Ash Effects on Catalyzed Diesel Particulate Filter Performance

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Abstract

As diesel emission regulations become increasingly stringent the use of Diesel Particulate Filters (DPFs) is ever increasing in OEM applications. Modern DPFs exhibit very high filtration efficiencies, however they need to be periodically cleaned (regenerated) in order to achieve efficient and safe operation of the vehicle. As typical diesel exhaust conditions are not hot enough to initiate and maintain particulate (soot) oxidation, active (engine) means are employed to raise the exhaust gas temperature up to the point that particulate oxidation can be self-sustained in the filter, at fast enough rates (>650 C). To achieve the oxidation of soot particles at lower temperatures (250 – 550 C) a number of direct and indirect catalytic measures can be employed ranging from fuel additives, generation of reactive species, and catalytic combustion of post-injected fuel and filter coatings promoting soot oxidation.

Modern trends in passenger car emission control systems are now emphasizing on so-called “fit-for-life” solutions overcoming the need for servicing (ash removal) of the DPF during the vehicle lifetime. Robustness and durability of the engine and emission control system is also clearly a first priority in heavy-duty surface transportation. These trends create new opportunities for the application of catalytic DPFs and new needs for multifunctional catalytic filters which: (i) will exhibit some oxidation activity under moderate exhaust temperature to prolong as much as possible the intervals between fixed regenerations, exploiting direct (i.e. through oxygen transfer) as well as indirect (through NO2 generation) soot oxidation, (ii) will exhibit reduced soot ignition temperatures compared to uncatalyzed filters to allow for energy savings during regeneration and (iii) will be tolerant to ash accumulation.

The objective of this work is to study the effect of ash ageing on uncatalyzed and catalyzed filters. Experimental data characterizing the material (permeability, soot and ash deposit properties) are obtained in a dedicated experimental set-up in the side stream of a modern Diesel engine as well as in an accelerated ash loading rig. Thermal as well as NO_2-assisted regeneration (soot oxidation) experiments of the sintered metal material coupons have been performed to assess the effect of ash layer on the filter regeneration performance.

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MOTIVATION

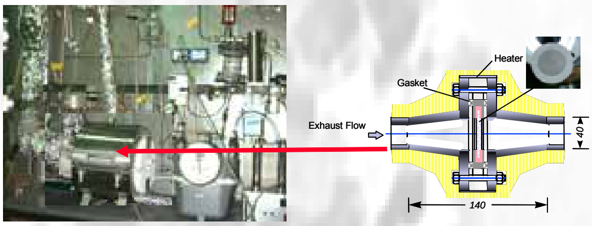
The objective of this work is to study the effect of ash ageing on uncatalyzed and catalyzed sintered metal material filter samples*. Experimental data characterizing the material are obtained in a dedicated experimental set-up in the side stream of a modern Diesel engine as well as in an accelerated ash loading rig. Thermal regeneration (soot oxidation) experiments of the sintered metal material filter samples have been performed to assess the effect of ash layer on the filter regeneration performance.

*Konstandopoulos A. G., Vlachos N., Stavropoulos I., Skopa S., Schumacher U., Woiki D., Frey M., (2005) "Study of a Sintered Metal Diesel Particulate Trap", SAE Tech. Paper No. 2005-01-0968 (SP-1940)

EXPERIMENTAL

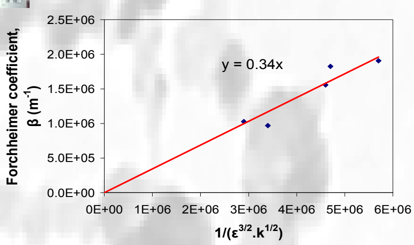
PERMEABILITY MEASUREMENT

Circular material filters are placed in a controlled air flow with the aid of a special holder and the pressure drop is recorded at various flow rates. The permeability values are calculated according to Darcy's law.

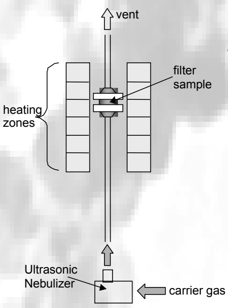


$$\Delta P_{clean} = \underbrace{\frac{\mu}{k} u w_s}_{Darcy} + \underbrace{\beta \rho u^2 w_s}_{Forchheimer}$$

Forchheimer coefficient $\beta = \frac{const.}{\varepsilon^{1.5}\sqrt{k}}$



ASH LOADING



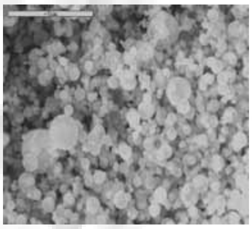
A novel ash synthesis and deposition process has been developed based on Aerosol Spray Pyrolysis (ASP) of oil-fuel droplets

- Diesel fuel and engine oil (50% - 50%)
- Engine oil used: SELENIA SAE 10W-40
- Ash content in engine oil: 0.95% (Ca, P, Zn, S)
- Filtration velocity = 14 cm/s
- Temperature = 700 C

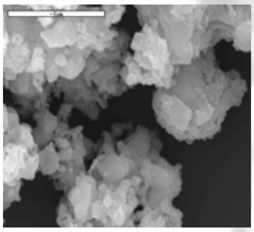
COMPARISON TO ENGINE ASH

- **Photographs with SEM**

Oil-derived ash

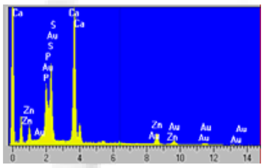


Engine ash



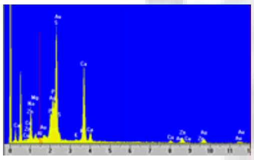
- **EDX analysis**

Oil-derived ash



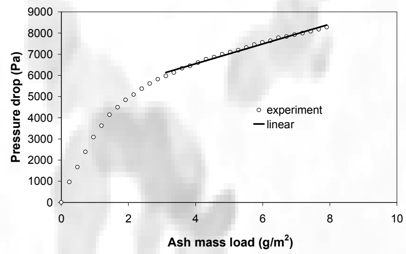
Ca, P, S, Zn

Engine ash



Ca, P, S, Zn, K, Cu

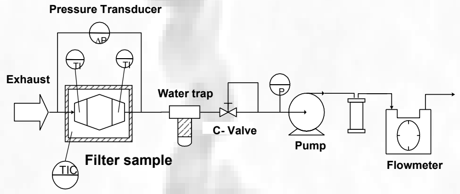
Ash properties



$$\Delta P_{ash\ layer} = \frac{\mu}{k_{ash}} u w_{ash} = \frac{\mu Q m_{ash}}{A^2} \frac{1}{\rho_{ash} k_{ash}}$$

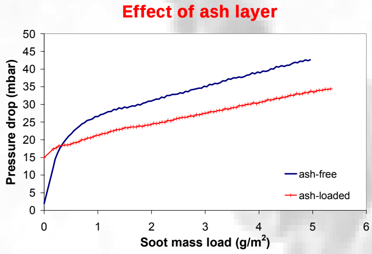
SOOT LOADING

Ash loaded filter samples have been subsequently loaded with engine soot. The results were compared to those obtained from the clean filter materials.

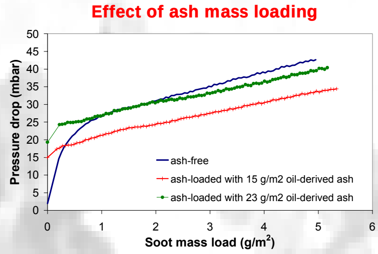


- EURO III diesel engine
- Temperature: 320 C
- Filtration velocity: 4 cm/s

Effect of ash layer

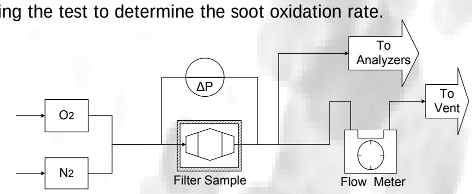


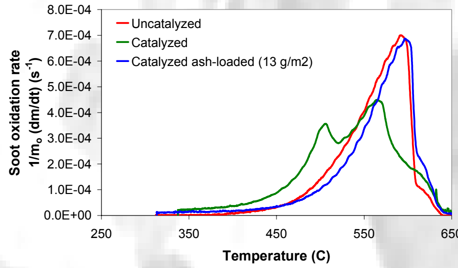
Effect of ash mass loading



REGENERATION

For the temperature programmed regeneration experiments the filters are exposed to a synthetic exhaust mixture (10 % O_2 in N_2) of constant volume flow rate at 1.5 std lpm. Temperature is ramped from 300 C to 700 C at a rate of 3 C/min and then it is kept constant at 700 C until regeneration is completed. Concentrations of CO and CO_2 are monitored during the test to determine the soot oxidation rate.





CONCLUSIONS

- A novel ash-loading procedure has been developed applicable for ash loading of sintered metal filter materials.
- This method looks promising since it can provide similar ash particle sizes and flow resistance behavior to that of engine ash.
- The pressure drop of an ash loaded filter sample although initially higher than the pressure drop of the clean filter, quickly establishes a lower loading rate. This phenomenon is attributed to a modification of the filter surface texture, caused by the deposited ash. This ash layer establishes a well-defined and sharp boundary between the soot cake and the interior of the filter wall, eliminating the deep-bed filtration regime, leading to a lower overall pressure drop.
- High ash loading can have deleterious effects on catalytic activity.

ACKNOWLEDGEMENTS

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