Automated Soot Mass Limit (SML) determination with DPG

Introduction

The Maximum permissible Soot Load (MSL – sometimes known as Soot Mass Limit - SML) on a DPF before thermal damage may occur during regeneration is an important parameter – determining the regeneration frequency and hence impacting the fuel economy.

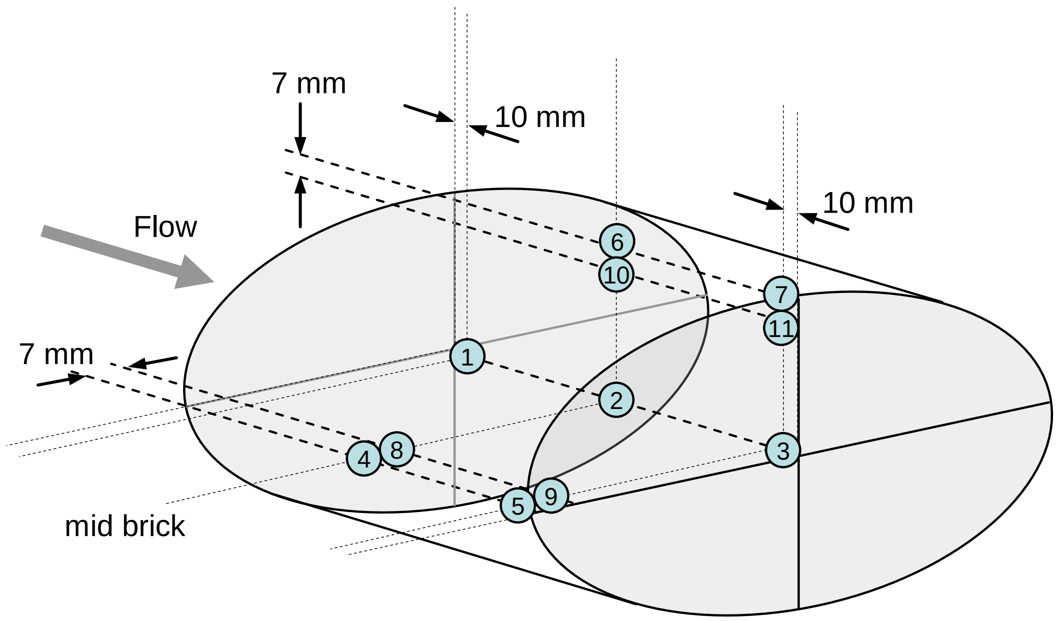
This application note describes an unattended test procedure which begins with a clean part and determines the level of soot which may be loaded before significant thermal damage results in the filtration efficiency from clean being reduced below a threshold value.

The procedure described here is emerging as an industry standard technique for determining the Maximum Soot Load for a DPF

DPG Configuration

This test is typically conducted on a 'bare brick' (ie not canned) which may or may not be coated. The brick is mounted in the DPG test section using a Filter Test Housing (FTH – see http://www.cambustion.com/products/dpg).

The brick is instrumented with thermocouples to resolve maximum temperatures and also maximum temperature gradients. These TCs are typically inserted from the rear and 0.5mm stainless steel sheathed are conveninent for exit cell dimensions of ~1mm. The figure below shows a typical arrangement of TCs for a 'race-track'. For a cylindrical DPF, the axes of symmetry allow fewer TCs to be used.



The maximum temperatures generally occur near to the axis at the rear of the brick and the highest temperature gradients typically also occur near the rear of the brick close to the edge (adjacent to the can).

DPF preparation

Before testing the DPF should be conditioned to remove any soot form the part. This may be done in an oven in air at ~650C for ~2hrs, or on a DPG using an appropriate regeneration schedule

Schedules used in Automated MSL determination

The following schedules are used in the Maximum Soot Load determination. They are combined in a 'Program' such that individual datafiles are automatically generated – which simplifies post-processing.

Efficiency measurement.

DPF efficiency is measured following a regeneration using the AVL415 smoke meter as described in Application note DPG 002.

MSL Regeneration

Regeneration at a total DPF flow of 62kg/hr as shown below. This causes the inlet temperature to rise to ~600C in 1 minute and ~ 650C after 5 mins.

Primary Air Flow	Secondary Air Flow	Fuel flow	Total flow	DPF inlet temp
23 kg/hr	37kg/hr	1.65kg/hr	61.65kg/hr	~650C

Load to target soot mass

The load is preceded by a warm-up phase of ~10minutes to allow the system to thermally stabilise. The load duration is then adjusted to achieve the target soot mass (ie at 10g/he sootload rate, a target mass of 40g will take 4 hours).

For the automated version of this test, the soot mass is not determined gravimetrically. In this case, the soot mass is estimated from measurements made by the AVL415 system. It is suggested that for most loads, an upstream measurement is made once per 10 minutes (600s).

Mode	Primary Air Flow	Secpondary Air Flow	Tertiary Air flow	Fuel flow	Total flow	DPF inlet temp
Warm-up	17.8 kg/hr	155 kg/hr	77.2 kg/hr	1.1kg/hr	250kg/hr	240C
Load 10g/hr	9.06 kg/hr	155 kg/hr	86 kg/hr	1.1kg/hr	250 kg/hr	240C

Test Schedule description

The following is a description of the test schedule – which may be unattended, together with an indication of the Test time.

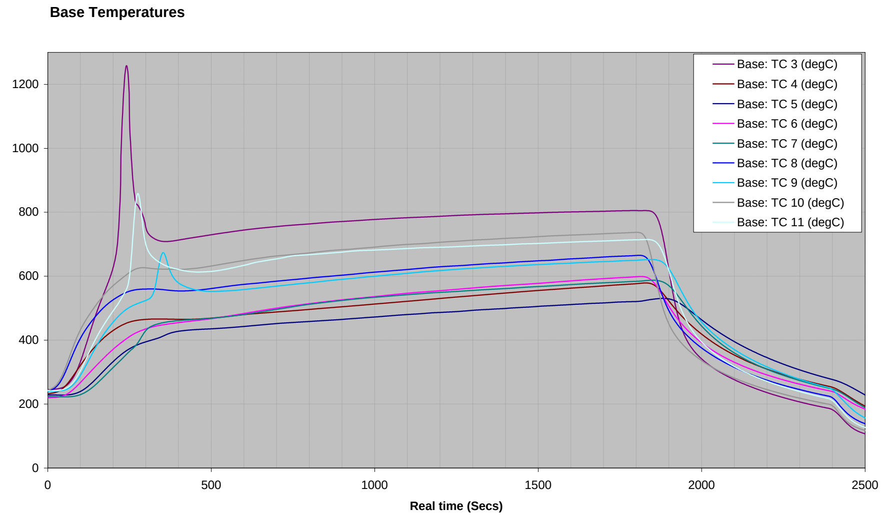
1.	Efficiency measurement	0.5 hrs
2.	MSL Regeneration	0.5 hrs
3.	Load to target soot mass	2.5 hrs
4.	MSL Regeneration	0.5 hrs
5.	Efficiency measurement	0.5 hrs
6.	MSL Regeneration	0.5 hrs
7.	Load to (target + Delta) soot mass	3 hrs
8.	MSL Regeneration	0.5 hrs
9.	Efficiency measurement	0.5 hrs
10.	MSL Regeneration	0.5 hrs
11.	Load to (target + Delta + Delta) soot mass	3.5 hrs
12.	MSL Regeneration	0.5 hrs
13.	Efficiency measurement	0.5 hrs
14.	Regeneration	0.5 hrs

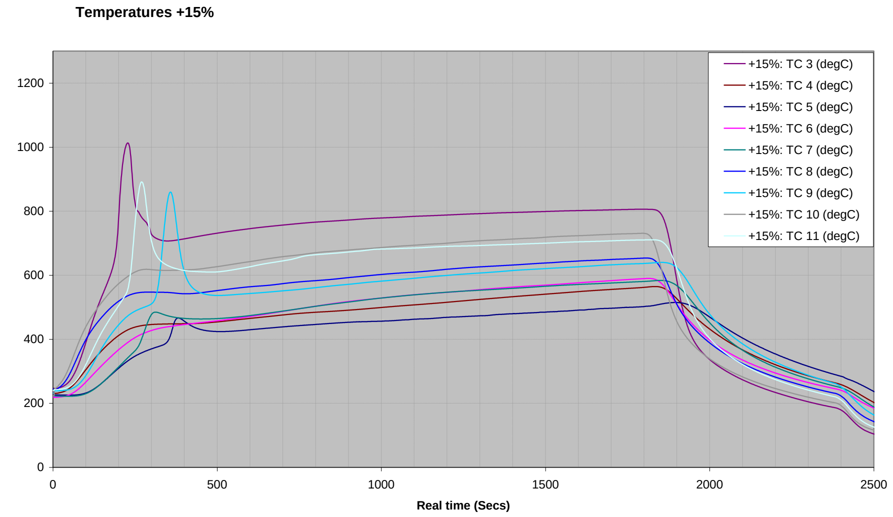
Total test time **14.5 hrs**

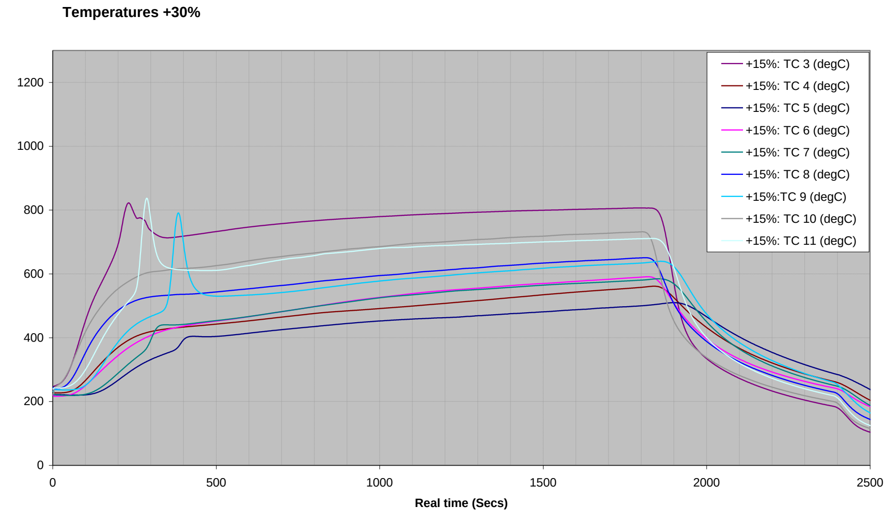
Results

DPF temperatures during MSL Regeneration

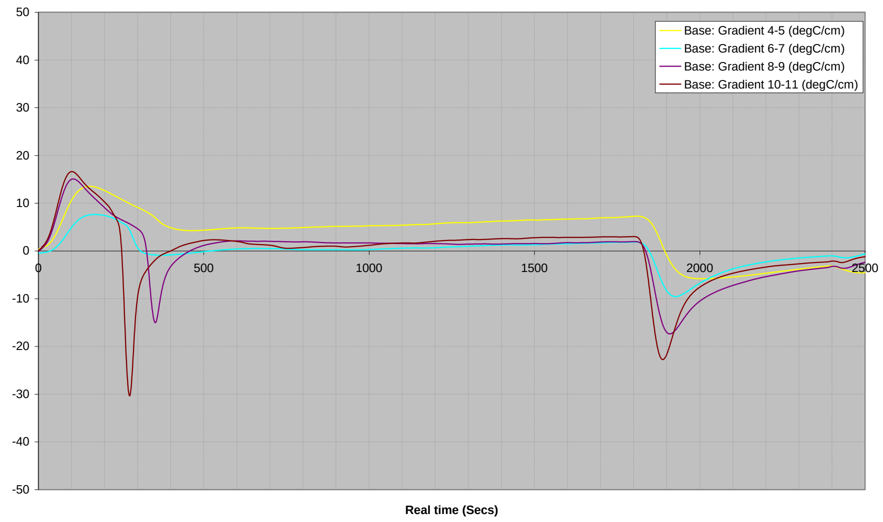
Below are internal temperatures in the DPF measured during the MSL regeneration.

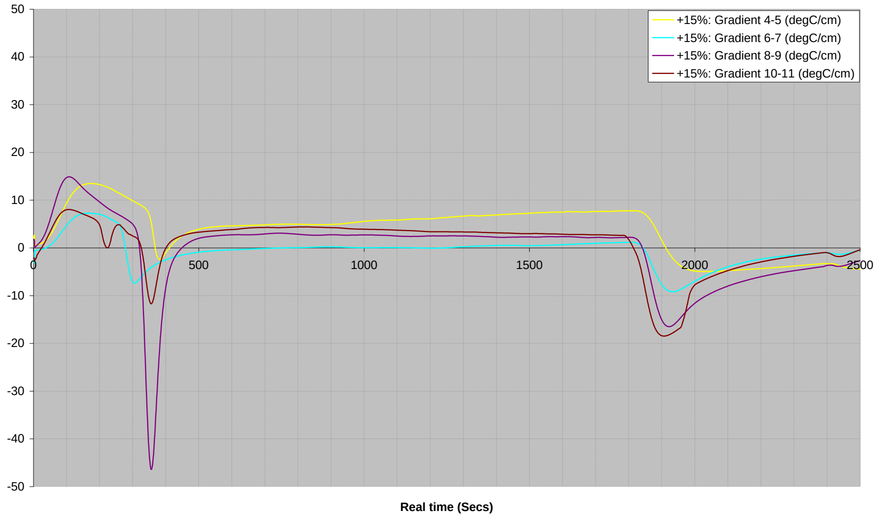


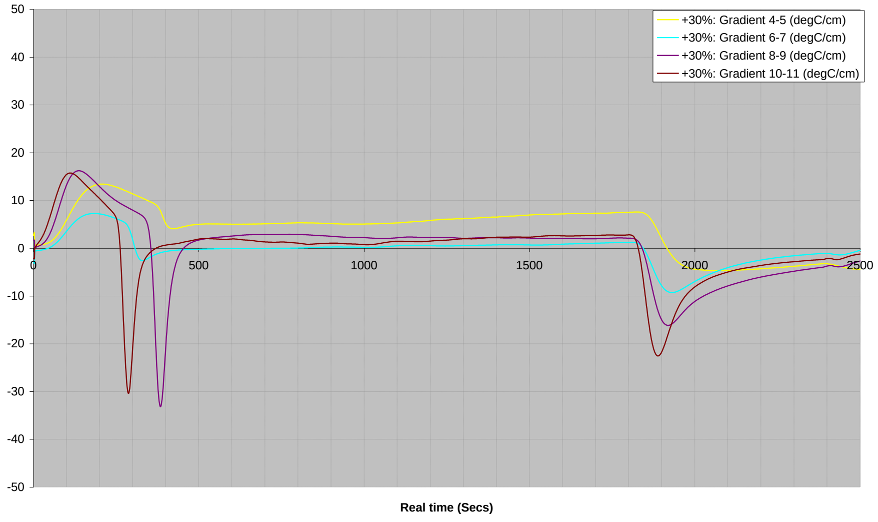




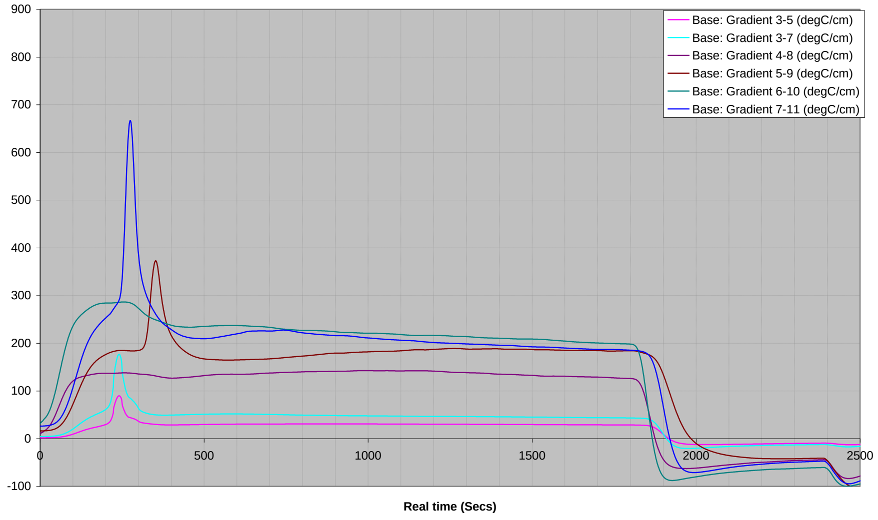
Axial Temperature Gradients

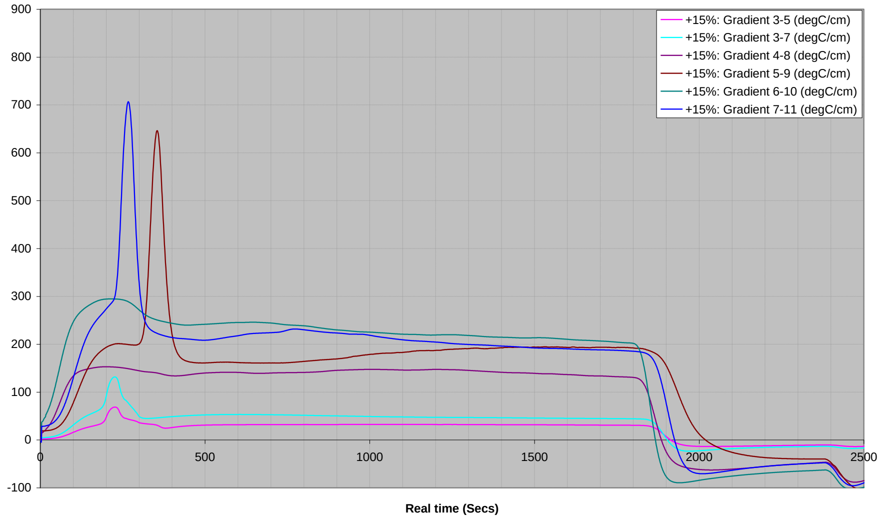


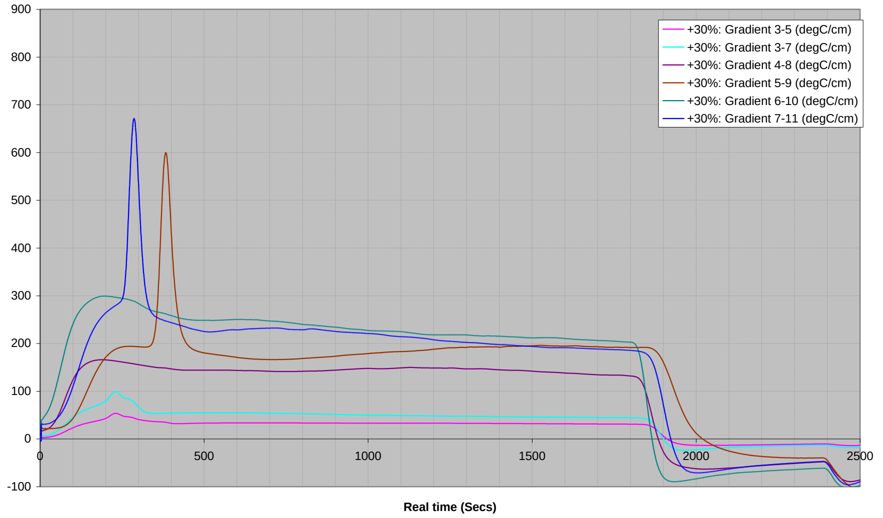




Radial Temperature Gradients



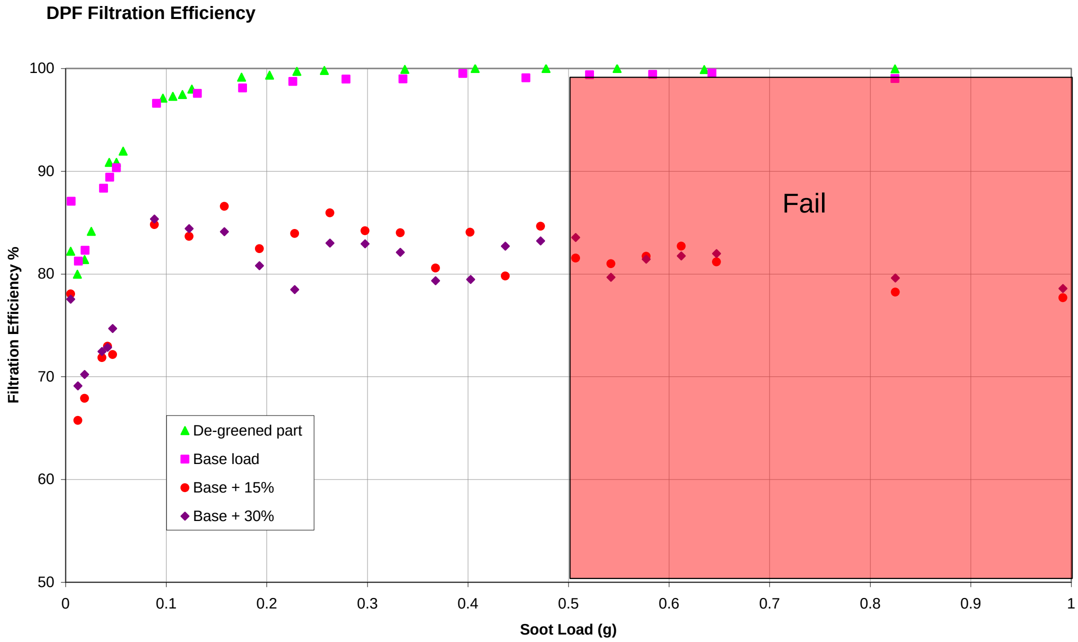




It will be noted that the radial temperature gradients are significantly higher than the axial temperature gradients (in terms of °C/cm)

DPF filtration efficiency

It has been suggested that a 'pass' criterion for the filtration efficiency characteristic may be defined as an efficiency of >99% at an estimated sootload (from the AVL415 smoke meter) of 0.5g



Discussion

For this part, the filtration efficiency test is failed for MSL regeneration at Base + 15% load and base +30% load – which indicates that the safe MSL is 'Base' for this part.

It will be noted that the maximum temperature occurring at the rear of the DPF is reduced for the second MSL regen (base +15%), however, it occurs earlier in the cycle and the other temperatures at the rear face are hotter. The radial gradients (which are probably the cause of thermal damage) are higher for the base +15% load.

Note also that the temperatures and gradients for the base +30% load are generally lower than for the base and base +15% tests. This is due to the part being sufficiently damaged to allow a significant proportion of the sootload to pass through the part (around 20% is indicated by the efficiency measurement). In addition to this, the flow distribution through the part may be significantly affected.

DPF Durability

Concerning durability, it has been suggested that 5 repeat MSL regenerations at the 'safe' MSL sootload with a 'pass' of the filtration efficiency criterion stated above (base load for this part). In addition to the above criterion, there must ne no surface cracks visible on a monolithic part. For segmented parts, cement cracks on the end face are permitted, but not in the segments.