Automated Repeatable DPF Testing with the Cambustion DPG

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Cambustion

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Contents

- DPG concept and production instrument
- Soot mass vs Δp
  - Soot generation repeatability
  - test to test & stability within test
  - instrument to instrument
- DPF flow testing –
  - effect of vacuum vs pressure testing
- Regeneration
  - measurement of effect of varying soot load
- DPF efficiency testing
  - smoke meter and number count based

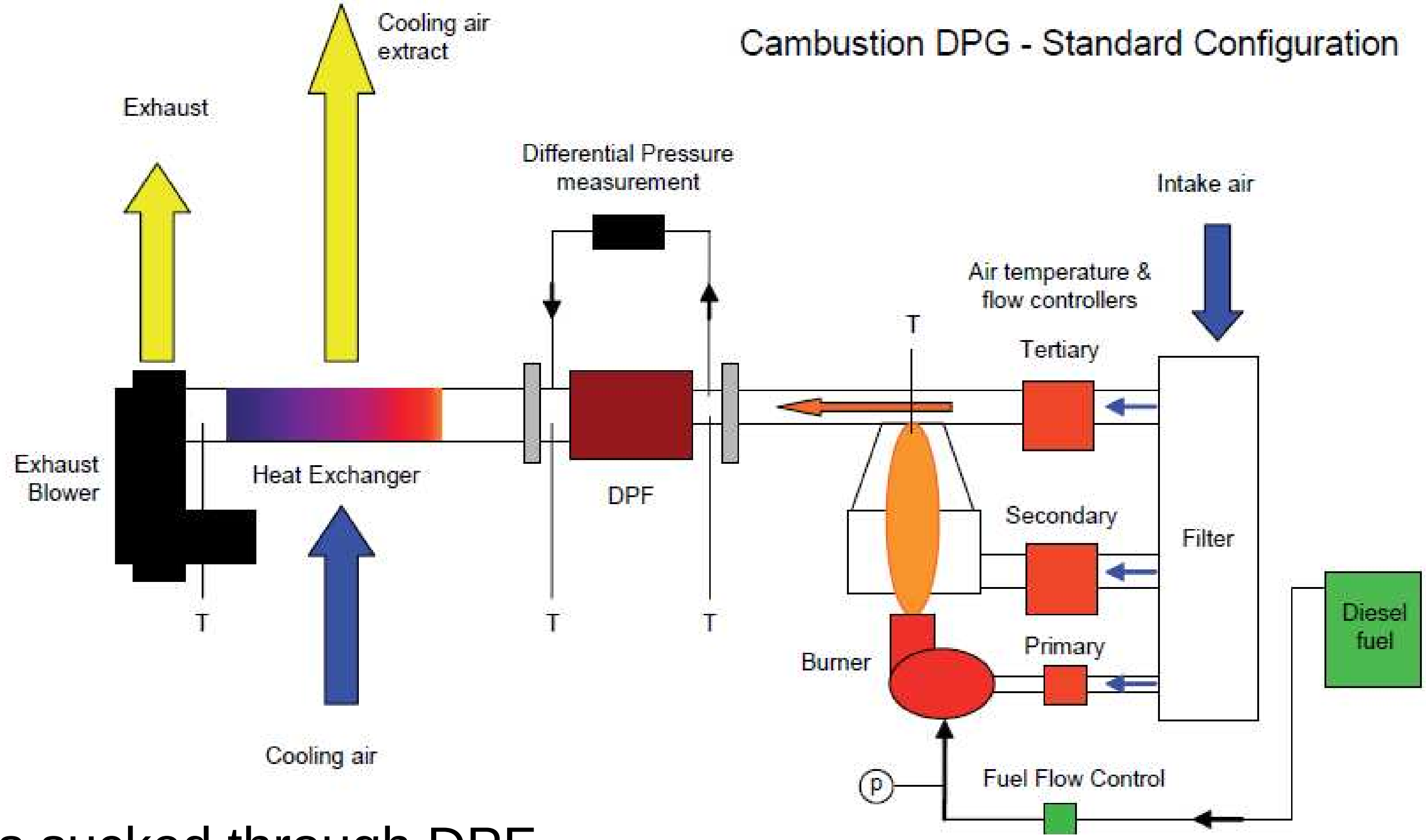
Challenges posed by DPF testing

- Repeatability
  - Engine soot rate (g/hr) variability – affected by DPF backpressure
  - Behaviour of soot depends on engine operating mode
  - Weighing of soot variable with conditions
- Cost
  - Representative testing requires DPF loading with engines on transient cycles
  - Expensive transient dynamometer facilities
  - High manpower requirements
- Control of conditions
  - Flow rate, temperature, soot rate, passive regeneration all compounded
  - Makes discrimination of effects of different factors very difficult

Cambustion DPG

- System for DPF testing:
  - Δp vs soot load characteristics
  - Filtration efficiency
  - Regeneration behaviour
- Diesel burner for soot generation 2 – 20 g/hr
- Testing at engine – like conditions
  - load over 250ºC, 300 kg/hr
  - flow test up to 600 m^3hr^{-1}
- Automated execution of test protocols
  - unattended operation

DPG Configuration



Airflow is sucked through DPF

- soot generator unaffected by DPF backpressure
- system at sub-ambient pressure for inherent safety

Primary & Secondary airflows & fuel flow control soot generation

- tertiary airflow & temperature allows independent control of DPF conditions

Demonstration of Soot Rate Repeatability

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Test Protocol

Part loaded 5 times over the course of 1 week

Each time loaded for 2 hours @ 10 g/hr nominal, in 5 phases

Soot mass recorded at the end of each phase.

To minimise variability in weighing:

- measurements performed on uncanned brick
- weighing performed ~200 C
- DPG can hold part in elevated temperature state until operator is ready to weigh.

Soot Generation Rate Repeatability

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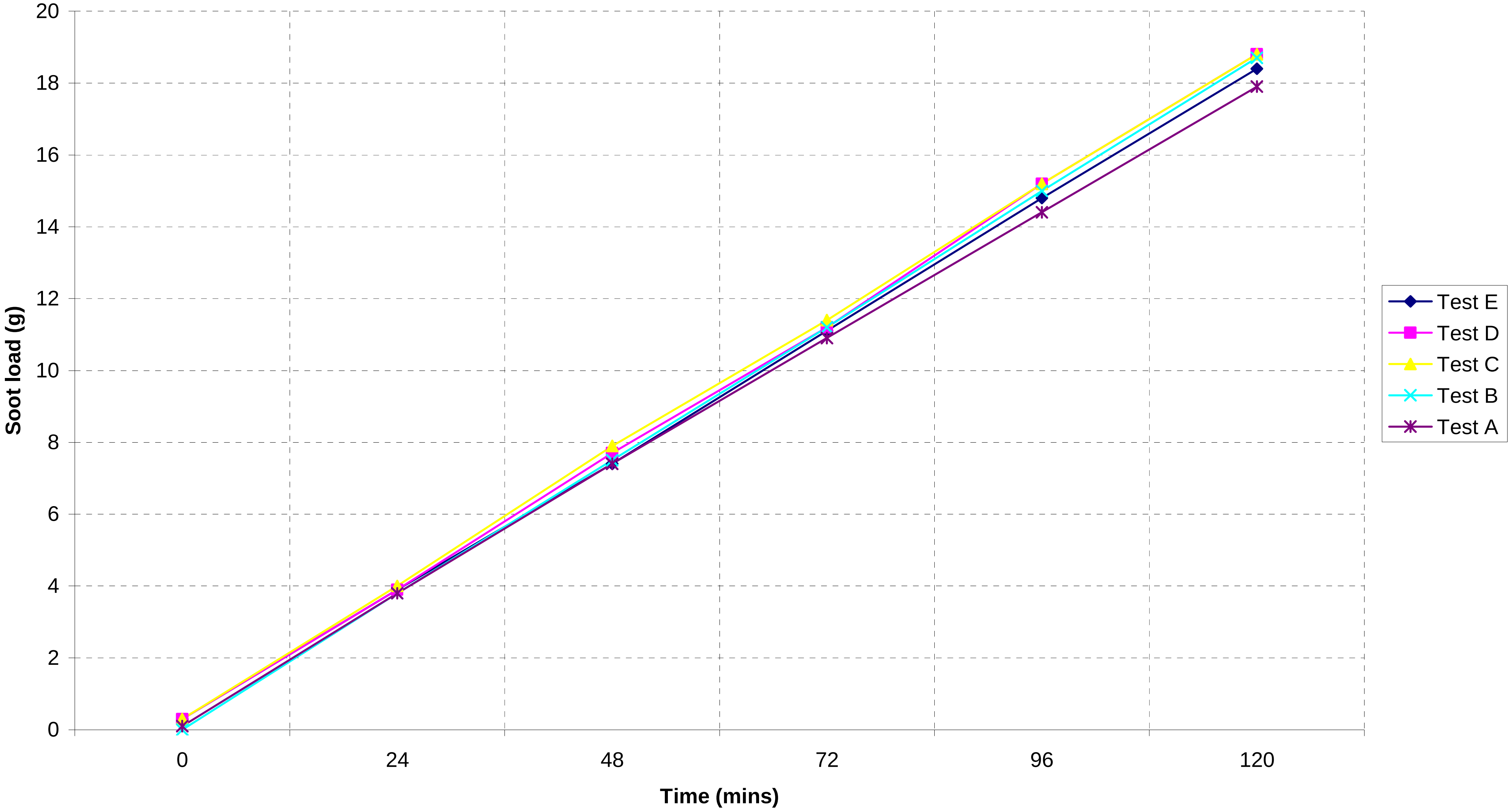
Repeatability of Soot Load Between and During Tests.



Mass Repeatability – Numerical Data

g load / phase

	Test A	Test B	Test C	Test D	Test E
0 – 24	3.6	3.6	3.7	3.8	3.7
24 – 48	3.5	3.8	3.9	3.7	3.6
48 – 72	3.7	3.5	3.5	3.7	3.5
72 – 96	3.7	4.0	3.8	3.8	3.5
96 - 120	3.6	3.6	3.6	3.7	3.5

Mean load 3.66 g / phase

deviation from mean

	Test A	Test B	Test C	Test D	Test E
0 – 24	-1.7%	-1.7%	+1.0%	+3.7%	+1.0%
24 – 48	-4.5%	+3.7%	+6.4%	+1.0%	-1.7%
48 – 72	+1.0%	-4.5%	-4.5%	+1.0%	-4.5%
72 – 96	+1.0%	+9.2%	+3.7%	+3.7%	-4.5%
96 - 120	-1.7%	-1.7%	-1.7%	+1.0%	-4.5%

standard deviation 3.7% of mean, max 9.2 %

Repeatability of Dp vs Soot Load

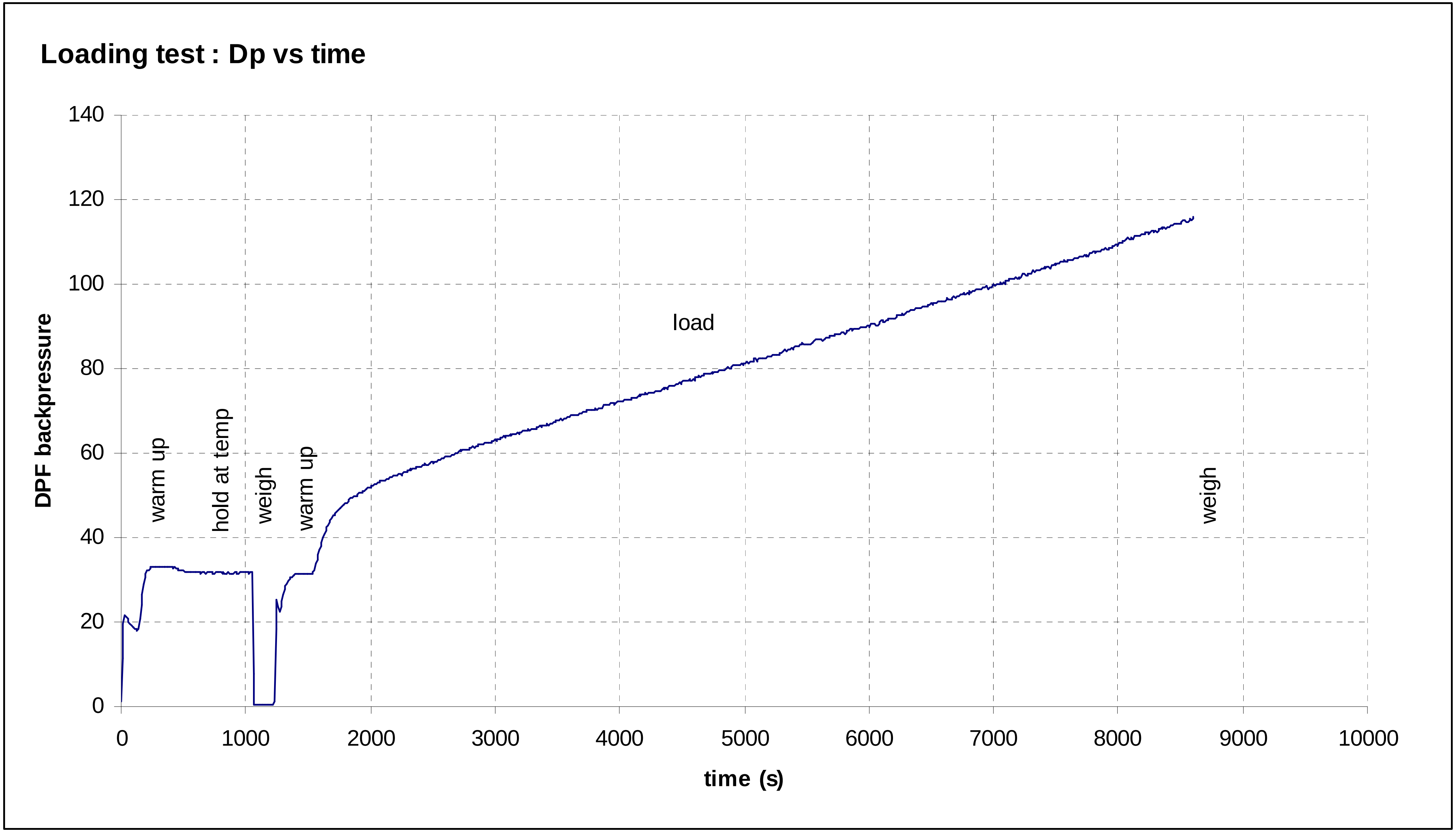
- Accurate Measurement of Dp vs Soot Load Characteristic:
  - ‘no soot’ warm-up phase followed by soot load
  - discriminates warm-up from pore filling effects in initial pressure rise

- Same part loaded to 25g nominal
- Loaded on 2 DPG instruments
- 3 tests on one instrument
- Soot load established by weighing at 200ºC
- Backpressure measurements corrected to common conditions: 240ºC, 250 kg/hr

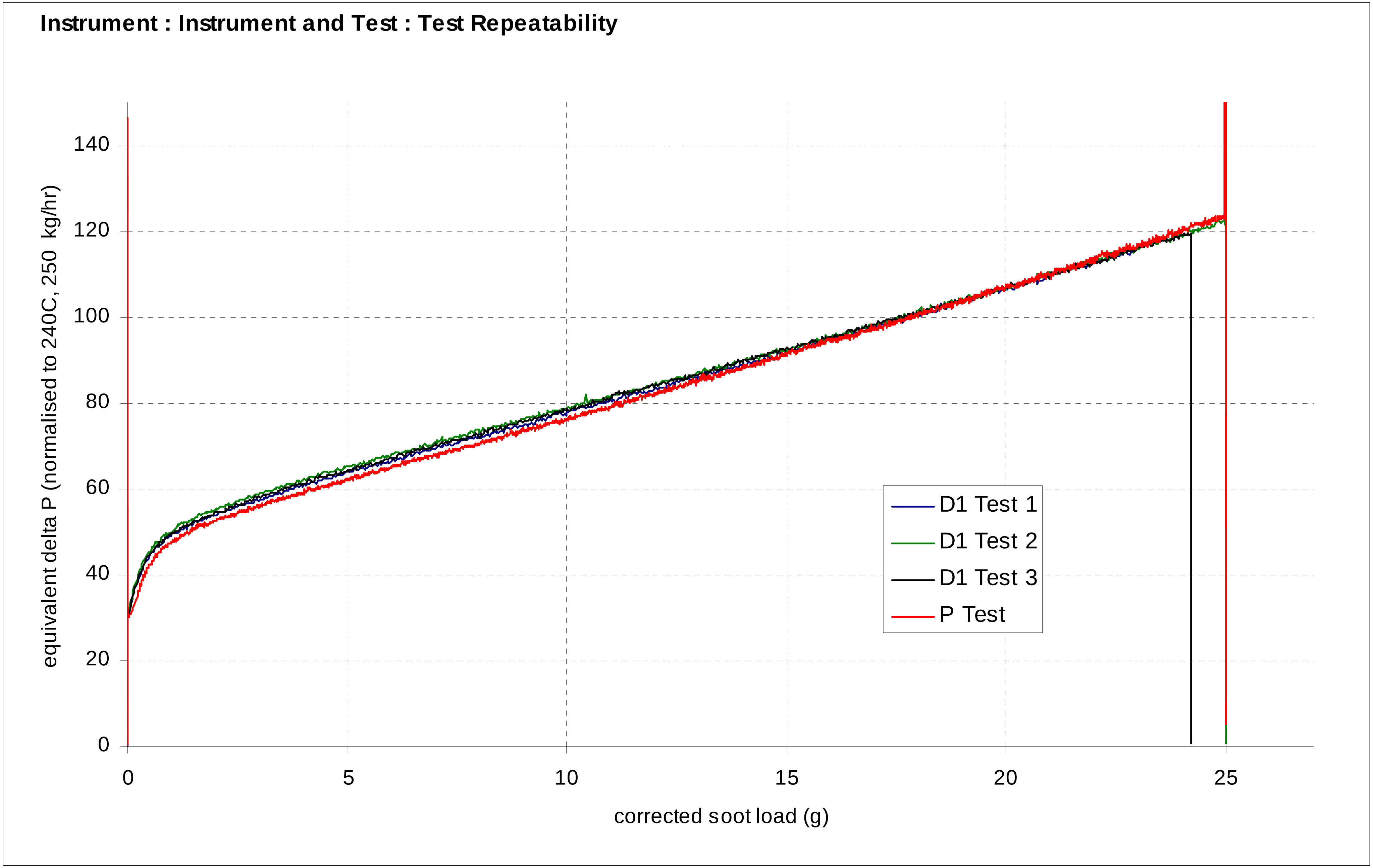
Soot Load Test Schedule

1. Stabilise airflows
2. Light burner and warm DPF under test without soot
3. Hold DPF at temperature until operator is ready for zero weight
4. Weigh DPF
5. Relight burner and warm DPF back up
6. Switch to soot loading condition and load for prescribed period
7. Switch to no soot condition and hold DPF at temperature for weighing
8. Weigh DPF

Features of Loading Test



Dp Test : Test Repeatability



DPF Flow Testing

DPG testing based on inlet p at atmosphere, exhaust sub atmospheric compare with engine or blown bench test with exhaust at atmosphere.

$\therefore$ overall pressure in DPF is lower in DPG than application

$\Rightarrow$ lower density

$\Rightarrow$ higher volumetric flow

$\Rightarrow$ higher measured backpressure

For comparability, consider pressure drop in element *dl* of DPF:

$$\frac{dp}{\rho} + udu + \frac{fu^2}{2A/P}dl = 0$$

momentum term: small
in walls of DPF

viscous pressure drop

Corrections between DPG and Blown Tests

Pressure drop from whole DPF

$$\left(p_{in}^2 - p_{out}^2\right) = \frac{p_s T f \dot{m}^2 l}{T_s \rho_s \left[A^3/P\right]}$$

- f = friction factor
- $[A/P^3]$ – length scale (hard to define for comparison between different DPFs)

Allows conversion of ‘sucked’ DPF measurements to blown conditions.

- small effect at low Δp

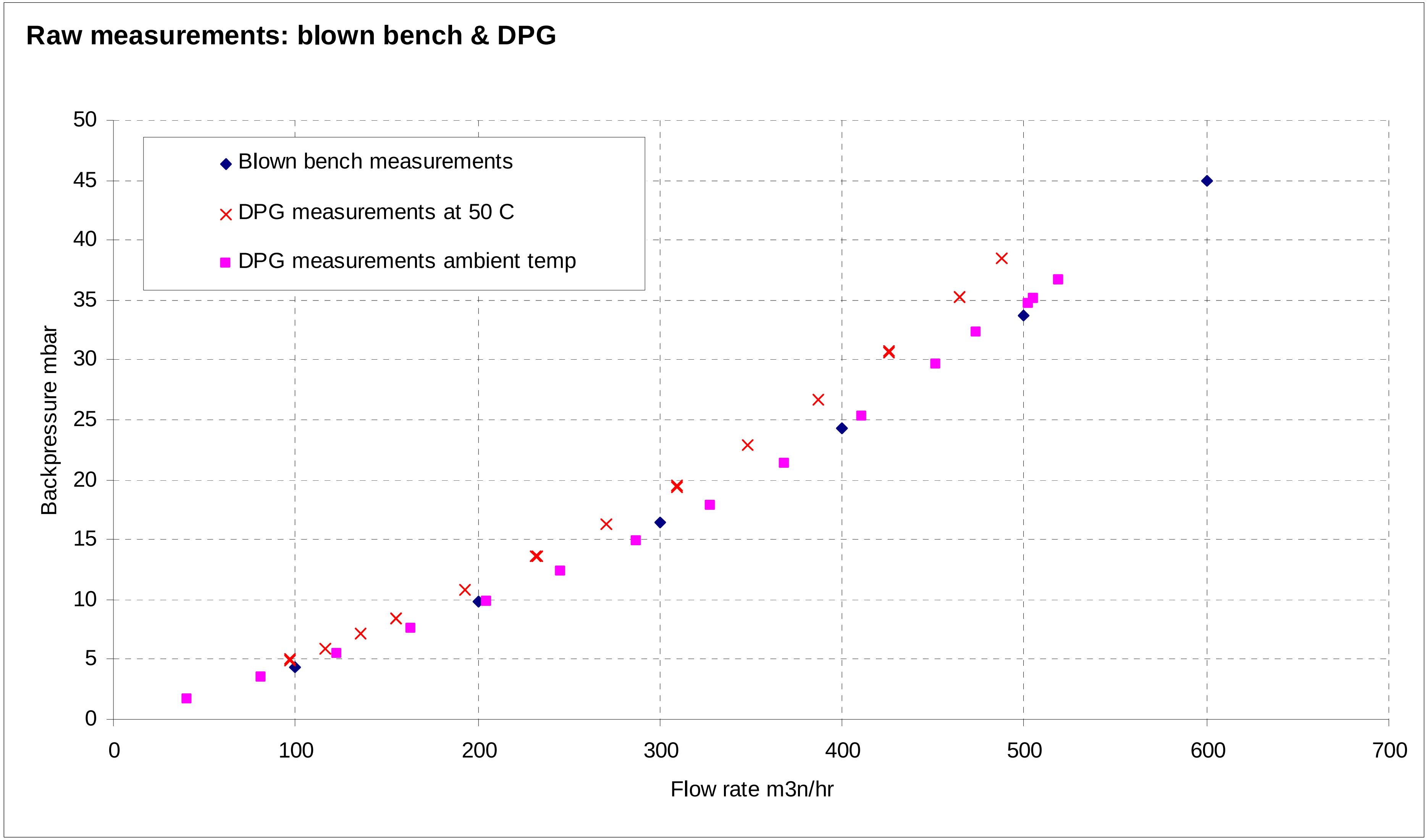
To relate DPG measurements to significantly different conditions, consider that f is a function only of Reynolds Number:

$$\mathrm{Re} = \frac{4}{\pi d}\frac{\dot{m}}{\mu}$$

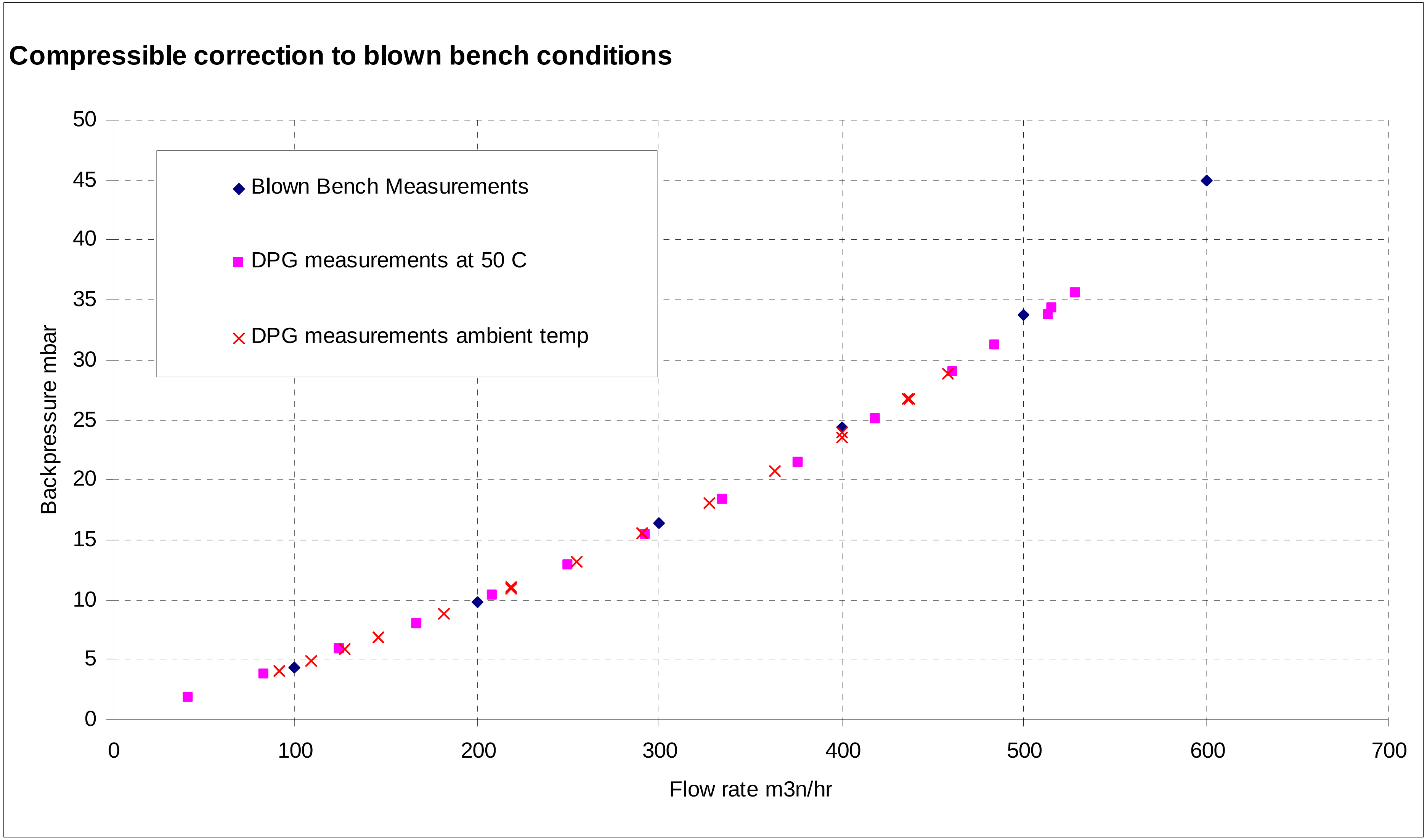
So if we want to relate DPG measurements to engine tests at different temperatures (hence viscosities), the mass flow is scaled.

Note that ambient temperature temperature flow tests are therefore equivalent to engine tests at a higher flow rate.

Correction of Flow Sweep Data



Correction of Flow Sweep Data



DPF Regeneration

DPG can easily generate temperatures in 600ºC to 800ºC range.

Achieved by:

- Increased fuel flow
- Reduced total air flow

Primary airflow increased to prevent soot production.

Operation is still overall lean.

Operation in the region around 600 ºC produces a relatively gentle, safe regeneration

Higher temperature regeneration followed by switch to colder flow conditions mimics DPF durability (maximum soot load) type testing.

Typical Regen : Cut to Idle Test

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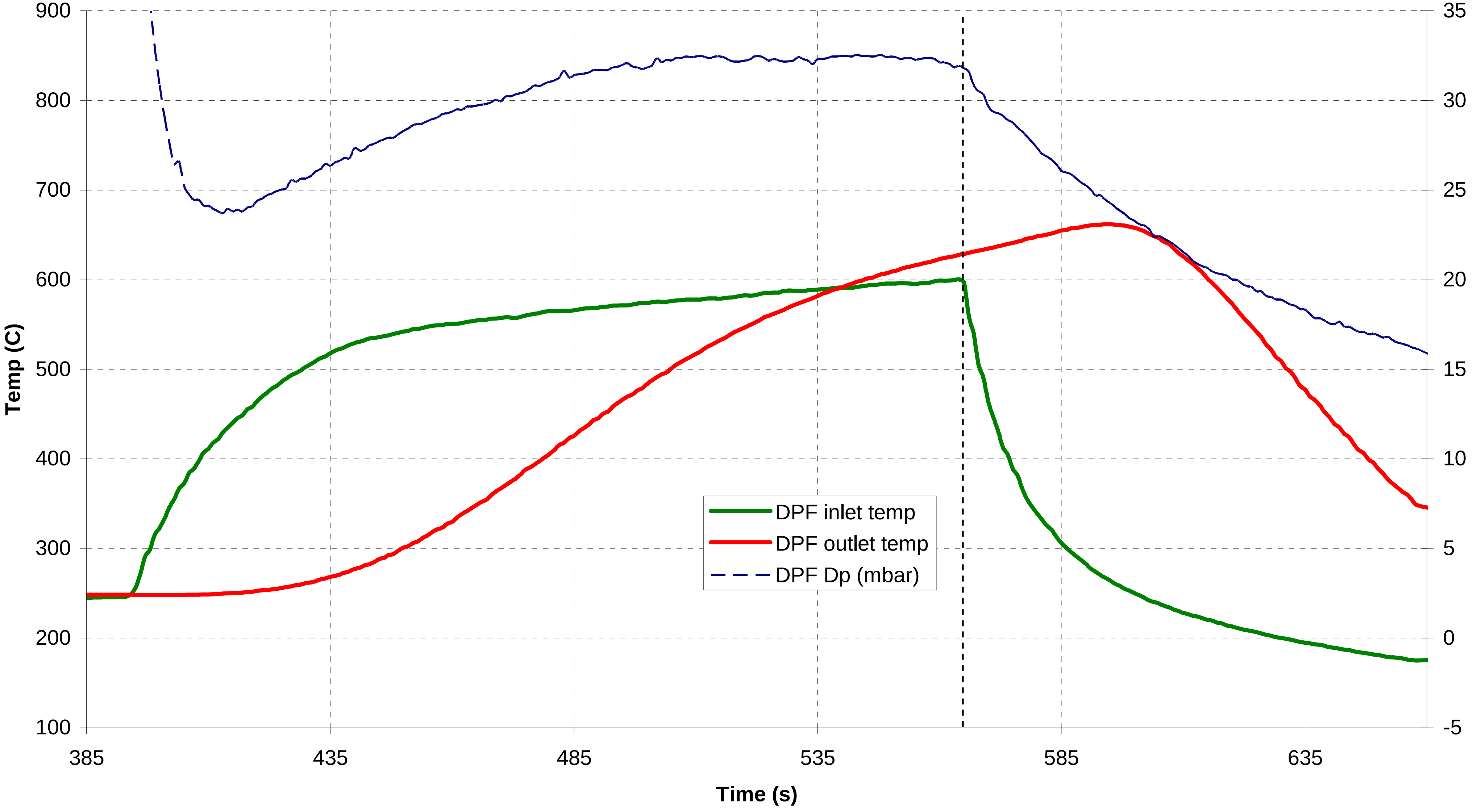
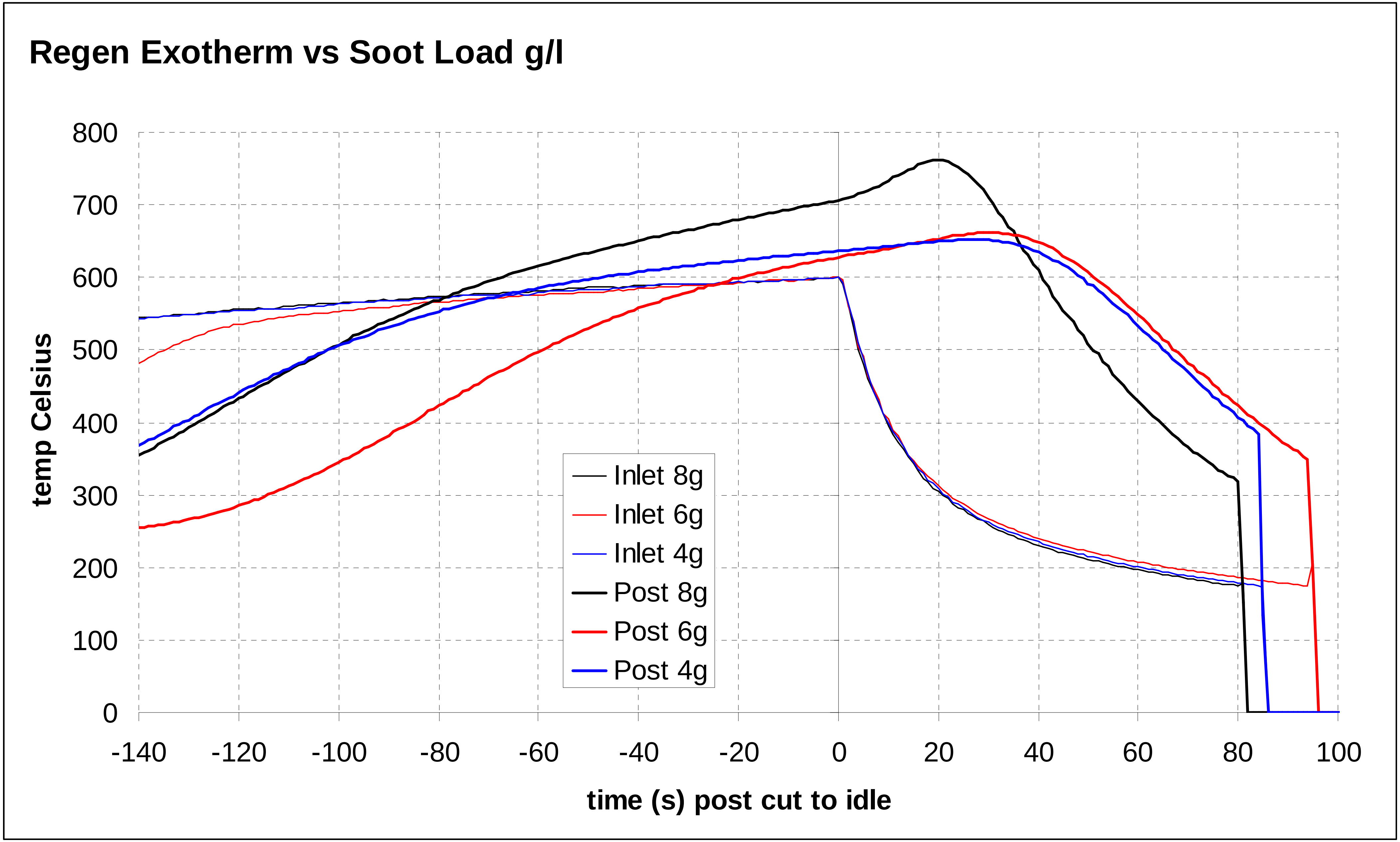


Effect of Soot Load on Exotherm



DPF Filtration Efficiency Measurement

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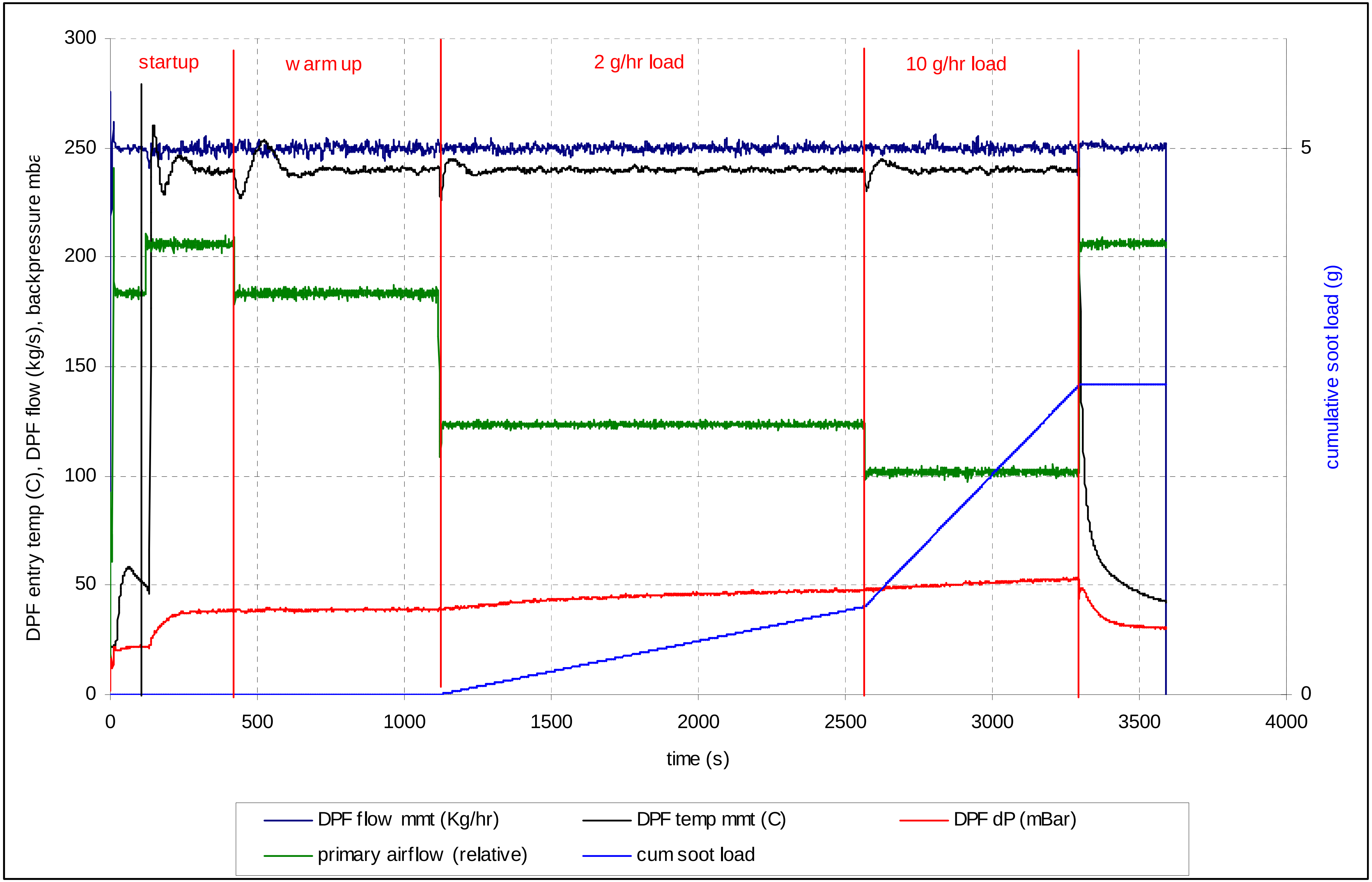
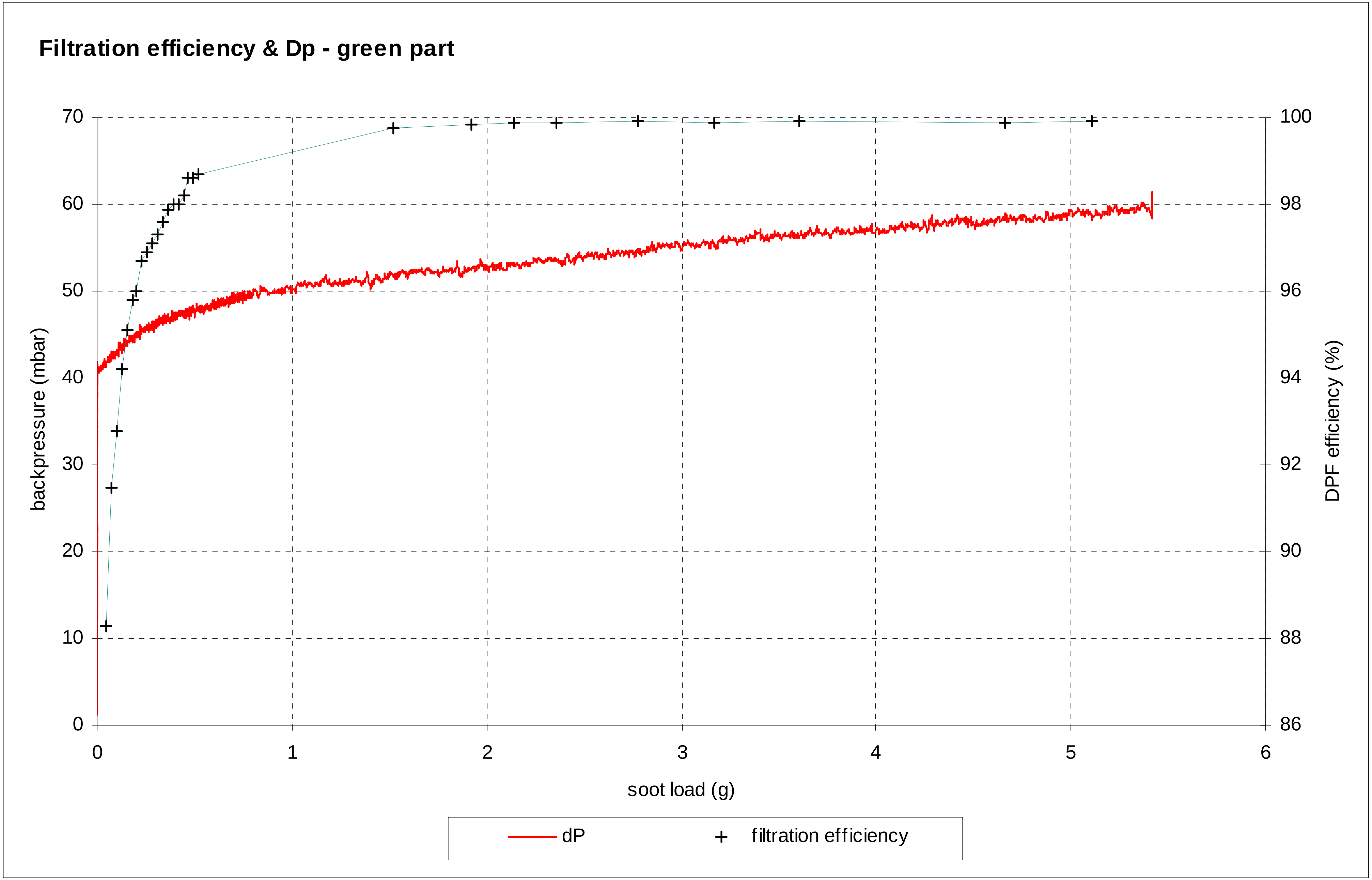
- Variation of DPF filtration efficiency as function of soot load measured with DPG
- Typical DPG installations use AVL415S smoke meter (paper blackening type) for soot rate monitoring and filtration measurement
  - good soot mass correlation
  - sensitivity just acceptable for efficiency monitoring to ~99.9%
  - smoke meter control & logging fully integrated into DPG software
- DPG operation can be tailored to optimise resolution of fast-changing filtration efficiency in pore-filling phase
  - soot rate reduced (2g/hr) to extend duration of pore filling phase
  - soot rate then increased to 10g/hr to accelerate measurement of loaded filtration efficiency, and improve sensitivity
  - smoke meter measurements scheduled to maximise downstream measurements (as DPG upstream concentration is very stable)
  - smoke meter sample volume automatically adapted to optimise sensitivity
  - DPF flow reduced to maximise soot concentration

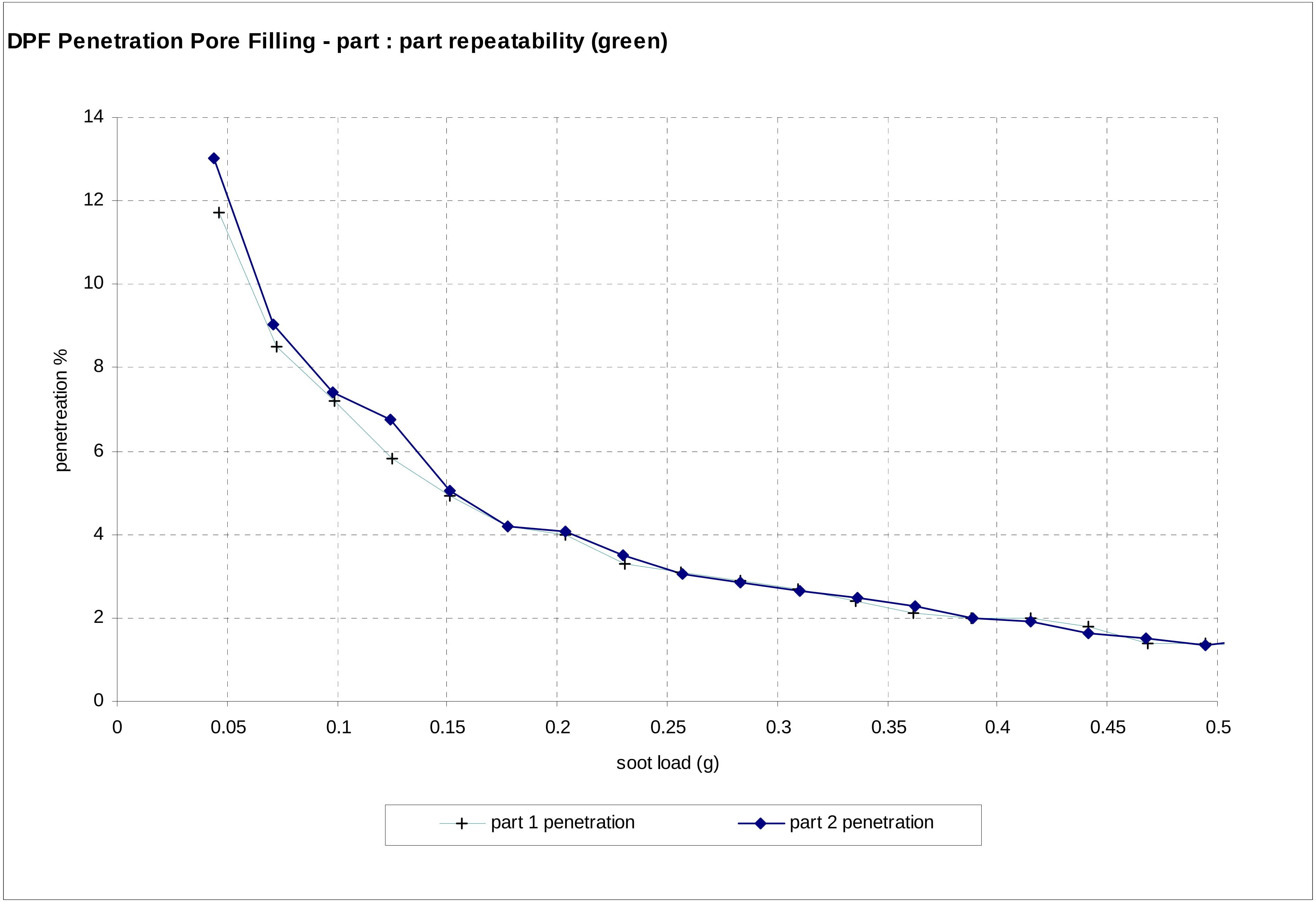
Typical Filtration Efficiency Test



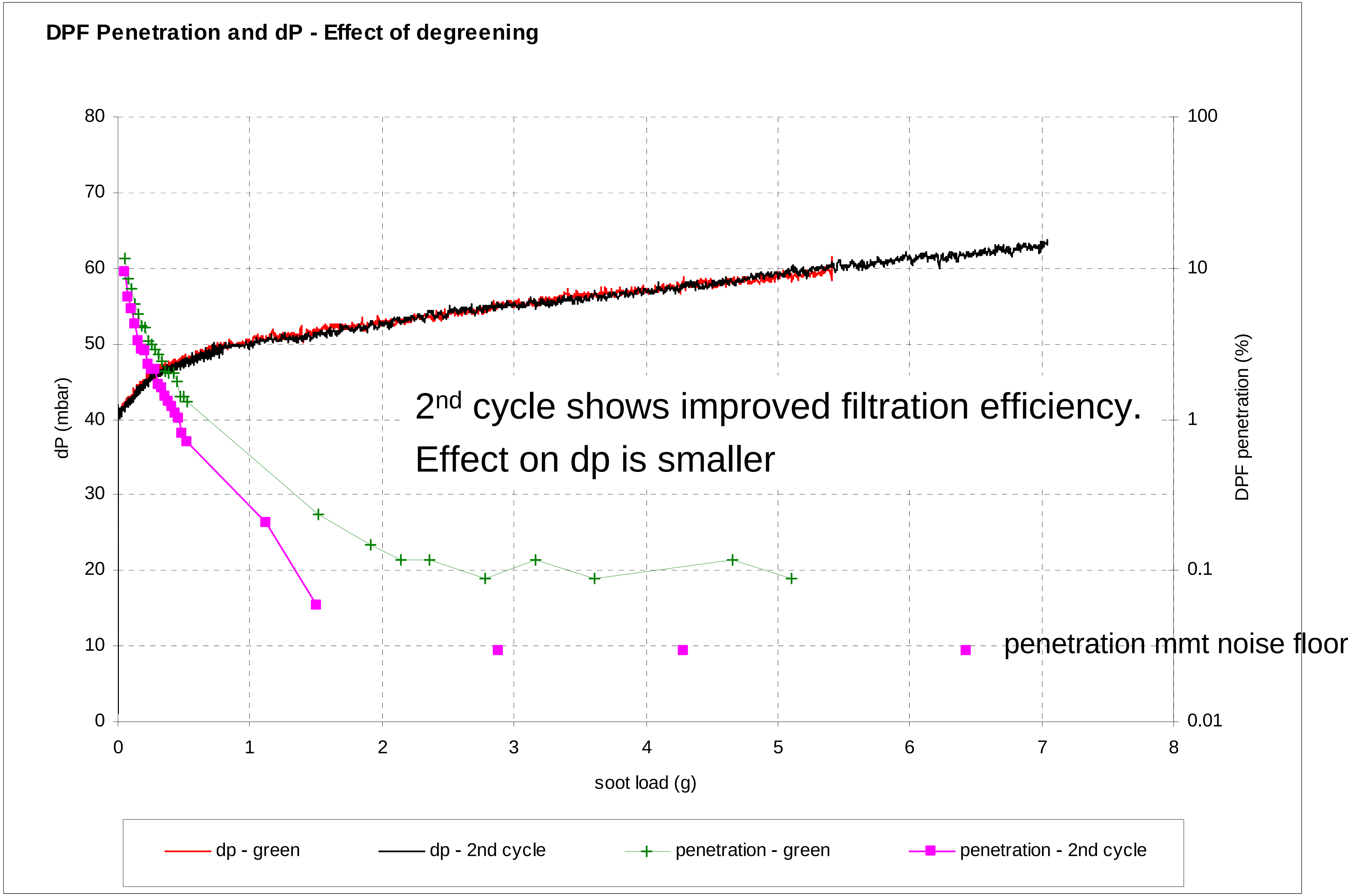
Filtration Efficiency vs Soot Load



Penetration Measurement Repeatability

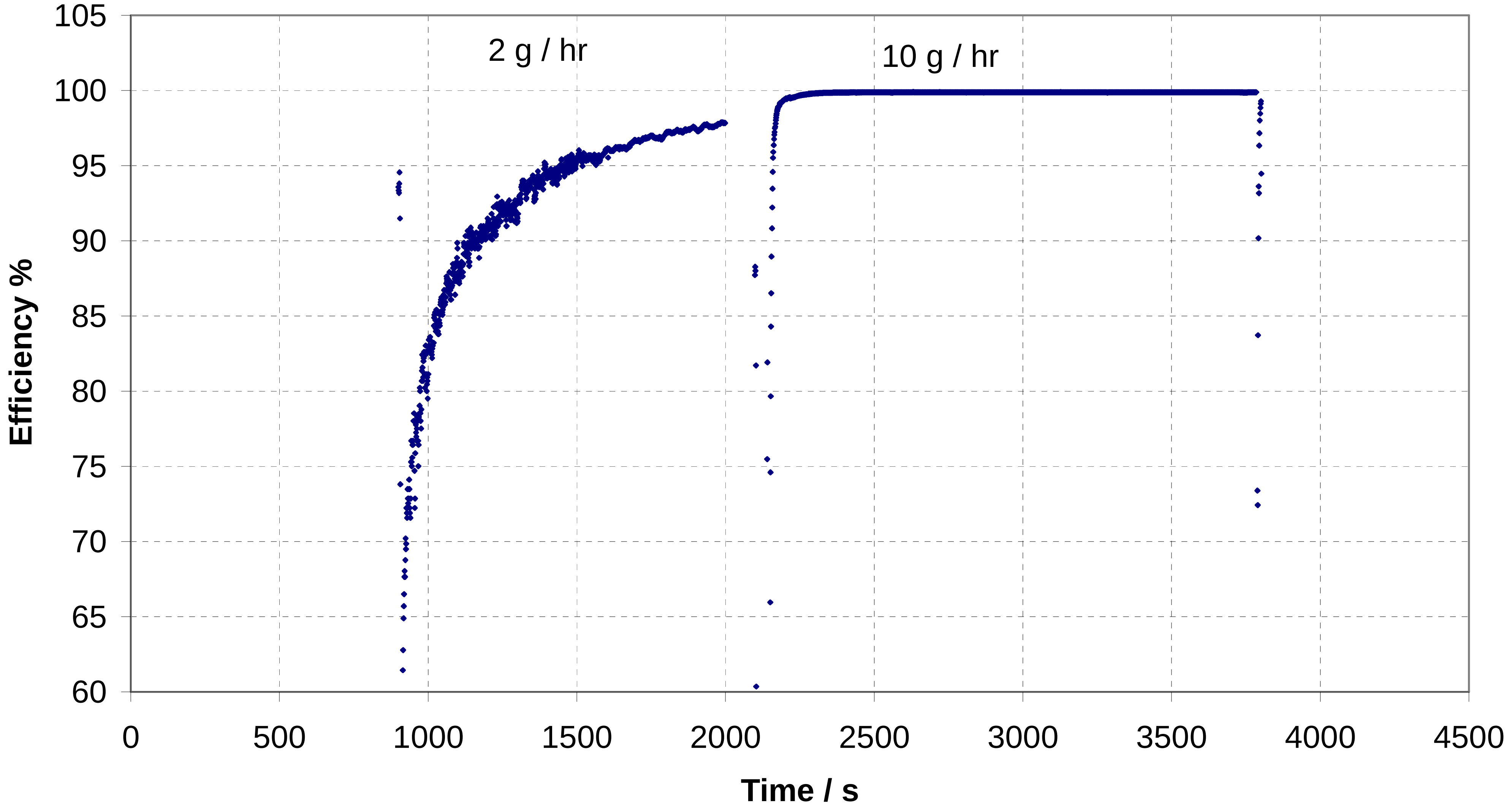


Effect of DPF Aging



Filtration Measurement with CPC + VPR

D1 DPF Number Efficiency



- Improved sensitivity compared with smoke meter
- Faster time response of measurements

Conclusions

Demonstrated measurements of

- Dp vs soot load characteristics
- Flow sweeps
- Regeneration behaviour
- Filtration Efficiency testing

with the DPG

Further work is continuing on extending these applications and optimising similarity of DPG measurements to engine tests.

I'd like to acknowledge the assistance of Ray Brand, Jon Symonds, Mark Rushton and Tim Hands in the experimental work reported here.