Low temperature regenerating microwave susceptible catalytic diesel particulate filter

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Highlights

- Specific procedure to increase the average pore diameter in the bare monoliths.
- The filter regeneration step has a decreased frequency and duration.
- The microwaves totally regenerated the catalytic DPF
- The combined use of microwaves and catalytic DPF allows a higher energy saving

1. Introduction

The wall flow diesel particulate filter (DPF) is the usual post-treatment device in Diesel engines for soot abatement, showing the best compromise between a high filtration efficiency and sustainable pressure drop [1]. The monoliths are characterized by alternatively plugged square channels, in this way the exhaust mass is forced to flow through the channels porous walls, and the filtering surface physically traps the soot [2]. Soot accumulation lead to a non-negligible pressure drop that increases the exhaust back-pressure, so the periodic burning of the accumulated soot is mandatory for its regeneration [1]. An innovative DPF configuration could be obtained by depositing a microwave susceptible and oxidant catalyst on a silicon carbide (SiC) filter, and by using the microwaves to heat up it to the soot oxidation temperature [3], so combining microwave heating with catalytic combustion for the oxidation of diesel soot at lower temperature and higher reaction rate with respect to a bare DPF [4]. This work focuses on the direct deposition (any washcoat was added) of a microwave susceptible oxidation catalyst on a specifically pretreated wall flow DPF, and on its regeneration by means of microwaves; in particular the optimized acid pretreatment was able to increase the average pore diameter of the bare SiC filter, and therefore increasing the potential active species load on the DPF. This approach allows to further reduce the soot oxidation temperature and keep the pressure drop low, so resulting in a lower filter regeneration frequency. In addition, the energy balance of the entire process was performed in order to compare the microwave assisted regeneration technology with the regeneration techniques employed currently, and so verify its feasibility.

2. Methods

In this work $CuFe_2O_4$ catalysed SiC monoliths (Pirelli Ecotechnology, 150 cpsi) with different loads of active species were prepared by repeated impregnation phases in the precursors solution, drying at 60°C and calcination at 1000°C after each impregnation, in order to obtain a load of active species up to 30%wt. The bare SiC monoliths, suitably shaped in a rectangular form, were previously dipped in a 1:1 mixture of $HF:HNO_3$ at a temperature of about 45°C for 30 min, following an optimized procedure to increase their average pore diameter [5]. The catalysed DPFs were characterized by Scanning Electron Microscopy, Energy dispersive spectroscopy, Hg porosimetry tests, N_2 adsorption at -196°C, applying BET method for the calculation of sample's surface area, and catalytic activity tests of soot deposition and on line microwave (MW) assisted regeneration. In addition the adherence of the catalyst to the filter was evaluated measuring the weight loss caused by exposing the monoliths to ultrasound, according to an optimized experimental procedure [5].

3. Results and discussion

The selected erosion procedure allowed to obtain (i) an average diameter increase from 17 to 24 μm after 30 minutes of treatment, considered as the optimal time for the pretreatment of SiC monoliths in the selected acid solution due to the gradual weakening for higher dipping times, and (ii) the increase of the specific surface area (calculated according to BET method) from 0.35 m^2/g up to 2.20 m^2/g with dipping time increasing from 0 to 30 minutes, since the roughness generated by the erosion process on the SiC granules surface increased the specific surface area. The SEM and SEM-EDAX analysis evidenced that also after the preliminary acid treatment of the bare monoliths, the previously obtained good homogeneous distribution of the active species on the support is confirmed [5], and resulted in the detection of the structural chemical elements (Si, C and O) and of the catalytic elements (Fe and Cu). In particular, the very low signals of C and Si confirmed the good coating of the SiC granules with the catalyst. The ultrasonic treatments evidenced that a weight loss lower than 0.1% occurs after just the first cycle, and that after there are no more weight losses. This important result confirmed the good adhesion of the active species also on the monoliths with modified porosity, even without any wash-coating procedure. The Specific Surface Area of a pretreated catalytic sample with a catalyst load of 20%wt was of 0.4 m^2/g, lower than that of the bare monolith after 30 min of dipping time; this decrease in the specific surface area is probably due to catalyst deposition on the roughness caused by the dipping in the acid solution. The Hg porosimetry tests showed that the preliminary acid treatment of the bare SiC monoliths resulted in an increased average pore diameter of the catalytic samples, if compared with the analogues without acid treatment. The on-line soot deposition tests (figure 1) showed that the porosity modifying procedure resulted in increasing of the time needed to reach the DP limit value corresponding to a soot load of about 5 g/l of filter. This very important result allows to obtain two fundamental consequences, (i) to increase the duration of the deposition phase, and (ii) the higher catalyst loading resulted in a higher catalytic activity during the regeneration phase, with a threshold catalyst temperature of about 350°C, and a regeneration step duration of about 15 minutes. In conclusion, the combination of microwave technology and of a microwave susceptible catalyst allowed to reach an energy saving higher than 60% during the regeneration phase of a DPF, if compared to the traditional fuel post-injection.

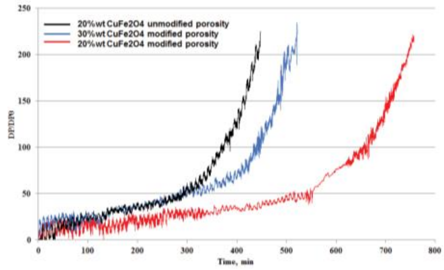

Figure 1. Effect of modified porosity and $CuFe_2O_4$ loading on SiC monoliths in terms of pressure drop (DP/DP0) during the soot deposition phase as function of the test time.

4. Conclusions

This work focuses on the direct deposition (any washcoat was added) of a microwave susceptible oxidation catalyst on a specifically pretreated wall flow DPF, and on its regeneration by means of microwaves. The on-line soot deposition tests showed that, due to porosity modifying procedure, the increase of copper ferrite loading up to 30%wt resulted in a soot deposition phase time still longer than the one of the unmodified filter but with a lower loading of catalyst. This very important result allows to obtain two fundamental consequences, (i) to increase the duration of the deposition phase, and (ii) the higher catalyst loading resulted in a higher catalytic activity during the regeneration phase, with a threshold catalyst temperature of about 350°C, and a regeneration step duration of about 15 minutes. In conclusion, the combination of microwave technology and of a microwave susceptible catalyst allowed to reach an energy saving higher than 60% during the regeneration phase of a DPF, if compared to the traditional fuel post-injection.

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Keywords
soot abatement; catalytic DPF; microwaves regeneration; environmental catalysis.