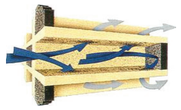
CAMBUSTION DPG Standalone Particulate Filter Test System

Introduction

Diesel Particulate Filters (DPFs) are the preferred method for meeting Diesel emissions legislation for road vehicles. As a result, a great deal of test and development work on DPFs is now in progress for a variety of applications. A clear need has emerged for a cost-effective and repeatable technique to test DPFs without the need for an engine or chassis dynamometer.



Gas Flow in a Monolith Filter
(Courtesy of Corning Inc.)

Cylindrical Wall-Flow Monoliths
Left: silicon carbide; Right: cordierite
(Courtesy of NGK)

Engine and vehicle facilities are not only expensive, but it can be very difficult to obtain good repeatability in such an environment. Further, independent adjustment of soot loading rate (g/hr), loading temperature and loading flow rate may be difficult without access to engine control unit variables and calibration.
This poster describes a new instrument to generate soot which is representative of a Diesel engine exhaust, to regenerate (thermally clean) DPFs, to map their thermal stresses, to load with ash and assess its effects in a controlled and repeatable manner via control of:

- Soot rate (g/hr)
- Soot load temperature (C)
- Exhaust flow rate (kg/hr)

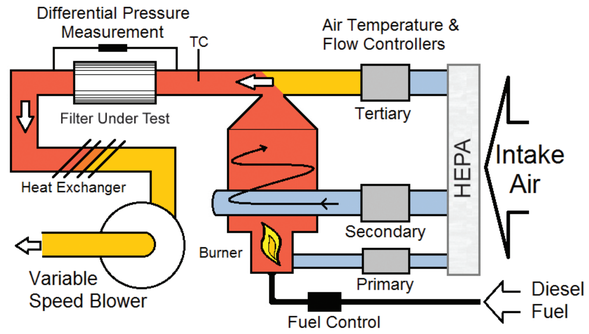
The burner is configured such that the soot generation is stable and repeatable (both in terms of concentration and composition) independent of the soot load on the DPF.

Tests GPFs and Light, Medium & Heavy Duty DPFs at full-scale flows
Soot and ash generated from Diesel fuel
Accelerated testing and unattended operation

1. DPG soot similar to engine soot
2. Measurement of Δp vs soot mass
3. Soot Mass Limit & regeneration
4. Filtration efficiency & catalytic tests
5. Minimal installation requirements / filter mounting options / control software

Operating Principle

The DPG burns Diesel fuel in a controlled primary air flow which mainly determines the soot rate. A flow of secondary air is introduced around the flame, keeping the soot away from the chamber walls and quenching the flame. The primary and secondary air flow, fuel flow and air temperatures are all controlled to ensure stability of the soot generation.



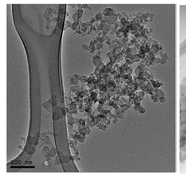
A tertiary air flow is mixed with the burner flow. This can be controlled over a wide range of flow and temperature to give control of the overall test filter temperature and flow independent of the burner parameters and therefore soot generation is not affected. The mixed flow is drawn through the test filter by a downstream blower. This ensures that the burner conditions are unaffected by the filter backpressure, and in particular that the soot rate therefore does not vary during loading.

For measurement of the filter parameters, the DPG includes measurement of the inlet pressure and filter Δp, gas flow and inlet & exhaust temperatures.

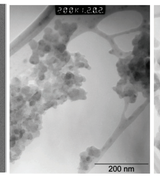
1. DPG Soot similar to engine soot

Soot Morphology

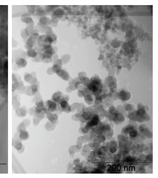
Below are TEM images of Diesel engine and DPG soot samples. These show a similar general morphology. In addition, the primary particle size is close to 20nm in all cases.



Light Duty Diesel engine soot



Heavy Duty Diesel engine soot



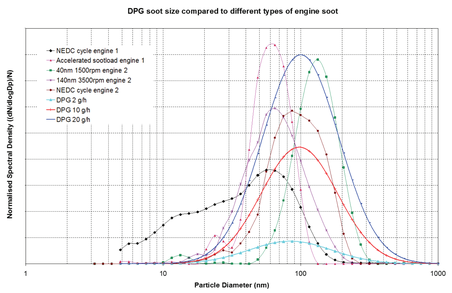
Cambustion DPG soot

Khalid Al Qureshi, EMS Energy Inst, Penn State Uni.

Dr Peter Harris, Centre for Advanced Microscopy, University of Reading

Aerosol size spectra (from DMS500)

Below are size spectra for various types of engine soot (NEDC cycle average, low load, high load, accelerated) as well as DPG soot generated at three different rates.



The spectra have been normalised to allow comparison of particle diameter. It can be seen that DPG soot diameter lies within the envelope of the various engine soot diameters.

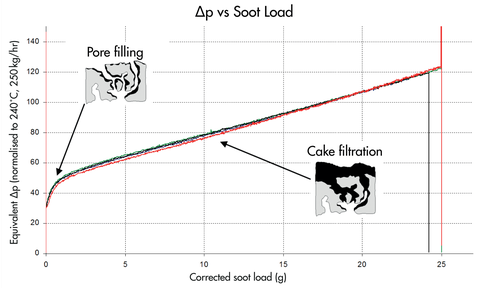
In addition to the above, the rise in backpressure for DPG soot and engine soot have been demonstrated to be similar (mbar/g deposited).

2. Measurement of Δp vs soot mass

The dependence of filter backpressure (Δp) on the soot load on a filter is a very important quality control parameter for modern engine control strategies where a backpressure sensor is used in the triggering of filter regenerations.

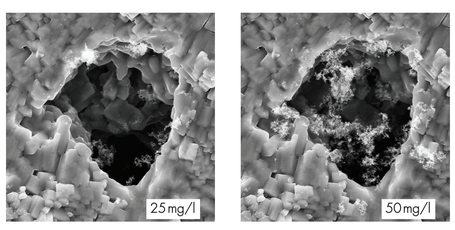
The DPG loads a filter from an empty state and continually monitors Δp and automatically processes the results using loaded and empty weighings of the filter to provide a far better measurement of loading behaviour than is achievable with engine testing.

The example below shows the backpressure characteristic of the same filter measured on four different DPG systems:



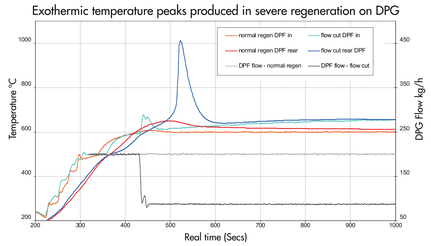
Compared with other filter test rigs, the DPG is unique in being able to perform these measurements at the full scale flow and temperature of the engine application, at a soot generation rate of 20g/h (or more), which significantly shortens test duration. The diesel burner produces soot more representative of engine soot than non-combustion sources.

Below are SEM images (courtesy Dr Simon Payne) which show DPG soot deposited on a single pore of an SiC DPF at two stages during pore filling.



3. Soot Mass Limit & regeneration

The unique capability of the DPG to both load a filter with soot and regenerate it enables an automated cycle to establish the soot mass limit (SML) for a given filter.



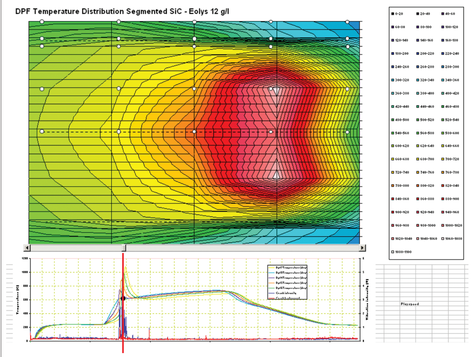
In this test, a filter is repeatedly loaded and severely regenerated, with an increased soot mass for each loading cycle. After each regeneration, the filtration efficiency is automatically measured to confirm whether the filter was damaged in the regeneration.

This test is typically run entirely automatically, 24 hours per day, achieving dramatically better productivity than engine testing.

Measurement of Temperature Distribution

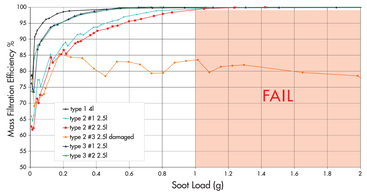
The DPG also includes up to 32 thermocouple inputs for monitoring temperature gradients within the filter.

Multiple thermocouples are easily inserted into a filter tested in the FTH



4. Filtration efficiency & catalytic tests

With the optional efficiency monitoring system (incorporating a smoke meter), the DPG can automatically measure the filtration efficiency of the filter as a function of the soot load.



This test resolves both the filtration efficiency of empty filters (critical for meeting modern Particle Number-based standards with high-porosity filters) and also the high stabilised efficiency of a loaded filter, (used to identify damaged filters). This test can then be used to automatically detect whether a filter has cracked under thermal stresses during regeneration testing.

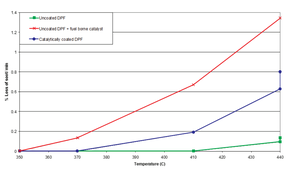
After overloaded regeneration - filtration efficiency poor

Cracks occur in the brittle DPF material due to internal stresses caused by extreme temperature gradients

In extreme cases oxidation of the SiC DPF material can occur (see dicolouration on exit surface of DPF)

Catalytic activity / Soot reactivity testing:

- DPG can be used to test for catalytic activity of coated DPF, or reactivity of soot *in-situ* on the DPF.
- Compared with filter TGA, this has the benefit of including:
  - diffusion limitation effect of the soot structure
  - catalyst : soot contact
- This test uses a sequence of increasing controlled temperature conditions, weighing after each one.

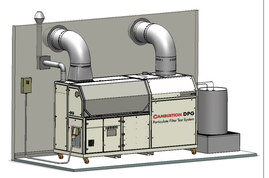


Sample Test Sequence

Soot load filter (DPG or engine)
Precondition @300ºC (removes VOF)
Stabilise temp @ 250ºC and weigh
20 minutes @ 350ºC
Stabilise temp @ 250ºC and weigh
20 minutes @ 370ºC
Stabilise temp @ 250ºC and weigh
20 minutes @ 410ºC
Stabilise temp @ 250ºC and weigh
20 minutes @ 440ºC
Stabilise temp @ 250ºC and weigh

5. Minimal installation requirements

DPG installation requires only minimal external services. The system includes its own cooling air fan and controller, plus filtering and temperature control of all inlet flows. It will draw and filter fuel directly from a tank or barrel.

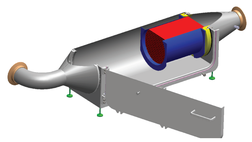


Ducts for cooling air inlet and exhaust, a stack for the burner exhaust, 3-phase electrical supply and a fuel tank are the only customer infrastructure requirements.

Filter mounting options & Filter Test Housing

The DPG can be used for testing whole vehicle exhaust systems, or canned filters up to approximately 13" diameter.

The Filter Test Housing (FTH) - shown below - is an accessory which allows testing of uncanned filters. This saves the time and cost associated with the canning process and improves the accuracy of gravimetric determination of soot load by allowing the filter to be weighed alone, without the artefacts due to changes in the mass of the support mat.



The filter is held in an adaptor in a flexible ceramic seal. Adaptors are available for a wide range of filter sizes up to 13" diameter, and custom shapes can easily be supplied as required.

Control Software

All operation of the DPG is controlled remotely from software running on a PC complete with safety interlocks. The software automatically runs complex test sequences, logs data files from testing and provides feedback to the operators on the state of the test. The software can also communicate automatically with weighing scales, eliminating operator error in the weighing of soot deposited on a filter.

The system can be configured with different specifications for different filter types and can then automatically assess a test pass/fail on the basis of filtration efficiency or Δp vs soot load. A .pdf report is automatically generated with the results of the test.