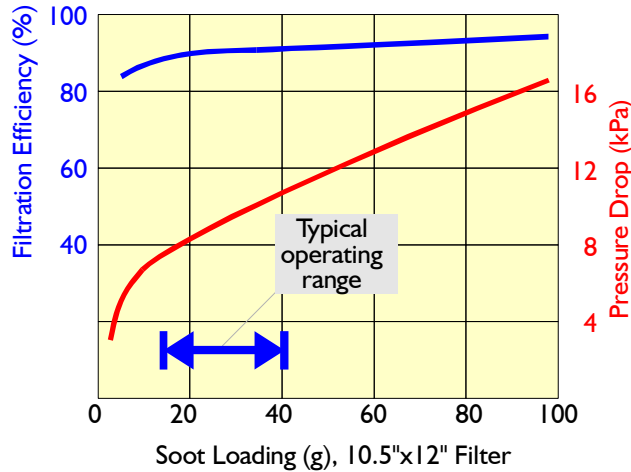


Figure 3. Typical Filtration Efficiency and Pressure Drop

Typical exhaust gas pressure drop on a properly regenerating filter is between 5 and 10 kPa (20-40" H₂O). There is a relationship between the exhaust gas temperature and the filter pressure drop. Applications with higher exhaust temperatures regenerate better, accumulate less soot in the filter, and experience lower pressure drop.

The filter pressure drop is also influenced by the engine-out DPM emissions. Dirty engines with high soot emissions require that more DPM is captured and oxidized in the filter, resulting in higher average soot loading and pressure drop. For this reason, filters are likely to work at a higher pressure drop when installed on high polluting engines.



Gas Phase Performance

Due to the presence of the oxidation catalyst, reductions in carbon monoxide (CO) and hydrocarbon (HC) emissions are also observed in the filter. The gas phase performance of the Nett® S-Series filters is similar to that of a standard diesel oxidation catalyst, as illustrated in Figure 4.

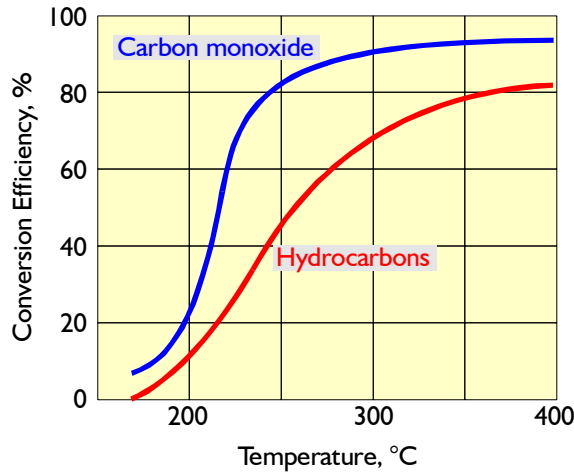


Figure 4. Conversion of CO and HC in Nett® S-Series Filter

The oxidation of soot in the filter requires quantities of oxygen. At moments, the concentration of oxygen in the filter may be insufficient for the reaction with CO. Therefore, the conversion efficiency of carbon monoxide may deteriorate when filters with high soot loading are regenerated.

Nett® S-Series filters do not change the total nitrogen oxides (NO_x) emissions from diesel engines.

Catalyst Types

Depending on the application, Nett® particulate filters can be ordered with one of the following catalyst types:

- Standard catalyst (SF and SC)
- Sulfate-suppressant catalyst (SE and SS)
- NO₂ suppressant catalyst (SN and SO)

The standard catalyst provides the best activity and the lowest regeneration temperature requirements. However, if high sulfur fuels are used, the catalyst may generate sulfate particulates at elevated temperatures. As a general guideline, the standard catalyst should be used in the following applications:

- All applications with ultra-low sulfur fuel (S < 15 ppm).
- All applications, regardless of fuel sulfur level, where sulfates are not considered a particulate emission and are not regulated. Examples of such applications include underground non-coal mining in the U.S. (DPM exposures measured as total carbon) or occupational health environments in Germany (particulates measured as elemental carbon).



The sulfate-suppressant catalyst eliminates the sulfate creation at the expense of a somewhat increased regeneration temperature requirement, typically by 10-15°C (20-30°F). This catalyst is used for applications with higher sulfur fuels (S > 15 ppm) which are sensitive to sulfate particulate emissions, such as most urban buses operated on high sulfur fuels.

Substrate Types

Nett® diesel particulate filters are available with two types of substrates:

- Cordierite substrates
- Silicon carbide (SiC) substrates

Cordierite substrates perform satisfactory in most heavy-duty applications with high exhaust temperatures. However, in low-temperature applications which may experience “uncontrolled regenerations”, cordierite is more susceptible for damage from high temperatures, such as melting. Silicon carbide has higher maximum operating temperature limits and better durability in high temperature applications. Disadvantages of SiC include higher weight and higher cost.

Standard Models of Nett S-Series Filters

Standard models of cordierite and SiC diesel particulate filters are listed in Table 1 and Table 2, respectively. Sizing for particular engines and applications should be consulted with our office before ordering.

Table 1 Nett® Diesel Particulate Filters: Cordierite Substrates (SF/SE)

Model*	Overall Dimensions	
	Diameter mm (in)	Length mm (in)
SF500	158 (6.2)	375 (14.8)
SF700	206 (8.1)	470 (18.5)
SF900	245 (9.6)	648 (25.5)
SF1000	282 (11.1)	678 (26.7)
SF1050	302 (11.9)	726 (28.6)
SF1100	302 (11.9)	777 (30.6)
SF1200	323 (12.7)	803 (31.6)
SF1500	399 (15.7)	870 (34.2)
SF1800	678 (18.7)	922 (36.3)
SF2000	526 (20.7)	972 (38.2)

* Model numbers in the table refer to standard catalysts. For sulfate-suppressed catalysts, replace SF with SE in the model number. For example, the SF500 filter with sulfate-suppressed catalyst coating has a model number SE500.

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Table 2 Nett® Diesel Particulate Filters: Silicon Carbide (SC/SS)

Model*	Overall Dimensions	
	Diameter <i>mm (in)</i>	Length <i>mm(in)</i>
SC2004	175 (6.9)	434 (17.08)
SC2006	203 (8.2)	475 (18.7)
SC2008	243 (9.6)	564 (22.2)
SC2011	281 (11.1)	602 (23.7)
SC2013	302 (11.9)	615 (24.2)
SC2505	175 (6.9)	485 (19.08)
SC2507	203 (8.2)	526 (20.7)
SC2510	243 (9.6)	615 (24.2)
SC2514	281 (11.1)	653 (25.7)
SC2516	302 (11.9)	665 (26.2)
SC3008	203 (8.2)	577 (22.7)
SC3006	175 (6.9)	545 (21.45)
SC3012	243 (9.6)	665 (26.2)
SC3017	281 (11.1)	704 (27.7)
SC3019	302 (11.9)	716 (28.2)

* Model numbers in the table refer to standard catalysts. For sulfate-suppressed catalysts, replace SC with SS in the model number. For example, the SC2011 filter with sulfate-suppressed catalyst coating has a model number SS2011.

Custom housing designs are available to fit any engine configuration. A filter control box including exhaust temperature and pressure drop gauges to monitor the filter performance is also available.

Sizing Charts

Sizing charts for standard models of cordierite and SiC diesel particulate filters are listed in Table 3 and Table 4, respectively. Sizing for particular engines and applications should be consulted with our office before ordering.

Due to technology progress and stringent emissions regulation, engine-out PM levels from modern diesel engines are much lower than PM levels 10 years ago. The maximum engine power for S-Series filters in the sizing charts below apply to more recent model year engines.



Table 3 Nett® Diesel Particulate Filters: Cordierite Substrates (SF/SE)

Model*	Max. Engine Power *	
	kW	hp
SF500	30	40
SF700	60	80
SF900	120	160
SF1000	165	220
SF1050	195	260
SF1100	224	300
SF1200	270	360
SF1500	420	560
SF1800	600	800
SF2000	745	1000

* The max. power applies to engines with engine-out PM of 0.05g/bhp-hr

Table 4 Nett® Diesel Particulate Filters: Silicon Carbide (SC/SS)

Model*	Max. Engine Power *	
	kW	hp
SC2004	41	55
SC2505	52	70
SC2006	56	75
SC3006	60	80
SC2507	71	95
SC2008	78	105
SC3008	82	110
SC2510	101	135
SC2011	108	145
SC3012	119	160
SC2013	127	170
SC2514	138	185
SC2516	156	210
SC3017	168	225
SC3019	190	255

* The max. power applies to engines with engine-out PM of 0.05g/bhp-hr

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Life Span and Durability

Catalyzed ceramic particulate filters have been used in underground mining applications for many years. The mining experience indicates that filters installed on properly selected engines have life spans of 8,000 to 12,000 engine hours. In retrofit highway applications, catalyzed filters have been demonstrated to last for more than 240,000 km (150,000 miles). The filter life span, however, may be shortened due to engine maintenance problems and/or improper duty/regeneration cycle. For example, excessive heat release, which may occur during the regeneration of a soot-overloaded unit, may cause catastrophic damage to the ceramic filter monolith.

The S-Series filter regeneration and durability can be negatively influenced by the following factors:

- leaking injectors or dirty intake air cleaners
- excessive engine oil consumption or presence of lube oil in the exhaust gas
- changes in the vehicle duty cycle resulting in lower exhaust gas temperatures.

Nett Technologies Inc. has a corporate policy of continuous product development. Specifications are subject to change without notice.