Thermal Shock Investigation of Aluminum Titanate-based Ceramic Filters under Robustness Testing

Dr. Kentaro Iwasaki Tomasz Kukielka, Artur Narewski,

SUMIKA CERAMICS POLAND Sp. z o.o.

ul. Bierutowska 87, 51-317 Wrocław, Poland

Sumitomo Chemical Aluminum Titanate as "SUMIPURE®"

Abstract

Diesel Particulate Filters (DPFs) are required to be shown as higher robustness performance under every severe circumstance since the fuel penalty issues are coming to reduce CO2 emission up to 90 g/km in 2020 (EU). It is considered that the DPF robustness mainly depends on the thermal stress coming from the temperature changes inside DPF during regeneration process (combustion duration for accumulated soot particles inside DPF).

Newly-developed DPF with higher thermal properties of Aluminum Titanate (AT) materials and unique cell design of asymmetric hexagonal structure has recently been developed. The characteristic is lower pressure drop especially under soot-deposition, and higher ash capacity based on the cell design. In this paper, various testing condition for the robustness performance on AT-DPF are addressed.

The result shows the thermal shock testing results with LDV engine bench system under drop-to-idle (DTI) condition a) and drop-to-non-load (DTNL) condition b) on AT-DPF (DPF size is 5.66 inches of diameter / 6 inches of length in cylindrical shape) with catalytic coating. While DTI mode simulates that the vehicle is driven to be climbed up to the steep hill with full-pedal and then kept to run on flat way without the pedal, DTNL mode climbing up to the hill with full-pedal and down the hill with constant engine rotation. At both modes, no damage in DPF to make soot-leakage behavior was observed after the testing. A remarkable difference was shown between both modes in temperature behavior after the post injection is over. DTI mode shows higher temperature on every points at DPF internal although the timing in temperature increase differs individually due to its material properties of lower heat conductivity of AT. On the other hand, it was observed that DTNL mode makes lower temperature especially on outer area of DPF. The behavior can be explained by the specific gas flow from engine side on the testing. At any timing before and after pot-injection-stopping for regeneration the higher gas flow is kept to be through DPF, resulting in making lower temperature on the outer position.

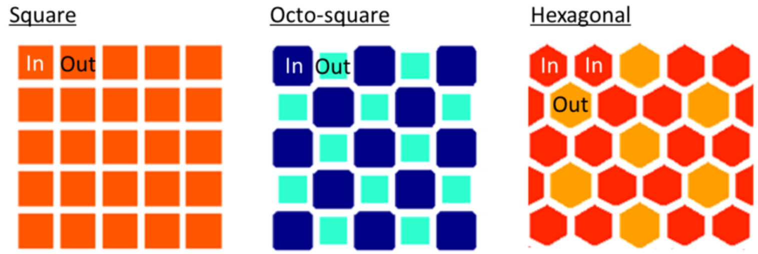
SUMIPURE® DPF Features

✓ Material Properties

Substrate	AT	SiC	Cordierite
CTE*1 [10^{-6} K^{-1}]	<1	4	<1
MOR/eMod = TSP*2 [x 10^3]	3.6	2.3	3.3
Material density [g cc^{-1}]	3.7	3.2	2.6
Heat capacity [kJ L^{-1} K^{-1}]	2.0	1.9	1.3

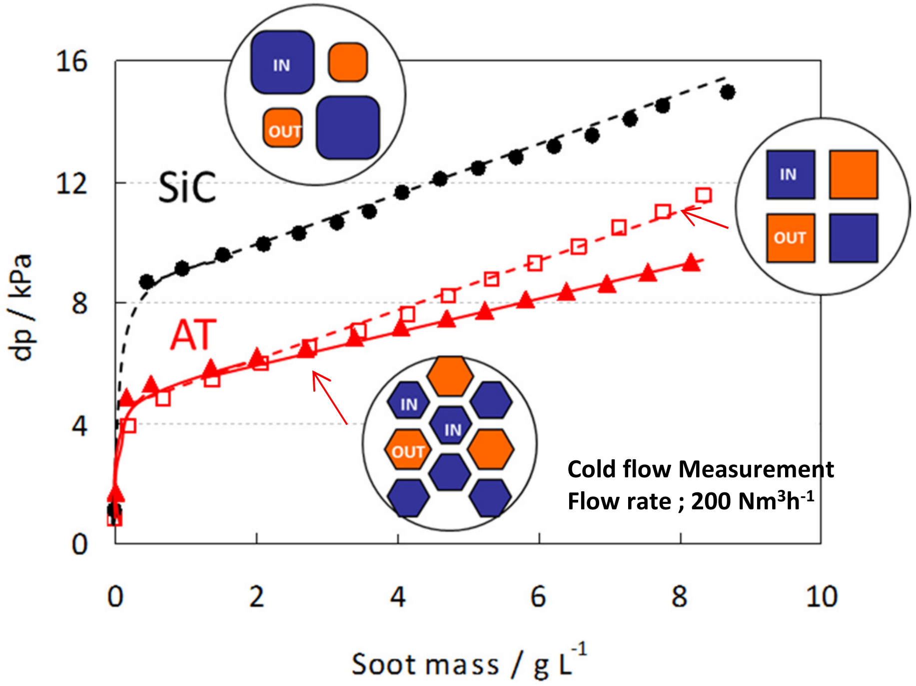
*1 Coefficient of Thermal Expansion
*2 Thermal Shock Parameter

✓ Cell Design Advantage

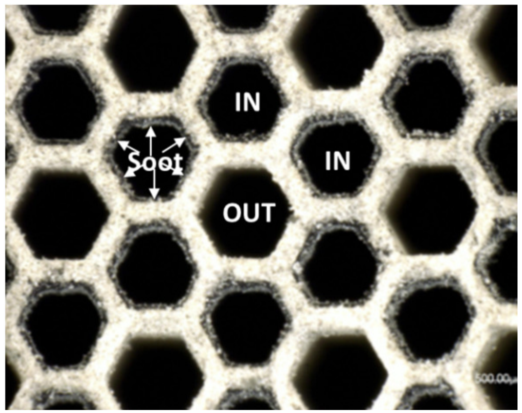


Cell design	Square	Octo-square	Hexagonal "Hex"
Ash capacity	Low	High	**High**
dp initial	Low	High	**Low**
dp w soot	High	Medium	**Very low**

Backpressure (dp) characteristics



Soot layers on inlet wall of DPF

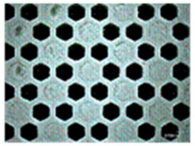


- **Higher filtration area**
  - → **Lower backpressure**
- **Higher Open frontal area (Ash capacity)**
  - → **Longer usage / Durability**

Research Motivation

DPF Thermal shock performance Study under Several Conditions

DPF specification

Material	Aluminum Titanate
Cell geometry	Hexagonal (HEX)
Photo of inlet face	
Catalytic Coating	On
Dimension	5.66D6L
Weight / g L^{-1}	800
Hydraulic diam. [IN/OUT] / mm	1.1 / 1.2
Cell density / cpsi	350
Wall thickness / mil	11
Open frontal area / %	41
Filtration area / m^2 L^{-1}	1.30

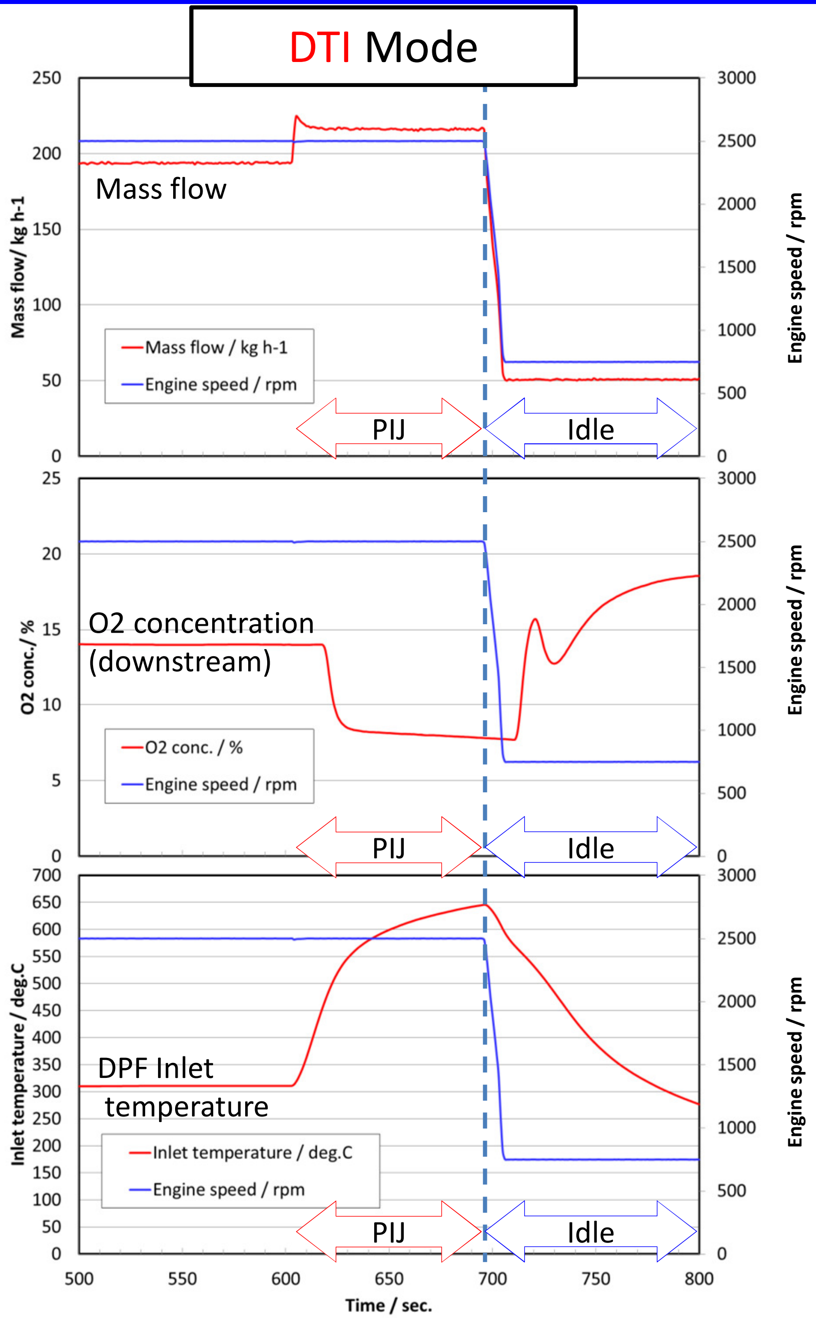
Engine specification for Testing

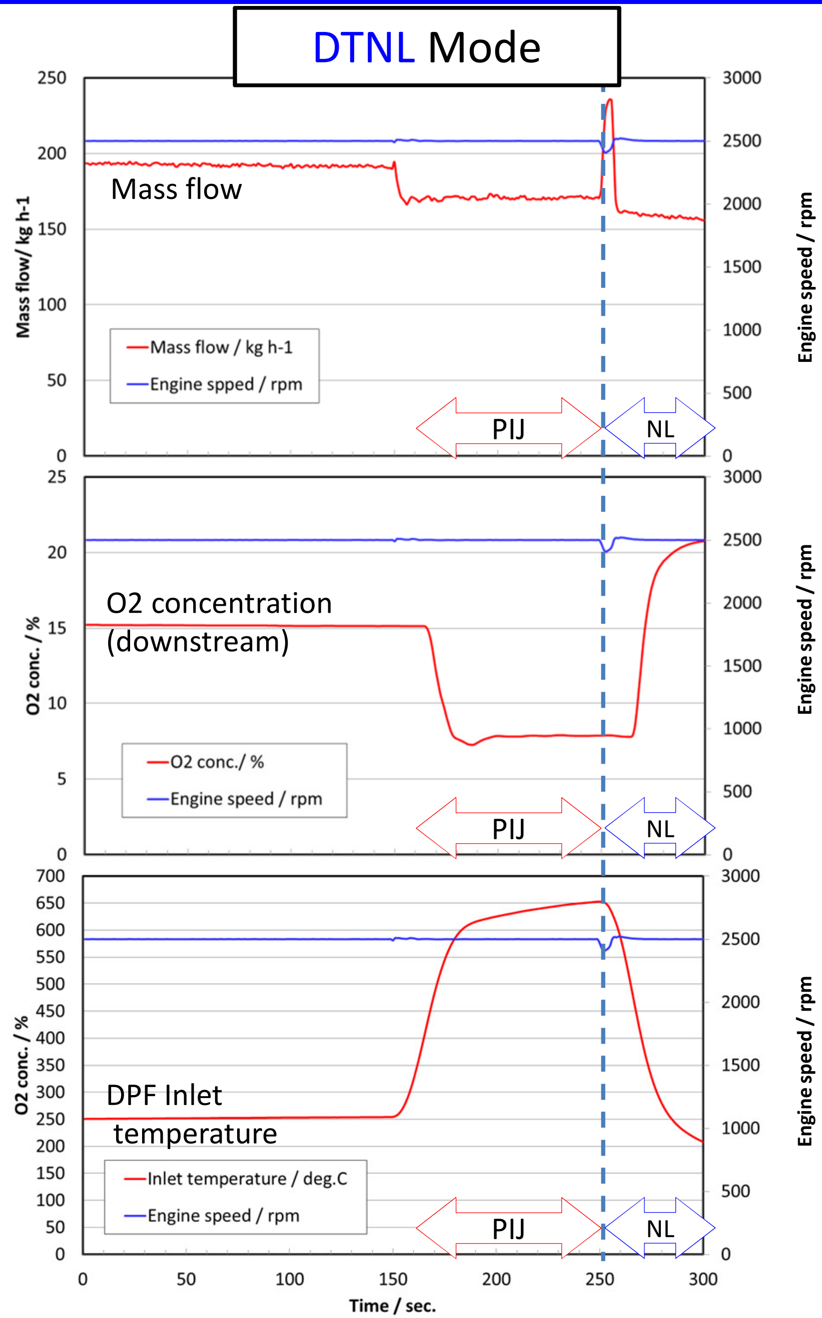
Type	2l-class engine – Inline 4
Air System	4 valves Turbocharger with VTG and Intercooler cooled HP-EGR Throttle Variable swirl
Injection System	Common Rail (Bosch) CP3 (p_{max}=1600bar)
Rated Power	110 kW
Rated Speed	3800 rpm
Maximum Speed	4800 rpm
Maximum Torque	330 Nm (1200-2400rpm)
ECU	EDC16C2 w/ full access

Thermal Shock Testing Condition Status

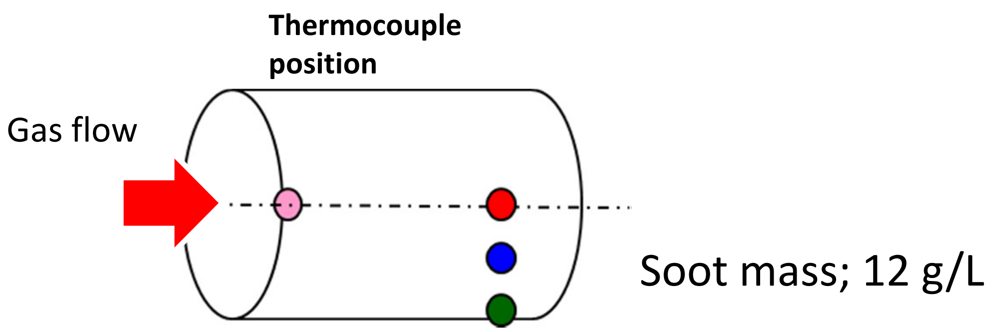
- Drop-to-idle (DTI) mode
- Drop-to-Non-Load(DTNL) mode

Experimental Input Condition

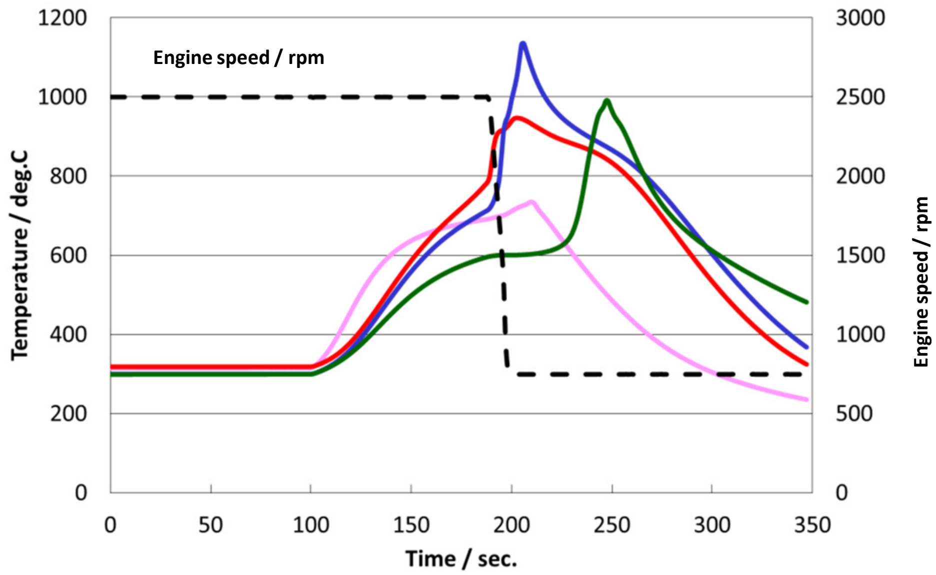




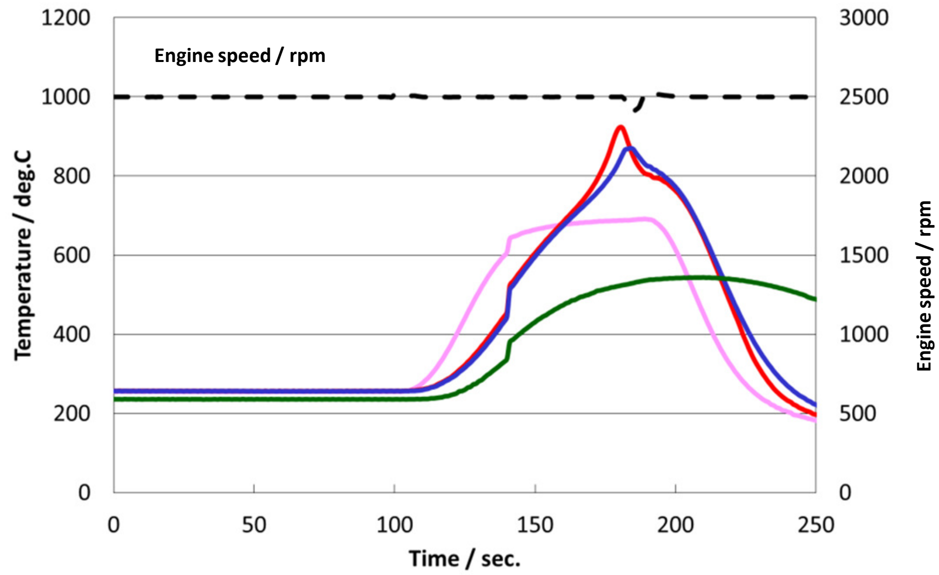
SUMIPURE® Internal DPF Temperature Profile



DTI Mode



DTNL Mode

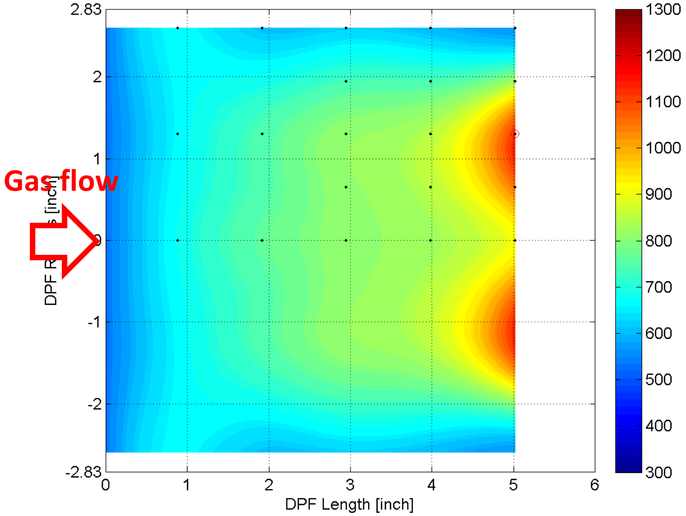


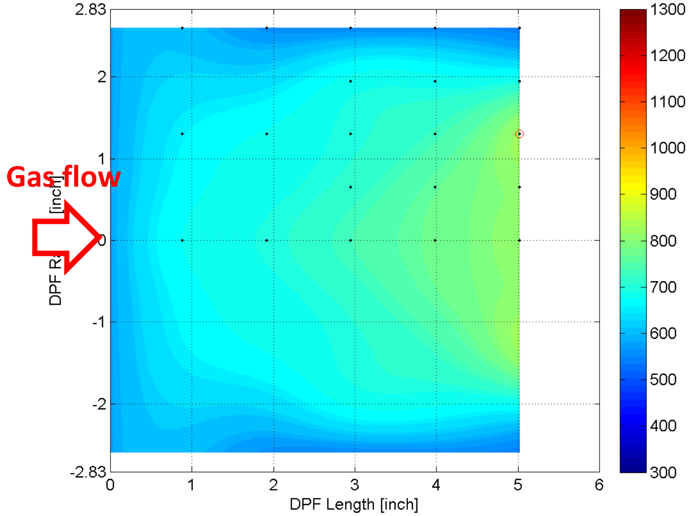
SUMIPURE™ Mapping at Maximum Temperature

Soot mass

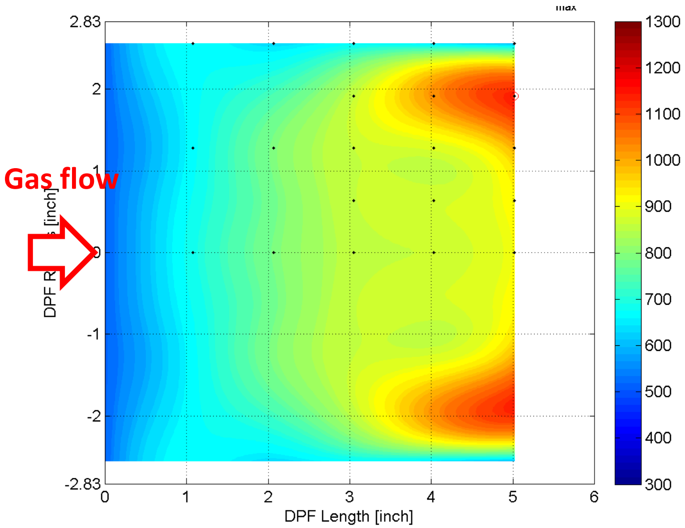
DTI Mode | DTNL Mode

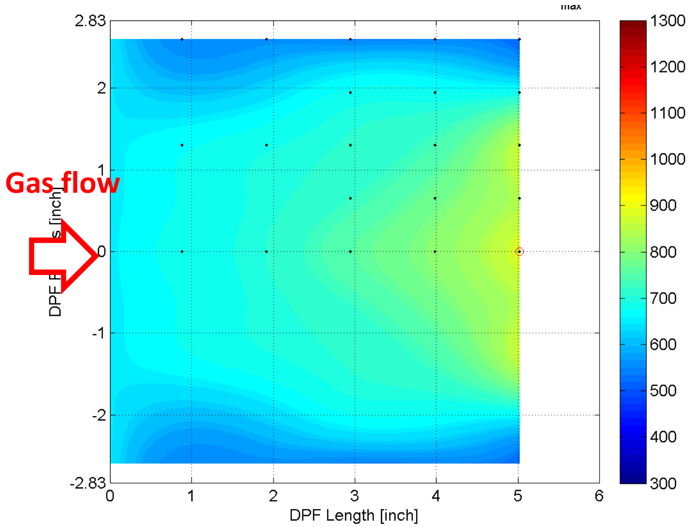
10 g/l





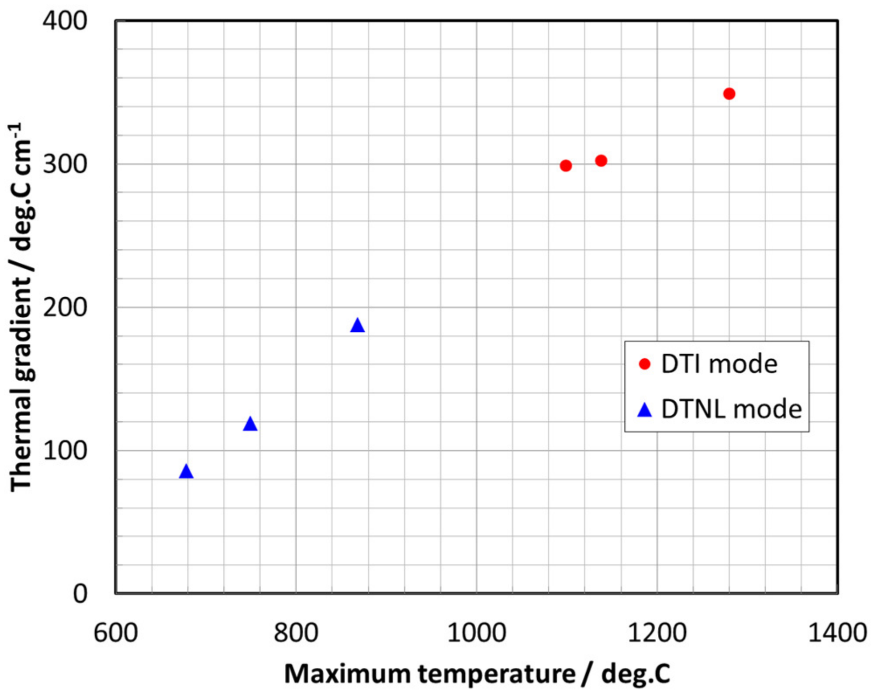
12 g/l



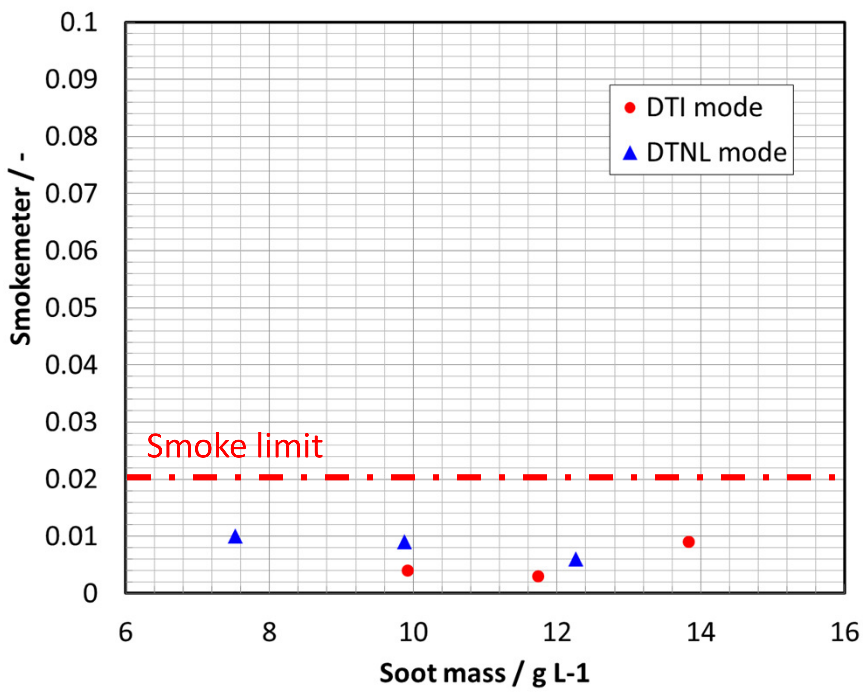


SUMIPURE® Thermal Shock Performance

Max temperature vs. thermal gradient



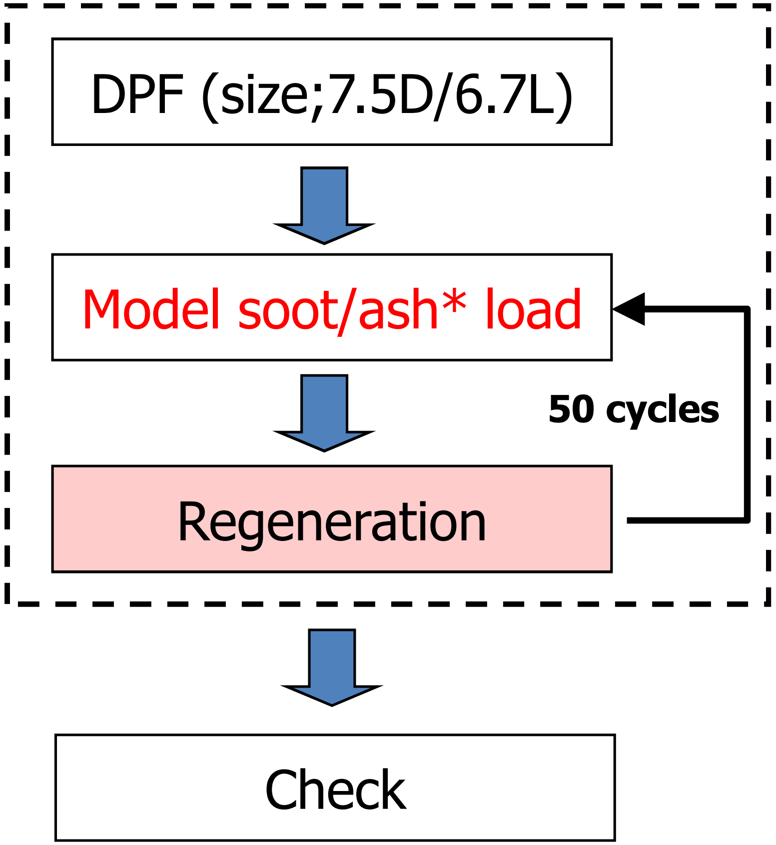
Soot-leakage Check after Thermal shock testing



SUMIPURE™ shows no remarkable damages on both thermal shock mode.

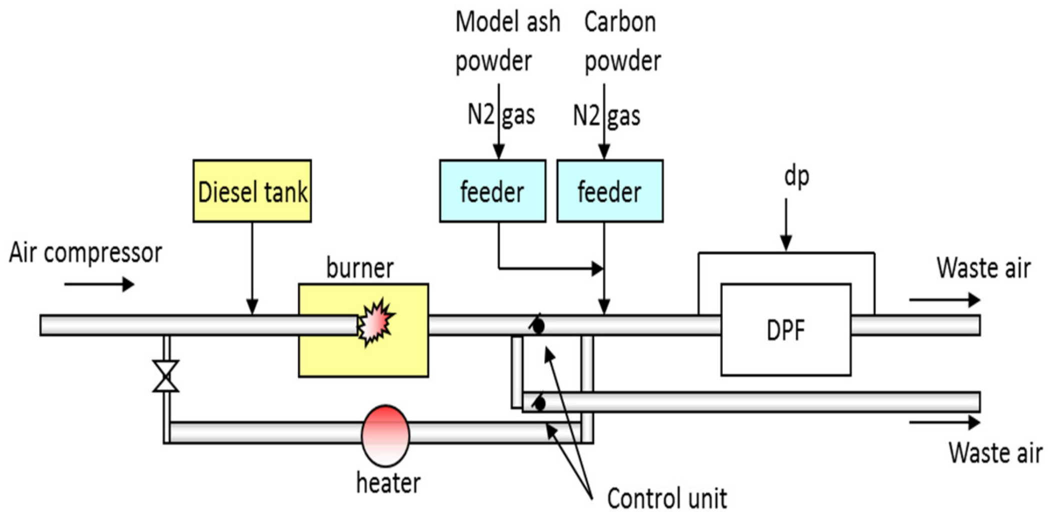
SUMIPURE® Durability Investigation

Experimental Flow Chart

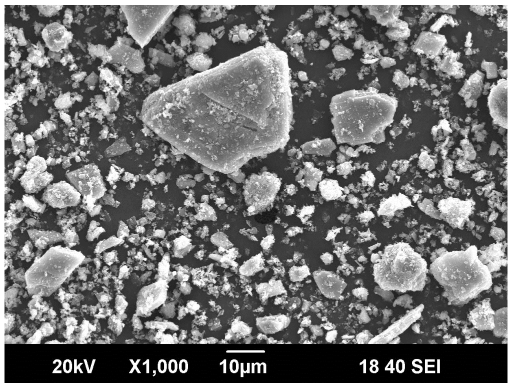


*Total ash :140 g/DPF
(= 300,000 km run.)

Heat Cyclic Specified Apparatus (soot/ash-dosing)



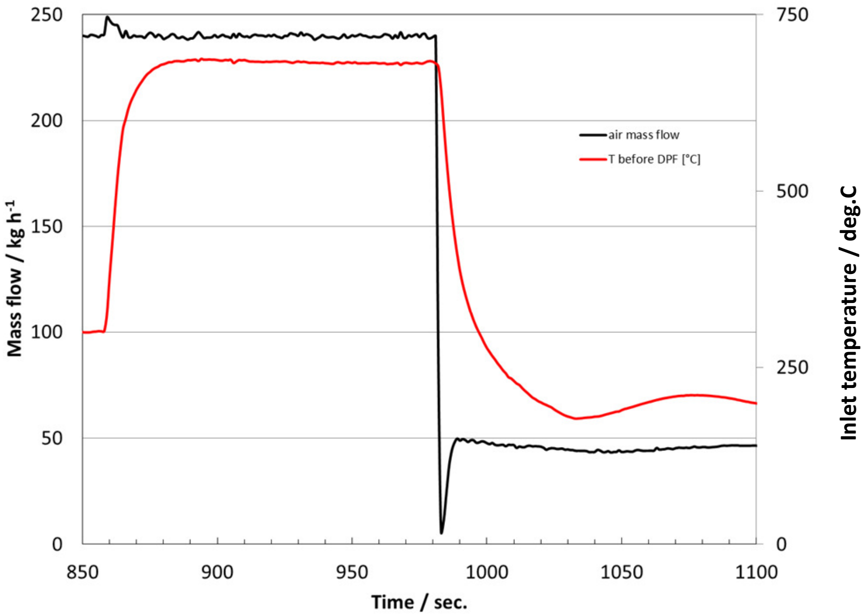
Model ash properties



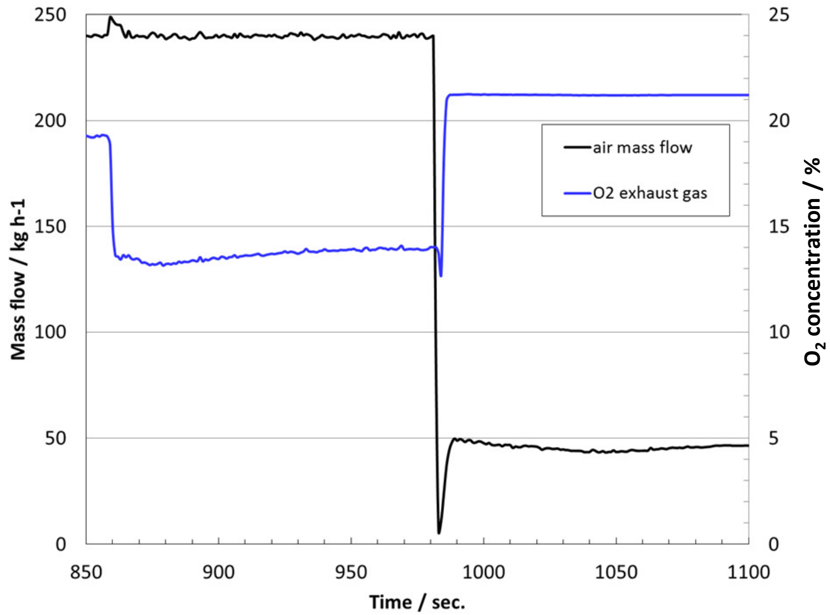
Weight %	Model ash
$Zn_3(PO_4)_2$	27
$Ca_3(PO_4)_2$	22
$CaSO_4$	19
$Mg_3(PO_4)_2$	19
Fe_2O_3	6
SiO_2	4
K_2CO_3	2
Na_2CO_3	1

SUMIPURE® Durability Testing ; Input Condition

Mass flow and DPF inlet temperature

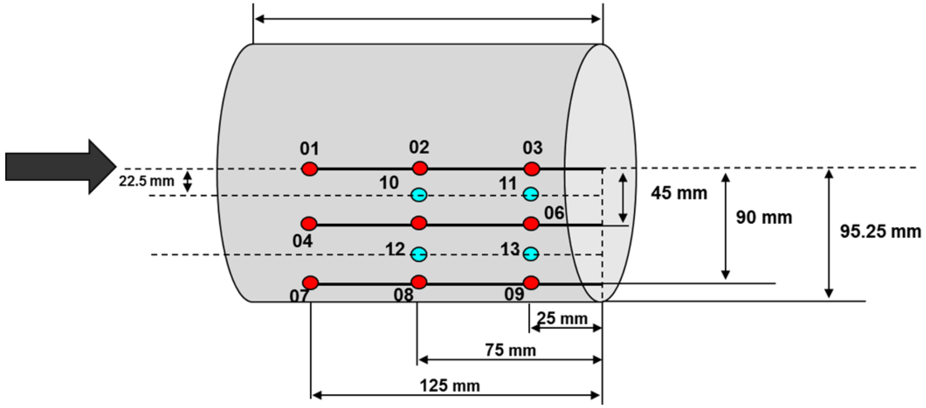


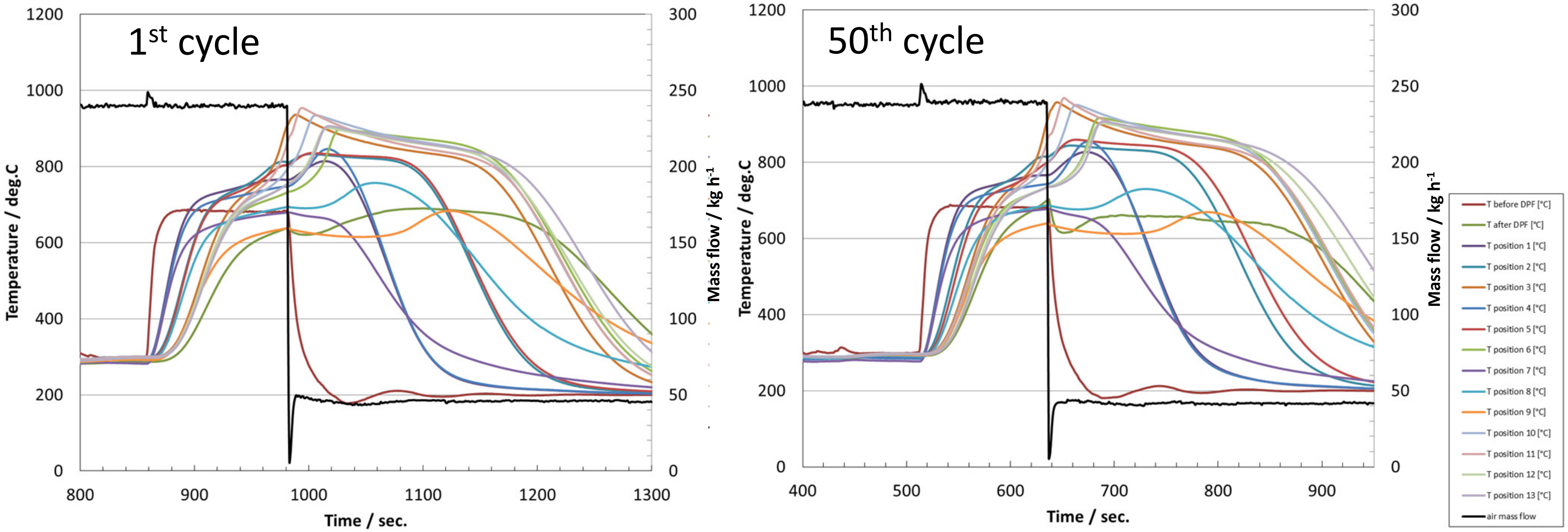
Mass flow and O2 concentration



SUMIPURE® Internal temperature behavior

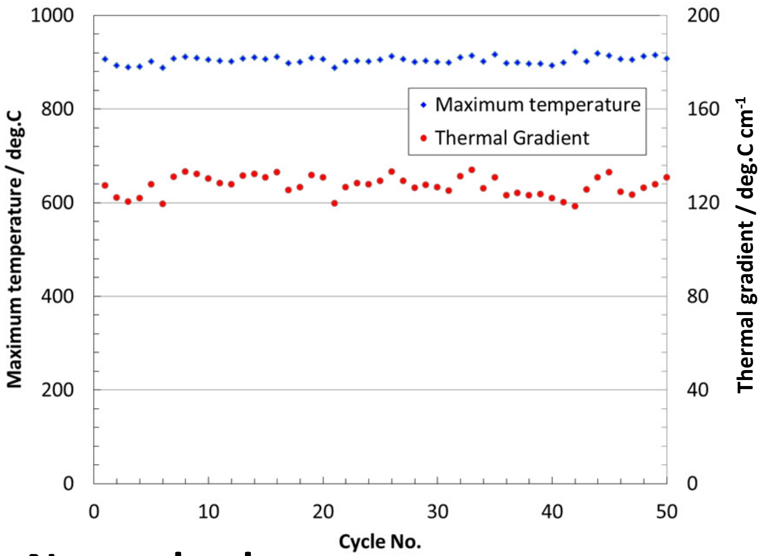
7.5D / 6.7L



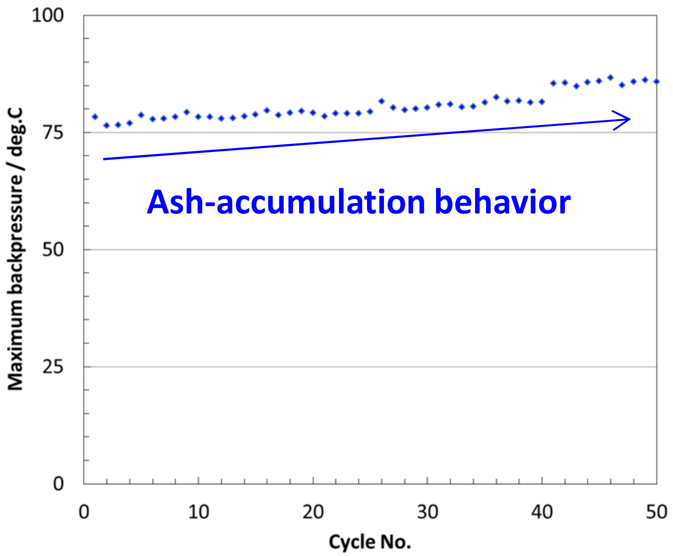


SUMIPURE® Durability Thermal Performance

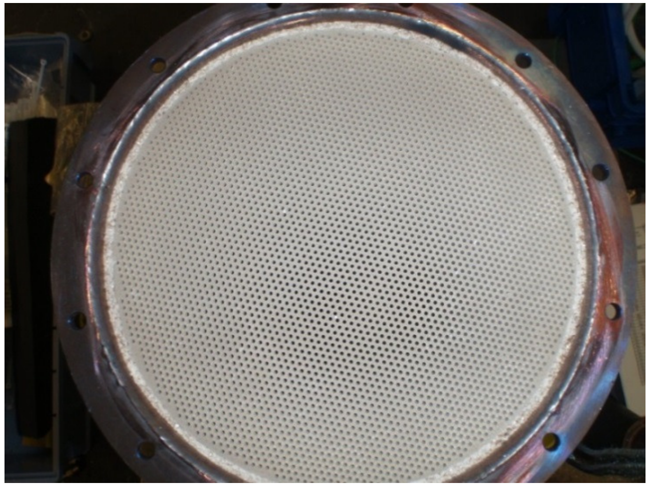
Cycle No. vs. Max T

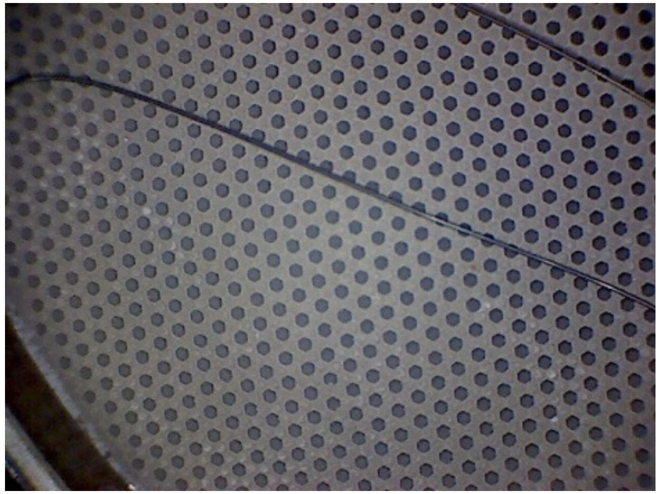


Cycle No. vs. backpressure



Outlet face of DPF after 50 cyclic testing.





No remarkable damages.

Conclusion

As for thermal shock testing condition,
Drop-to-idle (DTI) and Drop-to-non-load (DTNL) mode were performed.
DTI mode caused higher Tmax, and gradient than DTNL mode inside DPF.
SUMIPURE® shows no remarkable damages on both thermal shock mode.

In durability testing on heat-cyclic/ash-accumulation procedure,
SUMIPURE™ shows no remarkable damages (thermal shock crack/ash-melting).

Acknowledgement

The authors acknowledge Sumitomo Chemical Group for the contribution of DPFs preparation, and FEV GmbH for the validation on engine bench testing of DPFs.