# Influence of Gasoline Particulate Filter Technology on Meeting Future Emission Standards

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## ABSTRACT

The Gasoline Particulate Filter (GPF) has emerged as a critical component in the global strategy to reduce particulate emissions from spark-ignition (SI) engine vehicles. With increasingly stringent emissions legislation worldwide - specifically focusing on particulate mass and particulate number (PN) thresholds in both laboratory and Real Driving Emissions (RDE) testing - the GPF offers a robust and reliable means to meet compliance while safeguarding public health and contributing to environmental protection. As Brazil is aligning more closely with leading global emissions norms, the implementation of GPF technology in domestic and exported passenger vehicles is not only beneficial but will become essential. This article explores the formation of particulates in SI engines, the technical effectiveness of GPFs in capturing fine particulate matter and the challenges associated with GPF integration and control. State-of-the art GPF technology is explained, giving an insight into its evolution and tailpipe emissions optimization potential. The paper also evaluates GPF's potential role in helping Brazil meet its future regulatory goals and its contribution to cleaner urban air and global sustainability objectives.

## INTRODUCTION

PARTICULATE EMISSIONS – Historically, particulate emissions have been associated primarily with diesel engines, due to the high soot output caused by inhomogeneous mixture conditions. However, with the widespread adoption of Gasoline Direct Injection (GDI) technology in spark-ignition (SI) engines driven by the need for improved fuel economy and lower $CO_2$ emissions - a new challenge has emerged: increased particulate emissions.

Particles generated in SI engines consist of volatile species like sulphates, nitrates, and organic elements as well as solid species like carbonaceous fraction and ash [1]. The carbonaceous fraction, better known as soot, accounts for the vast majority of total particulate matter (PM).

Soot formation is a complex mix of chemical and physical phenomena. Pyrolysis is the primary process of particle formation. During pyrolysis fuel molecules break up forming radicals and organic compounds that react further to polycyclic aromatic hydrocarbons (PAHs), known as soot precursors. The soot precursors become primary particles after passing through a nucleation process. Subsequently, the primary particles combine with each other in the process of agglomeration, in which particles collide and stick, in this way forming larger particles [2].

Among many parameters classifying PM, one of the most important is the particulate size distribution. Particulates emitted from combustion engines can be sorted into two modes: nucleation particles with sizes smaller than 50 nm and agglomeration particles of sizes in the range of 50-200 nm [2]. Typical overall SI engine particulate size distribution ranges between 10-200 nm with peak concentration between 20-100 nm [3].

Several combustion parameters in an SI engine are favoring or hindering the soot formation. The hardware layout, especially the fuel injector layout and position are big influencing factors for the spray quality and the mixture homogeneity as well as the wall wetting of combustion chamber components [4].

The chemical composition and physical properties of the fuel also have a big influence on PM formation. Multiple studies indicate a very strong link between the aromatic content of the fuel and the engine PM emissions [5] [6] [7]. Ethanol which is widely used in Brazilian fleet is known for its soot reduction potential. Oxygenates like alcohol have a hydroxyl group (-OH), which promotes the oxidation of soot precursors and as a result decrease the PM emissions [8] [7] [9]. Some physical fuel characteristics, which influence the mixture formation process also have effect on soot emission. The higher the enthalpy of vaporization of the fuel, the more energy is required to evaporate it, which has especially strong influence in cold start and low temperature operating conditions. As a result, increasing enthalpy of evaporation, which happens with ethanol blending, tends to increase the PM emissions on a physical path [10].

Moreover, the soot formation is influenced by the air-fuel ratio with rich mixtures promoting soot formation by several orders of magnitude as the oxygen concentration is too low for oxidation of soot precursors and soot particles. The temperature of the combustion chamber components as well as the mixture also have a significant impact. Low temperatures during cold start and warm up hinder the fuel evaporation and air-fuel mixing, resulting in heterogeneous mixture and fuel-rich areas. Calibration parameters like injection pattern and rail pressure can be levers to optimize the raw soot emission [8].

HEALTH AND ENVIRONMENTAL EFFECTS OF PARTICULATE MATTER – The health implications of fine PM are profound. These particles (especially ultra-fine nucleation particles) can penetrate deep into the lungs and even enter the bloodstream, contributing to respiratory illnesses, cardiovascular diseases, and cancer. The World Health Organization (WHO) has classified airborne particulates as Group 1 carcinogens [11], which contribute to 7-10 million premature deaths annually. It is estimated that about one million deaths per year are avoided thanks to adoption of particulate filters [12].

Beyond health, particulates also contribute to climate change. Combustion engines emit jet-black soot particles, which effectively absorb sunlight and transfer the heat to the atmosphere. The global warming potential can be quantified in $CO_2$ equivalence ratio. According to detailed considerations by Mayer et al. [12] the instantaneous warming of 1 kg of emitted soot corresponds to the warming effect of $10^6$ kg of $CO_2$. Due to shorter residence time in atmosphere, the resulting average $CO_2$:soot equivalence can be estimated to 1:2000. There are now more than 500 million vehicles with installed particulate filters worldwide which have already prevented approximately 0.5 Mt of soot annually, an equivalent of 1000 Mt $CO_2$ – approximately 3% of the total global emission of $CO_2$.

GPF is a key technology for controlling particulate emissions from SI engines, which is essential for both public health and climate protection.

## GASOLINE PARTICULATE FILTER

The GPF is an advanced aftertreatment device installed in the exhaust system downstream of the three-way catalytic converter (TWCC). It is designed to trap and retain PM from the exhaust gases of SI engines.

A wall-flow GPF has a monolithic structure and consists of an array of axial parallel channels that are alternatively plugged at each end. The exhaust gas flowing into the rectangular channel cannot flow straight through it and thus has to flow across the porous wall into the outlet channel. Figure 1 schematically shows the exhaust gas flow regime inside the GPF.

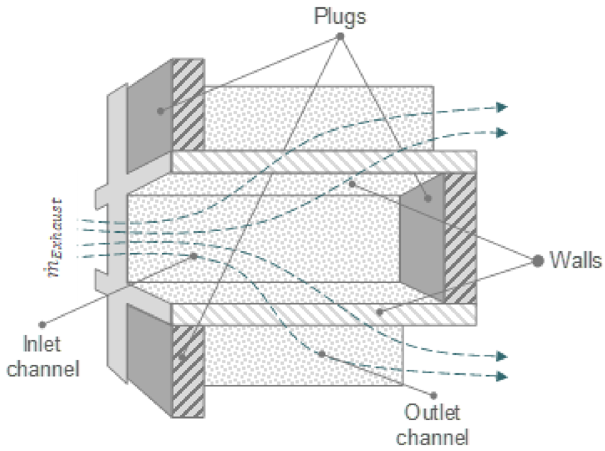


Figure 1. Channel flow of the GPF

Due to the wall porosity the particles are trapped inside the filter, reducing the tailpipe emissions. Filtration relies on four main mechanisms: diffusion, interception, inertial impaction, and sieving (see Figure 2).

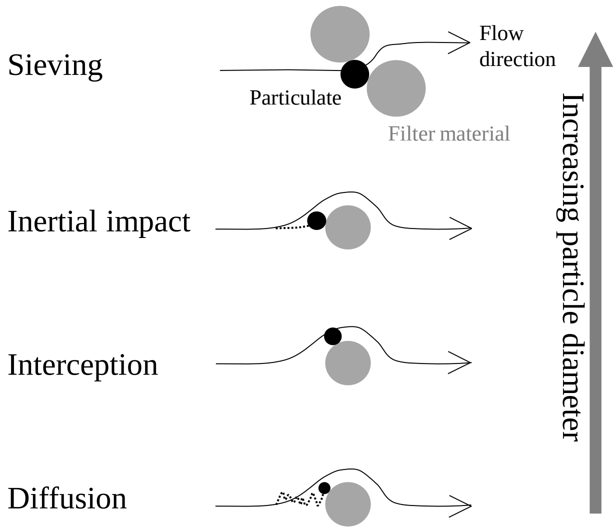


Figure 2. Filtration mechanisms [2]

Very small particles deviate from the flow line due to the Brownian motion and move towards the filter medium where they are collected. Interception occurs when the particle follows the gas stream but still comes sufficiently close to a filter medium to adhere to it. When the particle is large enough so that when the flow is displaced by the filter medium, the particle keeps its original course because of its inertia and is retained by the obstacle it encounters. The last mechanism is sieving and occurs when the particle is too big to fit inside the pore and to flow through it [2].

Filtration is initially realized by the monolith material, and it is referred to as depth filtration, because particles are trapped inside the wall. This filtration mode is characterized by a non-linear and rapid increase of pressure drop with the soot load, caused by the modification of permeability of porous material. However, when the soot load of the filter increases, the available storage space in the monolith wall is used up and the particles form a layer on top of the porous wall. Such filtration is called cake filtration and is characterized by fairly linear increase of pressure drop, caused by inlet channel section narrowing and the filtration surface reduction, associated with the growth of the soot cake [13]. Figure 3 illustrates the differences between these stages of filtration.

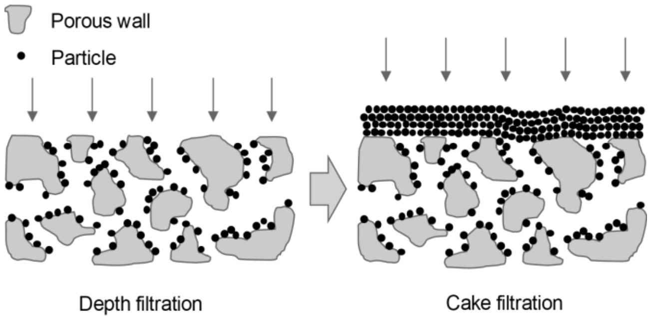


Figure 3. Depth and cake filtration

## EVOLUTION OF GPF TECHNOLOGY

The first mass produced vehicle equipped with GPF was launched by Daimler in 2014. Ever since the introduction of this technology, GPFs have evolved rapidly. Main development target is the minimization of pressure drop combined with high filtration efficiency. As an additional component in the exhaust system, the GPF adds flow resistance and therefore increases the backpressure of the engine. High pressure drop over the exhaust system can lead to decreased engine performance and fuel economy while higher residual gas rates in the combustion chamber can lead to combustion instability.

Early studies regarding GPF designs for GDI applications focus on cell density, web thickness and wall porosity to optimize the tradeoff between pressure drop and filtration efficiency. Results from Boger et al. [14] show that increasing the filtration efficiency directly correlates to higher pressure drop. First generation GPFs with low milage only provided filtration efficiencies below 70% in empty state. Nevertheless, filtration efficiency increases sharply with accumulation of soot or ash, therefore aging or slight soot load in the GPF is generally advantageous to its main function.

Apart from GPF integration as an add on component in the exhaust system, GPFs with catalytic coating were introduced. Coated GPF (cGPF) is often referred to as a four-way catalytic converter, because it reduces the nitrogen oxides ($NO_x$), oxidizes carbon monoxide (CO) and unburned hydrocarbons (HC) as well as traps PM. The solution with coating can be beneficial from a packaging perspective, as it can replace some of the TWCC volume, utilizing the given space more efficiently, reducing the number of components and simplifying the packaging. Additionally, the catalytic coating promotes the soot oxidation process, which is beneficial especially in lower regeneration temperatures. However, it comes at the expense of increased pressure drop and decreased thermal resistance during the soot oxidation process. Additionally, the soot and ash load can mechanically cover the effective area, decreasing the chemical conversion efficiency.

Advances in GPF technology brought a considerable improvement in the filtration efficiency without increasing the pressure drop to fulfil more stringent emission legislations. While early first generation GPFs had statistically uniform distributed pore sizes, advanced GPF designs avoid the tradeoff between pressure drop and filtration efficiency with modified pore entries at the surface layer. A schematic comparison between the microstructure of first and second generation GPFs is given in Figure 5. Very small pore sizes at the entry lead to a quick buildup of a soot cake enabling effective cake filtration already at low loading states and avoiding the deep bed penetration of particles. Hence the rapid increase of pressure drop with increasing soot load is avoided [15]. The change in pressure drop in empty state is only marginally changed. The parts measured by FEV selected for comparison between two generations even show a slight decrease in flow resistance without the soot load. Figure 4 shows the results of this comparison displaying the pressure drop and the filtration efficiency based on the soot loading state.

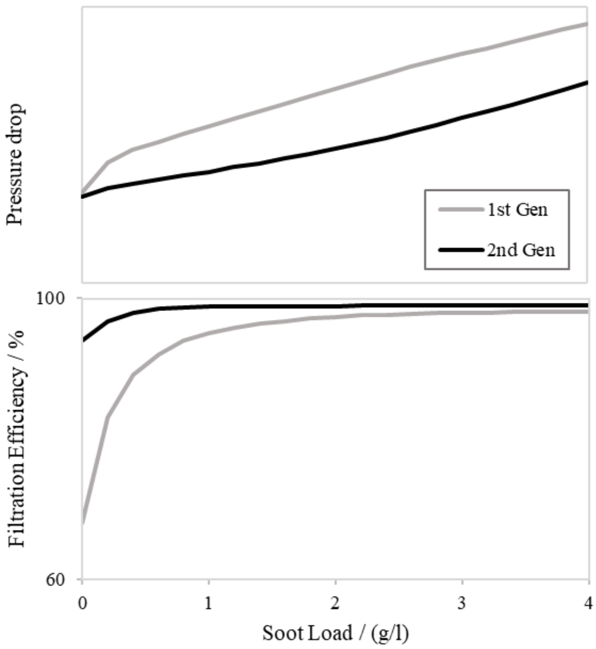


Figure 4. Comparison of filtration efficiency and pressure drop over soot load for old and new generation of GPF

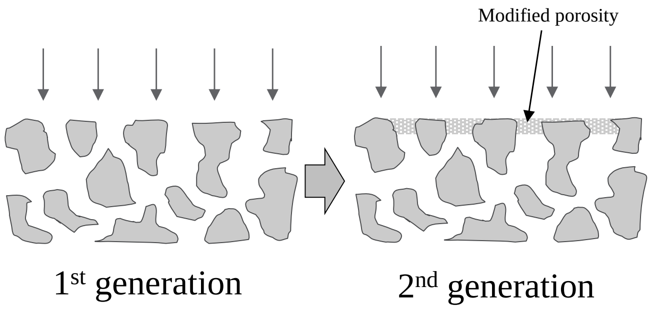


Figure 5. Schematic difference between old and new generations of GPF [16]

## IMPACT OF GPF ON EMISSIONS

GDI technology for SI engines was established to improve fuel economy compared to port fuel injection (PFI) but comes with a penalty for mixture preparation. Decreased homogeneity of the air-fuel mixture leads to significant raw particulate emissions produced by GDI engines [17]. Several studies assessed the potential for particulate emission reduction by hardware and calibration measures but still GPFs proved to be essential to safely fulfil particulate emission limits in many markets and are nowadays well known in passenger vehicle applications. Figure 6 shows the statistical distribution of PN emissions in WLTC based on the engine displacement for vehicles with and without GPF in the European market. All tested vehicles equipped with GPF are below the legal limit for PN while vehicles with low power to wight ratio are overstepping PN limit without GPF.

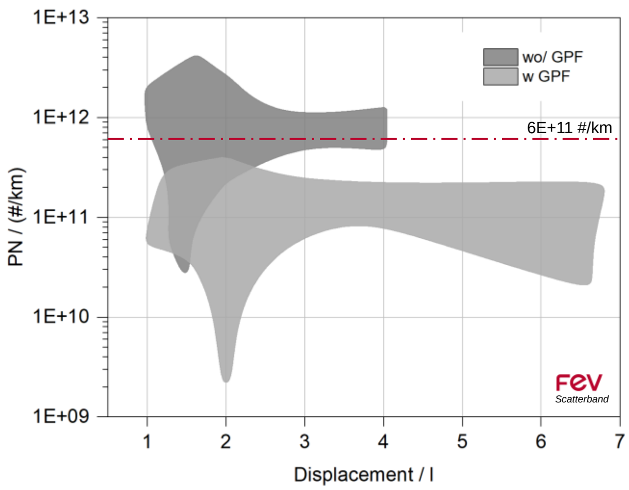


Figure 6. Particulate number over engine displacement in WLTC

While test conditions in WLTP are strictly defined regarding the driving profile, temperatures, and test-fuels, PN emissions get much more critical considering influences that are valid in RDE conditions [18]. A study from Görgen et al. [19] assessed the influence of RDE conditions on the PN Emissions. This study statistically quantified several RDE influences, displaying motivation for GPF during early stages of European 6d Temp legislation. Figure 7 shows how the variations in fuel composition, payload, temperature and driving style affect the PN result in RDE compared to laboratory conditions of WTLP. Displayed PN reduction shows how even the first generation GPFs with relatively low filtration efficiency contributed to achieving the particulate limits.

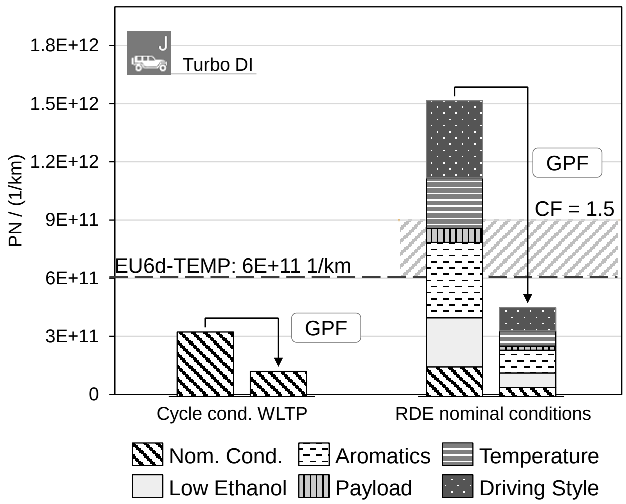


Figure 7. PN emissions with and without a GPF with RDE influences [19]

The effectiveness of a state-of-the-art GPF for different sizes of particulates has been assessed by Dorscheidt et al. [3]. In an empty state the GPF is characterized by remarkably high level of filtration efficiency for small nucleation mode particles in a wide range of engine operating points while the filtration efficiency for larger agglomeration mode particles sharply increases with the volume flow based on the deep bed filtration. With soot or ash loading enabling the cake filtration, the overall filtration efficiency further increases.

Figure 8 shows a comparison of particulate mass and number results from an emission cycle driven with a vehicle equipped with a modern GDI engine and state-of-the-art GPF. Three exhaust system variations are evaluated. The first test was driven with a GPF monolith removed, the second one with a brand new GPF without any stabilization milage accumulated, and the third one with GPF aged until its full-useful-life (FUL). The first graph shows the vehicle speed trace for all three driven cycles. The second one depicts integrated modal particulate mass diagrams. A mass emissions reduction of 89% is achieved already with a completely new GPF. A further reduction is accomplished over the accumulated milage, reaching 98% decrease for a FUL system, due to ash layer build up. Considering the third diagram which shows cumulated PN emissions, an excellent result of 99% drop is achieved directly with a new part. A stronger reduction of PN in comparison to mass comes from very good filtration efficiency for ultra-fine nucleation mode particles. Filtration slightly decreases for agglomeration mode particles, which have a bigger mass, therefore they are more highly represented in mass-based considerations. The levels of tailpipe PN concentrations are cut by 99.7% with an aged system, and are so small, that they are even lower than PN concentration in ambient air in areas that are considered to have air quality.

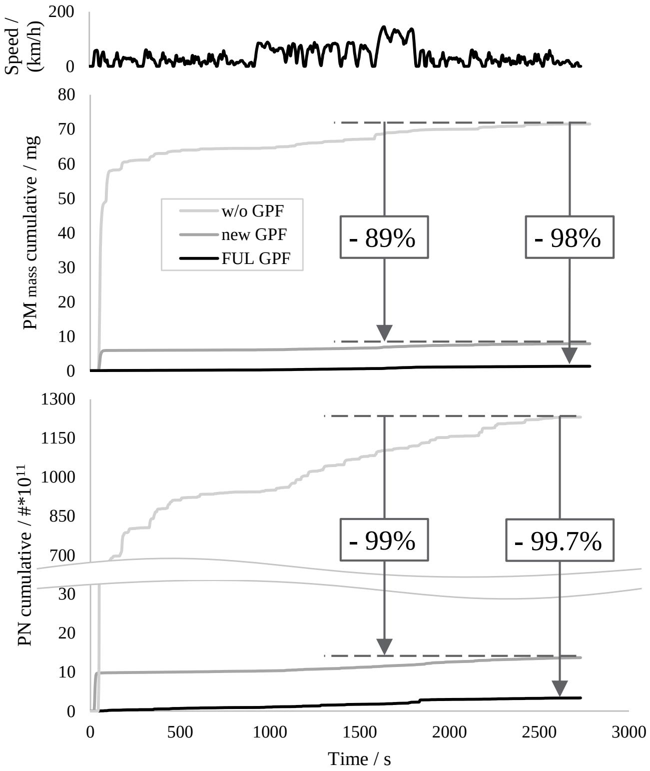


Figure 8. PN and PM mass tailpipe emissions during chassis dyno emission tests (without GPF; new GPF; FUL GPF)

## EMISSION LEGISLATION – GLOBAL TRENDS

REGULATORY FRAMEWORKS IN KEY MARKETS – global trend to decrease the impact of PM on air quality.

European Union – The EU has pioneered particulate emission limits for gasoline engines, starting with the Euro 6d Temp standard, which introduced a particulate number (PN) limit of 6×10¹¹ particles/km. This requirement combined with RDE effectively mandated the use of GPFs for compliance with European standards since 2017. The next step towards stricter particulate standards included in Euro 7 legislation coming into force in late 2026 aims at extending the lower size limit of counted particulates from 23 nm to 10 nm, driving the further development of GPF technology.

China – China 6 emissions standards mirror EU regulations closely, with PN limits applying from the outset and focus on real-world driving compliance. This has led to widespread GPF adoption in the Chinese market. With China 7 regulation it is expected that particulate standards will be further tightened.

India – India's Bharat Stage VI norms also follow the EU model, including PN limits and RDE testing in phased implementation.

United States – The U.S. Environmental Protection Agency (EPA) has traditionally focused on PM mass rather than number. Current Tier 3 regulation limits the mass to 3 mg/mile, which proved to be achievable without GPF. However, the introduction of Tier 4 regulations effective from model year 2027 are decreasing particulate limits down to 0.5 mg/mile, which according to EPA's considerations is equivalent to European limit of 6×10¹¹ particles/km [20]. Stricter mass limit combined with new cold start -7°C FTP procedure aims to encourage automakers to equip U.S.-market vehicles with GPFs [21].

IMPLICATIONS FOR BRAZIL – Brazil, as a follower of global emissions trends, currently does not enforce PN limits. The current emission regulation PROCONVE L8 limits PM emissions from 6 mg/km for highest BINs down to 2mg/km in lowest BINs (see Figure 9). These limits can be achievable for some engines using advanced engine-out emission optimization, without GPF. However, with the future PROCONVE L9 standards, there is strong anticipation that stricter PM and possibly PN limits will be introduced. These may include RDE requirements, pushing OEMs to adopt GPF technology in Brazilian market.

| Category | | | Level | NMOG+NOx (mg/km) | CO (mg/km) | PM (1) (mg/km) | Aldehydes (2) (mg/km) | $NH_3$ (3) ppm | EVAP (2) (g/test) | Refueling (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|
| Diesel LCVs | | | 320 | 320 | 1000 | 20 | - | 10 | - | 50 |
| | | | 280 | 280 | 1000 | 20 | - | | - | |
| | | | 250 | 250 | 1000 | 20 | - | | - | |
| | | | 220 | 220 | 1000 | 10 | - | | - | |
| | | | 200 | 200 | 1000 | 10 | - | | - | |
| | | | 170 | 170 | 1000 | 9 | - | | - | |
| | Spark Ignition LCVs (test mass > 1700kg) | | 140 | 140 | 1000 | 6 | 15 | | 0,5 | |
| | | | 110 | 110 | 1000 | 6 | 15 | | | |
| | | Spark Ignition LPVs and LCVs (test mass < 1700kg) | 80 | 80 | 1000 | 6 | 15 | | | |
| | | | 70 | 70 | 600 | 4 | 10 | | | |
| | | | 60 | 60 | 600 | 4 | 10 | | | |
| | | | 50 | 50 | 600 | 4 | 10 | | | |
| | | | 40 | 40 | 500 | 4 | 10 | | | |
| | | | 30 | 30 | 500 | 3 | 8 | | | |
| | | | 20 | 20 | 400 | 2 | 8 | | | |
| | | | 0 | 0 | 0 | 0 | 0 | | 0 | 0 |

Where:
LPV = Light Passenger Vehicle
LCV = Light Commercial Vehicle, including vehicles with special characteristics for off-road
(1) Applicable to Diesel vehicles and spark ignition vehicles with direct injection
(2) Applicable to spark ignition vehicles
(3) Applicable to Diesel vehicles with ATS using a liquid reducing agent

Figure 9. PROCONVE L8 emissions levels

## GPF INTEGRATION

There are different concepts for the GPF integration into the exhaust gas aftertreatment system (EATS) all with individual advantages and drawbacks. Main aspects to be considered for the GPF integration are packaging, exhaust backpressure, TWCC performance, GPF performance and costs. Some different exemplary concepts are shown in Figure 10. A downstream mounted GPF proves beneficial for the exhaust backpressure as the temperature at the GPF is lower than in closed coupled position causing the volume flow to be lower as well. However, the lower temperature compromises the soot oxidation in the GPF. A coated GPF in downstream position can balance out this drawback due to its catalytic characteristic. The close coupled position provides good conditions for light-off and soot oxidation but comes with high exhaust backpressure and aggravates the packaging due to the large volume required close to the engine.

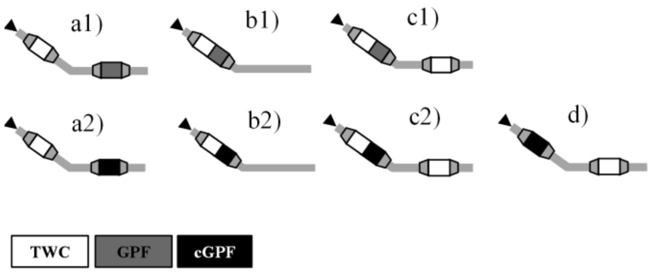


Figure 10. EATS configurations

The impacts of GPF on fuel consumption and $CO_2$ were assessed in several studies where different test cycles with various ETAS configurations with and without GPFs were performed. Joshi et al. [22] gives an overview of various studies. Matching results showing that the impact of GPFs on fuel consumption and $CO_2$ is up to 1% [23] or even not measurable within certification relevant operation [21]. For very high-speed operation an increase of 1.9% of fuel consumption was reported by Saito et al. [24]. Aged GPFs with increased ash loading were also not found to have a relevant influence on fuel consumption [25].

Figure 11 shows a scatter band of measured fleet of vehicles on Chinese and European markets with distribution of installed GPF volume plotted over the engine displacement. There is a trend that the filter volume is chosen slightly higher than the displacement. For large engines, especially ones with high specific power output, large GPF volumes are selected with volumes much bigger than their displacement. For engine layout with two-cylinder banks the total GPF volume often is split up into two bank-individual GPFs.

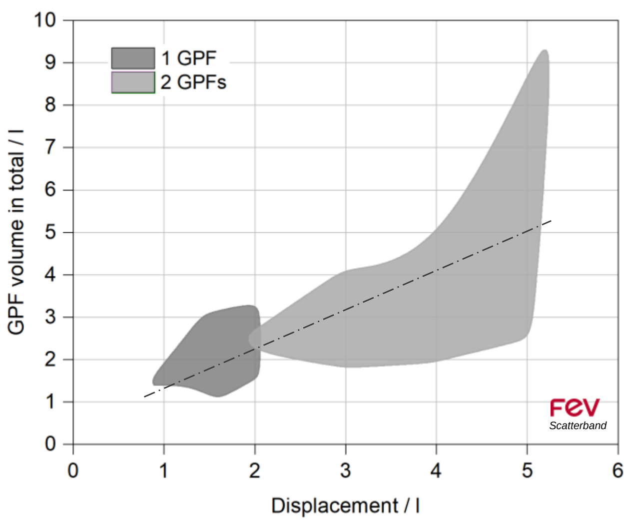


Figure 11. GPF volume over engine displacement – statistical data from the fleet

There is no universally favored system layout, as it always depends on project-specific properties. A well-designed EATS with properly integrated GPFs proves to meet the most stringent emission targets without significantly impacting fuel consumption and $CO_2$ emissions.

## GPF CONTROL AND CALIBRATION

As discussed before, the main objective of the GPF is capturing the engine out particles. However, as the amount of stored PM increases so does the engine backpressure. Due to this the filter must be periodically emptied in the event called regeneration. The stored soot can be oxidized if the GPF is provided with oxygen and sufficient temperature, giving room for accommodation of further soot particles.

Required oxygen is typically delivered during the fuel cut-off phases, which occur during deceleration. The fuel injection is disabled for the sake of fuel economy and the engine pumps the air from the intake to the exhaust. Such spontaneous regeneration is referred to as passive regeneration and constitutes a prime pathway for soot oxidation.

Gasoline engines are characterized by high exhaust gas temperatures and relatively low PM emissions, therefore in the vast majority of vehicle use cases passive regeneration is sufficient to keep the filter loading on a very small level. Considering the PM emission relative to the engine operating point, the biggest soot formation is observed during high loads and engine speeds. Such an operation occurs only during dynamic or high-speed motorway driving, which are inevitably associated with high exhaust gas temperatures and frequent fuel cut-offs.

However, in borderline cases combining worst case circumstances like frequent cold starts, very short trips, low ambient temperatures, low quality fuels and operating the engine constantly on a low load, the conditions necessary for passive regeneration are not met and the soot generation is relatively high. This may lead to excessive soot loading which comes at the cost of increased engine backpressure, negatively influencing fuel consumption and performance. Furthermore, critical soot loading state combined with high GPF temperature can lead to very quick soot oxidation rate during the fuel cut-off resulting in uncontrolled exothermic heat release which in turn melts the porous filtering material and causes GPF failure.

SOOT LOAD MONITORING – The above concerns necessitate constant monitoring of the soot loading state. Since it is not possible to directly measure the mass of soot stored in the filter, the soot load must be determined in indirect ways. There are two main methods to determine the soot load during vehicle operation, typically both being applied in parallel.

One of the approaches is a flow resistance-based estimation of the loading, achieved through measuring the pressure drop across the GPF. The correlation between soot load and delta pressure over the GPF is used to estimate the soot loading state. This method is relatively cheap to implement and additionally serves a diagnostic function of missing brick detection. However, it has several limitations and inaccuracy sources.

The pressure drop increases together with the volume flow. For low volume flow conditions (low loads and low engine speeds) the pressure rise with increasing soot load is too small, limiting the ability of load detection. Therefore, the pressure-based model can be updated only during higher volume flows through the filter. Another source of inaccuracy is the volume flow calculation. The exhaust volume flow is not directly measurable, but it is calculated based on engine operating parameters and modelled exhaust system conditions. Due to this the accuracy of the calculations is limited, especially for transient conditions, which frequently occur during driving.

Due to limitations of pressure-based soot load detection, it is typically supported by the second approach - model based soot monitoring. The soot model consists of the engine out soot emission model and the soot oxidation model, which calculate respectively the GPF soot inflow and outflow. The raw soot emission is calculated based on engine operation parameters like speed, load, lambda, temperatures, operation modes etc. The impact of all these influences needs to be measured and parametrized for a specific engine. The calibration of this model is based on extensive vehicle and engine dyno testing in a wide range of operating conditions. Model needs to precisely mirror the soot emissions in every scenario like for example cold start with extremely low temperatures or very dynamic driving. The soot oxidation calculation is based on parameters like soot load, oxygen mass flow, GPF temperature, and more. Calibrating the soot oxidation model requires a test campaign where the GPF is repeatedly loaded with soot and regenerated at varying conditions. The soot oxidation rate is calculated based on the soot mass difference before and after the regeneration event. This procedure needs to be done for a wide range of soot loads, GPF temperatures and oxygen mass flows to cover all conditions happening during real driving.

REGENERATION MEASURES – In order to prevent overloading, several active regeneration strategies exist, where upstream conditions are altered to facilitate the soot oxidation. Depending on the soot load, different escalation levels are defined with increasingly aggressive regeneration measures. In the soot load range, which still allows for passive regeneration from the perspective of thermal destruction, GPF heating measures can be applied to promote soot oxidation in naturally occurring fuel cut-off events. This can be realized by increased idle speed, retarded ignition, lambda split or additional e-motor torque demand in hybrid vehicles to increase the engine load point.

If the soot load exceeds the limit for safe passive regeneration, high oxygen concentrations in the exhaust gas must be avoided for the sake of component protection. Active regeneration can be induced by lean engine operation ($\lambda>1$) which provides only a few percent oxygen concentration in exhaust gas, and it is combined with GPF heating measures. With this soot oxidation can take place in a more controlled and safe manner with lower temperature increase. However lean engine operation disables the conversion of NOx in the TWCC resulting in high emissions. This is why an active regeneration strategy with lean engine operation is avoided by a large number of OEMs. In most instances passive regeneration and active heating measures are sufficient even in very extreme conditions. However, if the strategies described above are not sufficient for successful regeneration, the driver is requested to visit the workshop, in which so called service regeneration is triggered with a workshop tester. It is typically realized in standstill with aggressive GPF heating strategy and lean mixture operation.

COMPONENT PROTECTION – As mentioned before high soot loads come with the risk of thermal destruction of the GPF. Hence it is necessary to control the fuel cut-off occurrence when high soot load is detected. This avoids high oxygen concentration in the exhaust gas and therefore the uncontrolled quick combustion of the soot cannot take place. Fuel cut-off inhibition strategy must be precisely tuned to allow for as much passive regeneration as possible, however it should have enough safety margin to ensure component safety over the entire vehicle lifetime.

Another limiting factor for the soot load is the pressure drop across the GPF respectively the exhaust backpressure. Firstly, the mechanical pressure limits of EATS components cannot be exceeded. Secondly, the combustion quality can be compromised by high exhaust backpressure due to the negative impact on the charge exchange, which in the worst case can lead to misfiring or engine damage. To prevent hardware failures, the engine torque and engine speed must be limited at high soot load. However, in usual operation the soot levels are low meaning that these limitations are very rarely active in real operation.

All the aforementioned strategies are interconnected and together with the driver warning concept they form a complete GPF coordination logic. These strategies and controls need to be parametrized and tailored to a specific powertrain and vehicle configuration. With over 30 GPF calibration projects across multiple platforms and millions of units on the road globally, FEV has built extensive expertise in efficient calibration processes. Our big database driven development tools are helping us to significantly shorten the GPF integration and calibration process.

## AFTERTREATMENT SYSTEM AGING AND GPF LOADING USING BURNER TEST BENCH [26]

The emission durability goal of Brazil's PROCONVE L8 regulations was set to 160.000 km. The main challenge to achieve durability goals is to properly define the exhaust aftertreatment system and adjust the engine controls accordingly to be able to reach the required standards with parts that reached their full-useful life and beyond. Preparing such parts is essential for a complete development process.

FEV has developed a patented burner test bench which is used for the synthetic aging of exhaust aftertreatment systems. FEV burner bench aging procedure has proven to be representative of real aging and much more time and cost effective compared to the engine test bench, or the vehicle endurance run.

Both TWCC and cGPF are chemically active components. The aging processes over lifetime for these components consist of physical, chemical, and thermal impacts, each of which has an influence on the deactivation of the aftertreatment systems. The prevailing pathway for deactivation and malfunction of catalytic coating is thermal aging. Burner test bench can precisely control and reproduce the operating conditions for accelerated thermal aging by controlling all important operating conditions like exhaust mass-flow, lambda, and temperature.

Additionally, to thermal aging, FEV has developed procedures and equipment for accelerated GPF ash loading. Lube oil is the main source of ash production in exhaust gas of a combustion engine, therefore the ash loading method is based on controlled oil combustion. A schematic representation of the burner test bench with ash loading function is shown in Figure 12. This unit allows lubricating oil to be sprayed into the flame and operates independently of the operating point of the burner. By using secondary air and a defined outlet nozzle, the oil can be atomized into droplets of different sizes, which allows to match ash properties with the one generated by a real engine [26].

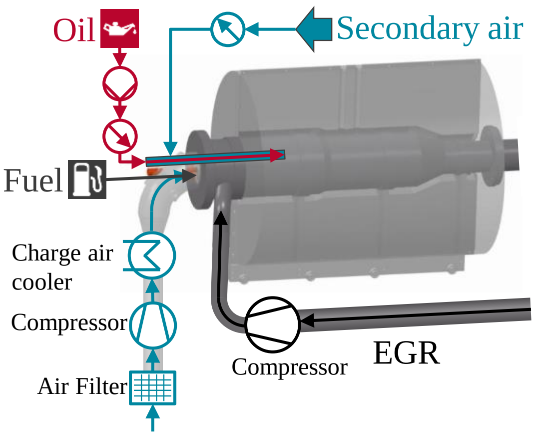


Figure 12. Burner with oil injection

While the GPF filtration properties improve during the lifetime, because of a positive effect of ash on filtration efficiency, the ash is negatively influencing the catalytic conversion of coated GPFs and comes with a penalty of increased pressure drop.

Furthermore, the burner test bench can also be used for accelerated soot loading needed during the GPF calibration phase. The patented soot generation procedure significantly reduces the costs and shortens the development time. The properties like particulate sizes, their distribution, chemical makeup, burning rates and influence on pressure drop were proven to be representative of soot that is generated by SI engine in real driving conditions [27].

With its facilities, FEV can conduct the necessary testing in-house and thus produce the corresponding aftertreatment systems in compliance with the law. During the initial development of catalysts, proof of deterioration is one of the most important instruments for demonstrating durability. By combining aging and testing, crucial steps in EATS design are ensured.

## CONCLUSIONS

The Gasoline Particulate Filter is a mature, well-proven technology that has been instrumental in reducing particulate emissions from modern gasoline engines, particularly those using direct injection. Over the past decade, GPFs have evolved into robust, maintenance-free components that integrate seamlessly with existing aftertreatment systems.

With environmental regulations worldwide, tightening the particulate mass and number limits, applicable in increasingly broad boundary conditions and real-driving compliance, Brazil is expected to follow this global path. The implementation of future standards after PROCONVE L8 will likely necessitate the adoption of GPFs in the Brazilian fleet.

Given their demonstrated reliability, efficiency, and minimal impact on fuel economy and drivability, GPFs offer a practical and effective solution to upcoming challenges. Combined with proper system integration and robust calibration, they will play a pivotal role in achieving cleaner air and a more sustainable automotive future in Brazil and beyond.

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