



Maximum Soot Load (MSL) testing of DPFs on the DPG

It is widely accepted that the most damaging conditions for a DPF consist of the initiation of regeneration in a loaded part, followed by an idle condition – which sustains the regeneration with oxygen, but with a very low exhaust flow.

This application note describes a technique for evaluation of DPFs (coated or uncoated) for:

- Maximum Soot Load capacity (before thermal degradation during 'idle' regeneration)
- General performance in regeneration (i.e. how much soot is removed)
- An associated initial evaluation of the effect of 'zoned' soot loading – where the sootload is distributed unevenly on the part is discussed in DPG 005

Engine Max Soot Load Test

An engine-based Maximum Soot Load (MSL) test typically involves:

1. 'Warm-up mode' - Heating the loaded DPF to a temperature below that for regeneration (around 350°C) at a mid speed/load point.
2. 'Regeneration mode' - When the part is at a consistent temperature throughout, the engine load is increased to bring the inlet temperature to the DPF to >600°C – which is sufficient to initiate regeneration
3. 'Idle mode' - After a short period with this high inlet temperature (typically 2-3 minutes), the engine idles and the exhaust flow is reduced to ~50kg/hr (for a 2l engine). The very lean overall combustion leads to a high oxygen content in the exhaust. Further, the low heat capacity of the exhaust flow leads to very high exothermic temperatures which can cause the thermal degradation of the DPF.

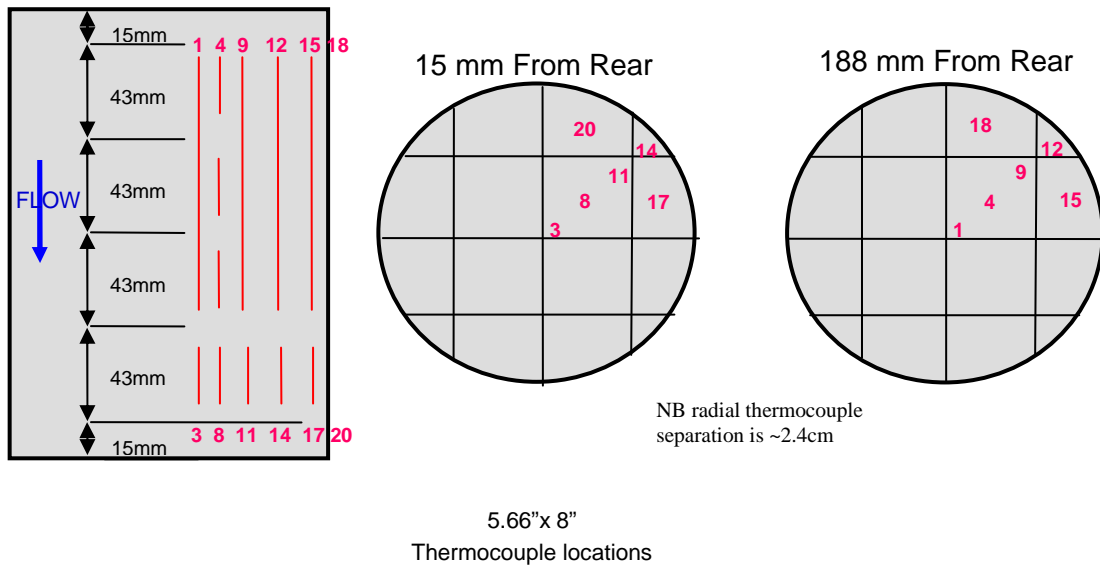
Hardware set-up description.

The DPF part for testing (5.66"x 8") is mounted in the working section of the DPG (note that a 'bare-brick' can be tested in the Filter Test Housing accessory). The part is typically instrumented with thermocouples to monitor the internal DPF temperatures. These are inserted from the rear and are usually 0.5mm diameter (note that the cell dimensions are ~1mm x 1mm). The DPG can log up to 16 user thermocouples. The thermocouples should be located with regard to the following:

- The regeneration temperatures are generally higher towards the rear of the DPF and also higher near to the centreline.
- Cells adjacent to cement joints between DPF sections are generally lower than nearby cells with flow on all sides.

The diagram below shows useful locations for 12 internal thermocouples.

Thermocouple instrumentation



DPG Schedule description

The DPG schedule is developed in order to simulate the engine-based MSL test as follows (if the loaded weight is not known, the part must be heated to ~200C to determine this). The modes refer to the graph below.

1. 'Warm-up mode' - The loaded part is heated to a consistent temperature throughout (typically 10 minutes). In this mode the exhaust conditions at DPF inlet are controlled to setpoints of ~200kg/hr, 350°C
2. 'Regeneration mode' - The tertiary (dilution) air flow is removed, the DPF flow is controlled to ~75kg/hr and the DPF inlet temperature rises from 350°C to ~700°C in around 180s.
3. 'Idle mode' - The burner is disabled and the DPF flow controlled to 50kg/hr (typically 5 minutes).

The part was loaded to a soot mass of 26.3g at a rate of ~ 10g/hr – giving a distributed soot load of ~8g/l.

Following the simulated MSL, the part was reweighed and the soot removed was established to be 8.1g (ie ~31%)

Notes

The Oxygen concentration in the DPG exhaust gas is generally higher than engine exhaust due to the air dilution flows. Approximate concentrations in

- Figure 1 are:

Warm-up mode	18%
Regeneration mode	14%
'Idle' mode	21% (burner off)
- The regeneration 'efficiency' – ie the percentage of soot removed in the MSL regeneration can be determined by reheating the test part to ~200°C, re-weighing and comparing with the relevant zero weight. Typically, 30-60% of the loaded soot is removed during a DPG MSL test. The distribution of the soot remaining at the end of the test may be significant (possibly mostly away from the centreline and towards the front of the part). This distribution may be inferred from thermocouple data in the DPF. Note that the 'state' of soot remaining at the end of an MSL test may be different to the loaded soot – typically, the heating will reduce any organic HC content.
- Whilst the inlet temperature to the DPF is not controlled during the onset of regeneration, the burner flows of air and fuel are controlled and the rise rate in this temperature is fairly repeatable test to test as long as the warm-up phase is sufficient to stabilise the metal pipe-work temperatures upstream of the DPF.
- The damage mechanisms to DPFs depend on the substrate material and the DPF construction. They may be associated with maximum temperature criteria (~950C for this test). However, spatial rate of change of temperature can also be significant. Determination of the maximum thermal gradients (in °C/cm) from the installed thermocouples and comparison to the theoretical maximum permissible from a material datasheet has been suggested. The maximum thermal gradients occur at the rear face of the DPF and are shown in Figure 2. The highest thermal gradient is ~ 113 °C/cm – between TCs 11 and 13 – although this includes a cement 'boundary'. The maximum gradient within a single section of the brick is ~103 °C/cm.
- The maximum temperature, temperature gradient and regeneration efficiency are all affected by the length of time which initiates the regeneration (between the warm-up and the cut to idle). If this time is too short, the soot in the DPF tends to be 'blown out'. If the time is too long, then all the soot is burnt at the higher flowrate and the exotherm is reduced. In practice, this optimal time must be determined with several tests (slowly increasing the regeneration time and monitoring the maximum temperature, temperature gradient and regeneration efficiency). From experience the optimal cut to idle point occurs shortly after the peak in DPF pressure drop (which is useful to know if thermocouples are not fitted to a part).
- The DPG can be used to accurately assess any degradation in the filtration performance a DPF part following MSL testing (described in a different application note). Note however, that parts which have small cracks can still filter Diesel aerosol very efficiently immediately after an MSL test. In general, establishing whether a DPF part is damaged following an MSL test can be difficult and filtration performance is sometimes not a useful criterion. Parts which **do** show a degradation in filtration can be rejected (one criterion under discussion is a pass/fail based on whether a part achieves > 99% filtration efficiency with a soot load of 0.5g/l). Other techniques for establishing whether a part is cracked include various scanning and imaging methods (including ultra-sound and X ray (CT scans)), however, none of these are simple and cheap....
- Concerning part acceptance by a customer, it has been suggested that a DPG schedule similar to that above be conducted at increasing sootloads beginning at 15% below the suppliers suggested MSL (in the engine calibration), at the suggested MSL and also at 15% above the suggested MSL. In terms of durability, passing the cracking and filtration criteria after 5 successive DPG MSL schedules at the suppliers suggested MSL value has been suggested.

Figure 1 DPF thermocouple outputs during DPG simulated MSL regeneration

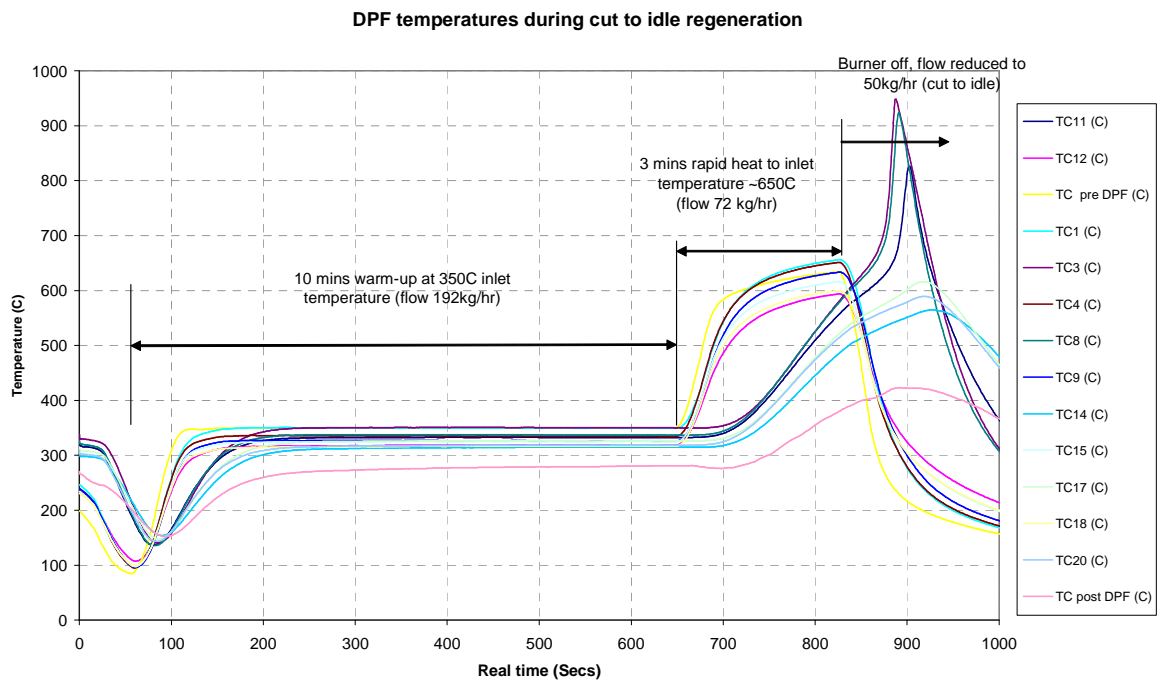


Figure 2 Temperature gradients at rear of DPF

Temperature differences at rear of DPF

