Cambustion service for
Diesel Particulate Filter performance testing

Summary

Below are described fundamental DPF performance tests which are becoming the basis for Industry-wide Standards. Cambustion (see www.cambustion.com) provides a confidential, UK-based testing service to determine these characteristics on behalf of customers using a Diesel Particulate Generator DPF testing system.
The DPG may be used to load DPFs from Light & Medium Duty engines.

Introduction

To date, many vehicle suppliers demand a wide range of different performance criteria for DPFs – based on a variety of tests. These are conducted on various experimental platforms (including engines, burners or blowers) using a variety of soot aerosols (from gaseous fuels, Diesel, Carbon black)
Over the last few years, there has been a general convergence towards a set of important characteristic performance measurements which are now being adopted by an increasing proportion of manufacturers. These tests are performed on a burner-based rig, fuelled by Diesel known as the DPG (described in detail in [1])
This article outlines some of the important performance characteristics and associated tests.

Standard DPF Characteristics

Below are listed four important performance criteria for DPFs with which suppliers are being required to demonstrate compliance.
The approximate costs of testing (inclusive of test data and report) are outlined in the Appendix

Pressure drop

The difference between the static pressure at entry and exit of the DPF is a fundamental performance criterion. The measurement is affected by gas flow, gas composition, gas pressure and gas temperature (which is affected by DPF internal temperature).

Pressure drop vs Flow

Typically, the backpressure performance of a clean DPF is characterised on a standard flow bench which may be 'blown' (where the inlet DPF pressure is above atmosphere) or 'sucked' (where the inlet DPF pressure is approximately atmospheric). For comparison, the pressure drop characteristic needs to be quoted at standard conditions of flow and temperature (the working fluid is usually air). Conversion between 'blown' and 'sucked' measurements can be made with good accuracy. Figure 1 shows the typical pressure drop vs flow characteristic converted to standard conditions (1 bar, 25°C at exit) for a DPF part measured on a blown bench and on a DPG at two temperatures (note that the DPG sucks the gas through the DPF).

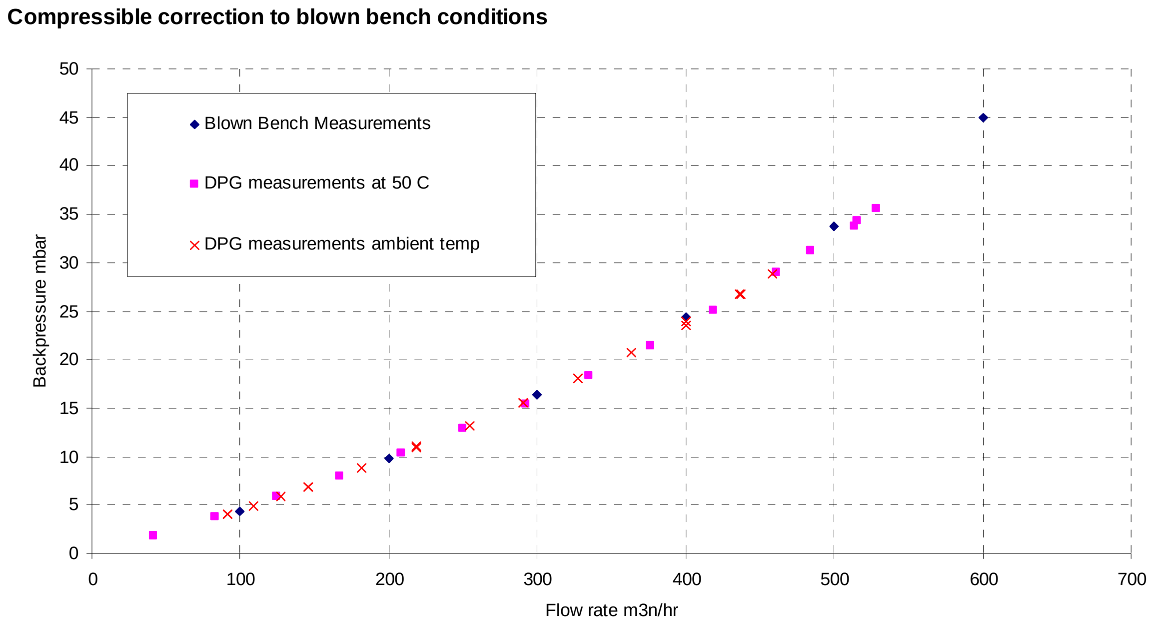


Figure 1 Pressure drop vs flow rate for DPF

Pressure drop vs Sootload

The way in which the pressure drop changes with sootload on the DPF is an important performance characteristic. This is because most engine control units use a measurement of this pressure drop, together with a mathematical model (accounting for engine flow and DPF temperature) in order to determine the soot load on the DPF – and, in particular, the sootload at which the DPF should be regenerated. Concerning a standard measurement, it is worth noting that the pressure drop across the DPF may be measured relatively easily and accurately with a suitable transducer, however, the weight of soot loaded onto a DPF can be difficult to measure. In particular the hygroscopic nature of the substrate and soot means that the weight of water absorbed from the ambient air can have a significant effect. This effect is reduced by weighing DPFs at elevated temperature (~200°C).

Whilst the pressure drop can be determined continuously and '*in situ*', the weight is usually determined at discrete times during a soot load. In this case, the pressure drop vs sootload characteristic is approximated by assuming that the soot loading rate is constant or modified by an additional measurement of soot concentration (which may be discrete or continuous). Figure 2 is graph of DPF pressure drop vs sootload determined in this way.

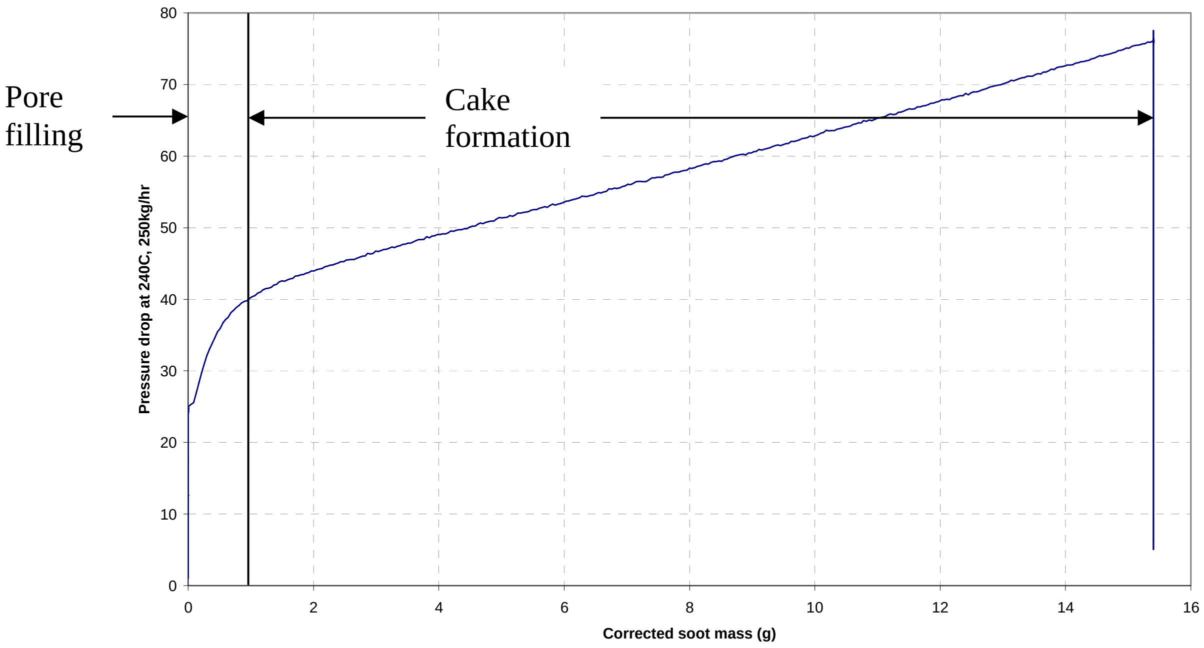
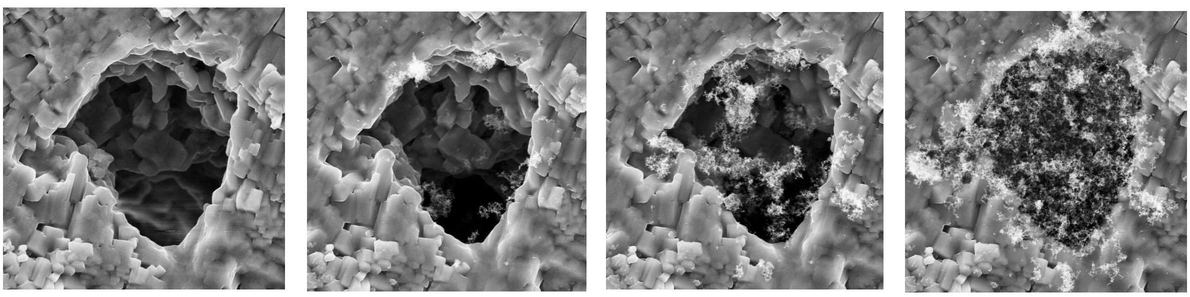


Figure 2 Pressure Drop (mbar) vs sootload for a SiC DPF

Filtration Efficiency

Filtration efficiency is a useful criterion for defining DPF 'failure'.

The filtration of a DPF is due to two phenomena. The first of these is the filtration effect of the substrate and is a function of the pore diameter/length distribution and space velocity. Generally, the average particle size in Diesel exhaust is much less than the mean pore size in a wall flow DPF and therefore the particles are filtered by diffusion to the walls of the substrate, where they become deposited. This phase of loading may be known as the pore filling phase – indicated in Figure 2. Once the pores are 'bridged' by the particles, the filtration occurs through the soot 'cake'. In this situation, the mean pore size is less than the mean particle diameter and the trapping of particles is highly efficient. This phase of loading may be known as the cake formation phase – indicated in Figure 2
This is shown in Figure 3 below which is a single pore of a Cordierite substrate being loaded with Diesel particulate at an STP pore velocity of 5cm/s. The filter load is indicated beneath each image.



0mg/l 25mg/l 50mg/l 100mg/l

Figure 3 30x30um SEM images of Cordierite pore of DPF loading from clean with DPG soot [2]

The images correspond to 'pore-filling' of the DPF.

The above means that the filtration efficiency of a DPF which has no soot deposited on it tends to rise rapidly as soot load increases and the very high efficiencies characteristic of wall-flow DPFs are only attained after sufficient soot has been deposited in order to bridge the majority of the pores in the substrate.

The graph below shows the change in soot mass filtration efficiency with soot load measured with an AVL415S smoke meter.

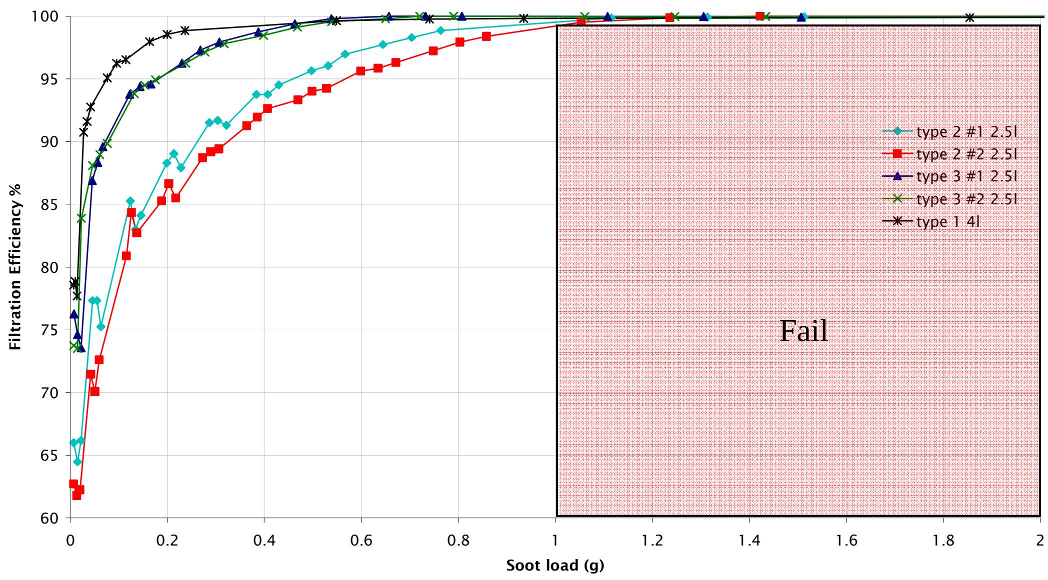


Figure 4 Mass based filtration efficiency of various DPFs as a function of total sootload

The filtration efficiency can be a convenient criterion to apply in categorising DPFs as damaged or not. For example, one criterion for a damaged DPF may be a mass filtration efficiency of less than 99% at a DPF sootload of 1.0g. Filtration efficiency trajectories which fail this criterion will be within the pink rectangle shown in Figure 4.

Soot Mass Limit (Maximum Soot Load)

Physical damage to DPFs can sometimes occur as the result of cracking associated with the high thermal stress which may be associated with exothermic regeneration – particularly at low space velocity (where the heat capacity of the exhaust gas is relatively low). The potential exothermic energy for a DPF is proportional to the soot loaded on it.

Drop to idle

In a vehicle, damage to a DPF can be associated with regeneration of a highly loaded part which is initiated at a high engine load and space velocity, but then the vehicle is idled – with high Oxygen concentration and low space velocity. These conditions are often referred to as 'Drop to Idle'. Figure 5 shows the effect of the flow reduction at the start of regeneration on the temperatures at the exit of the DPF (which are generally the highest measured). The data corresponds to a DPF loaded to 8g/l with an inlet temperature ramp of ~200°C/min. In one case the flow during the regeneration is maintained at 200kg/hr, in the other case, the flow is reduced to 80kg/hr. The resultant exotherm causes high temperatures and temperature gradients and the thermal stress can lead to DPF damage.

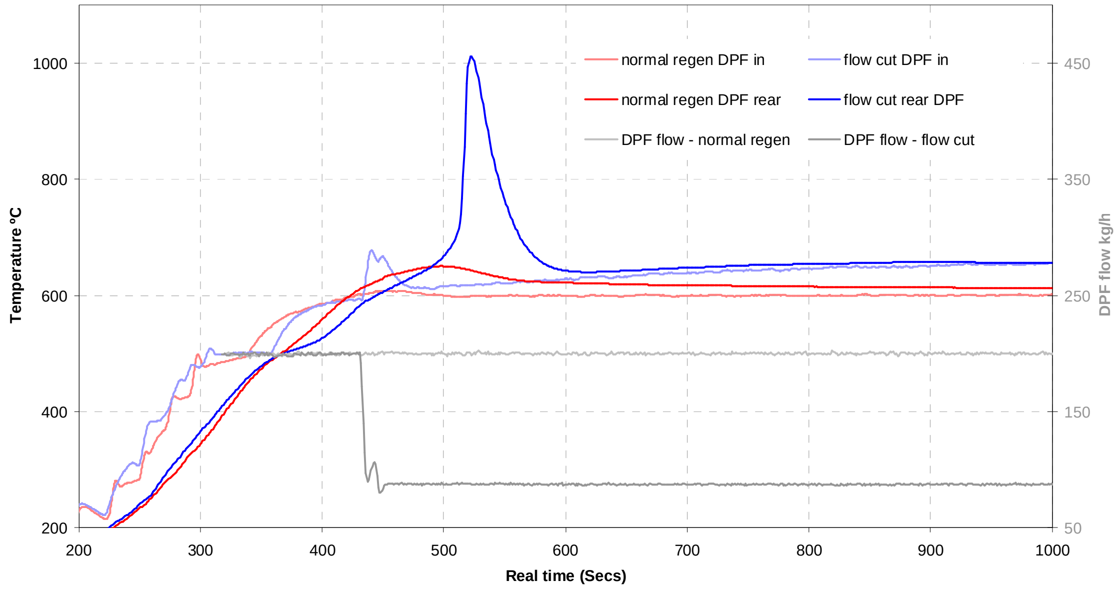


Figure 5 Effect of flow reduction in regeneration on temperature at rear of DPF

Once a criterion for failure of a DPF has been defined, the durability of a part to a highly exothermic regeneration allows the definition of the maximum soot mass with which a part may be loaded, before a low flow regeneration (or 'Drop to Idle') may result in thermal damage. This is sometimes known as the Soot Mass Limit (SML) or Maximum Soot Load (MSL). It is usually expressed in terms of grams/ litre of DPF volume.

Figure 6 shows the soot mass filtration efficiency (determined using an AVL415 soot meter) measured on a DPG following low flow regenerations for a clean part and for loaded parts with increasing sootloads from a base load of 6g/l. The reduction in efficiency at 0.5g total sootload indicates that the DPF is damaged by the low flow regeneration at the 'base +15%'. This indicates that the Soot Mass Limit for this part is between 6 and 7 g/l. The test program to produce this data can be run automatically and unattended.

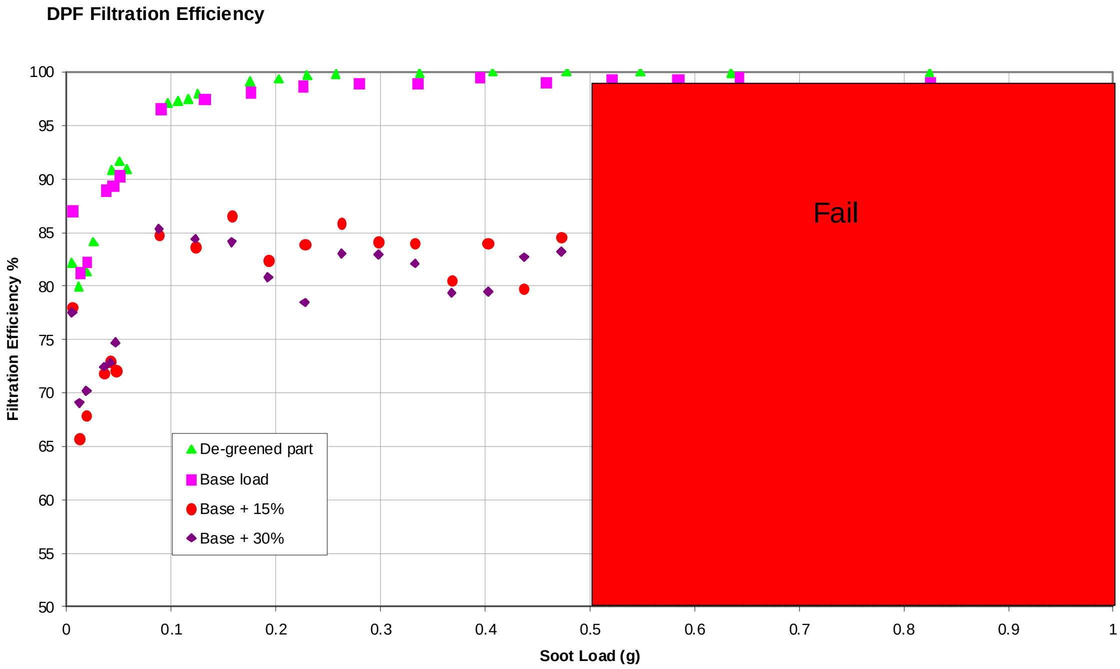


Figure 6 Post 'Drop to idle' Regeneration filtration efficiency measured at increasing sootload

The general capabilities of the DPG for regeneration testing (including acoustic in-situ crack detection) are discussed in [3].

Durability

Once the Soot Mass Limit before thermal damage on a low - flow regeneration has been established the 'Durability' of a DPF to multiple generations can be defined as: Not failing (using the DPF efficiency criterion outlined above) following N regenerations at or below the SML (or MSL).

References

1. Hands, T., Twigg, M. V., Gallinger, M.: 'A New Instrument for Diesel Particulate Filter Functional Tests in Development and Quality Control Applications'. SAE Paper 2010-01-0809
2. Payne. S. 'Visualisation and monitoring of Diesel Particulate Filtration', Poster presented at Combustion Generated Nanoparticles 15th ETH Conference, June 2011.
3. Reavell, K.: 'DPF Regeneration Using a Diesel Particulate Generator', 9th FAD Conference, Dresden November 2011.

Appendix – approximate test costing

Below is a table giving prices for different tests (including raw data and report).
Please note the following:

- There may be an additional set-up cost
- Discount may be applied for multiple part testing
- The tests listed may sometimes be changed to accommodate varying customer requirements (flow rate, temperature etc).
- For more information/ accurate test costing, please contact dpgsupport@cambustion.com

Test Description	**Approx. price per DPF tested**
Pressure drop vs flow	£200
Pressure drop vs sootload	£550
Filtration Efficiency measurement	£450
Soot Mass Limit Determination – up to 4 increasing loads	£3000
Durability Determination – up to 7 cycles	£3200