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EXPERIMENTAL STUDY OF PARTIAL REGENERATION

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ABSTRACT – It is well known that diesel particulate filters (DPF) can be subjected to incomplete regeneration which can lead to DFP failure when a severe regeneration follows many partial regenerations. The following study concentrates on C-DPF (Catalysed Diesel Particulate Filter) filters made of R-SiC (Recrystallized Silicon Carbide) from Saint-Gobain and aims at studying the soot distribution in the filter as a function of regeneration efficiency. The soot distribution is deduced from a radial velocity profile using a specific test bench.

First, an experimental protocol has been designed to produce a controlled partial regeneration. This protocol allows us to obtain the desired regeneration efficiency. To measure the velocity profiles at the filter outlet a specific test bench has been designed and built. We use a propeller anemometer with a diameter of 9 mm.

Test results do not show a direct linear correlation between the pressure drop efficiency (ratio of the total pressure loss of the filter before regeneration on the pressure loss after regeneration) and the mass efficiency (ratio of the soot mass after regeneration on the soot mass before regeneration) during partial regenerations. On the contrary a very good linear correlation between the mean velocity and the regeneration efficiency has been observed.

Moreover, it could also be observed that more the regeneration efficiency increases and more the radial distribution of remaining soot in the filter is uniform. This result shows that partial regeneration in the case of a controlled regeneration tends to have a uniform distribution of soot in the radial direction and thus to not concentrate soot which are not regenerated.

Then, we have seen that the correlation between the mean velocity and the remaining soot after partial regeneration is different from that obtained during loading. Thus, to load a filter completely then to empty it partially does not give the same result as to load it partially. We think that the regeneration that we used modifies the organization of soot inside the filter.

TECHNICAL PAPER - Today, catalysed diesel particulate filter (C-DPF) technology seems to be the most promising solution to deal with the future emission standard requirements for diesel vehicles. This system can reduce totally soot, CO and HC. Diesel particulate filters, in real world-driving, are often submitted to incomplete regeneration. These incomplete regenerations could be dangerous for filter integrity because the remaining soot in the channels may be non-uniform. This non-uniform distribution and especially the density of remaining soots (1) and a change of their physicochemical composition (2) can cause local important temperature gradients and thus break the filter. So, a very good comprehension of this phenomenon is necessary.

Currently, numerical and experimental studies about loading and complete regeneration are well-known. On the other hand, experimental studies which allow to visualize and to quantify the soot distribution after a partial regeneration are not very widespread (3). However, theoretical studies are more common (4), (5).

So, we have created a system which allows us to observe the localization, in the radial direction of the C-DPF, of soot after the loading or the remaining soot after a controlled partial regeneration.

EXPERIMENTAL

ENGINE BENCH

The test engine used is a 2.0 litre direct injection diesel engine with post-injection which allow us to regenerate the filter. The catalysed diesel particulate filter that we used is in close-couple position.

FILTER AND CATALYST

Characteristics of the filter are summarized in tab.1:

	Filtre
Material	RSiC
Coating	40 g/ft^3 Pt
Geometry	Square
Cell density (CPSI)	311
Wall thickness (µm)	280
Diameter*Length	5,66’’ x 6’’

Tab. 1 : Characteristics of filter

ENGINE OPERATION POINTS

Loading

Loadings are carried out at 3000 rpm, 50 Nm with a temperature of exhaust gas about 250°C.

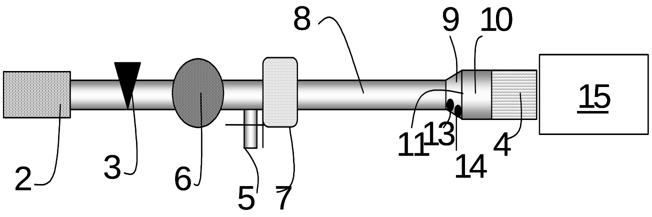
Controlled regeneration

The regeneration carried out is a controlled regeneration protocol with filters loading at 7g/l. The duration of the post-injection period is 10 minutes on the engine operation point 1700 rpm, 95 Nm. The amount of oxidized soot depends on the upstream filter temperature. We control this temperature thanks to the amount of fuel injected during the post-injection period.

VELOCITY MEASUREMENT

Measuring the flow at the filter outlet is a very difficult task. Non-intrusive methods such as LDA (Laser Doppler Anemometry) or PIV (Particle Image Velocimetry) can be used but it is very difficult because the filter would retain the particles of the seeding. So we use an intrusive method. The propeller anemometer of 9mm of diameter that we use is intrusive but don’t disturb a lot the flow (6). Moreover, this apparatus show a very good precision.

Figure 1 presents the experimental device which measure the velocity profile and figure 2 represents a picture of the system of displacement with the anemometer MiniAir20 Micro manufactured by Schiltknecht.



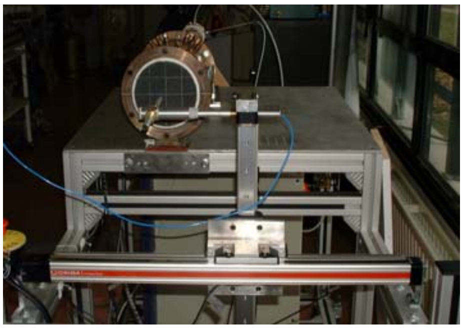


Figure 1: Diagram of the apparatus

Figure 2: Photo of the apparatus

The flow rate is obtained with a centrifugal pump (maximum flow rate about 350 m3/h). In order to control the overall pressure drop (4), a valve (3) is located upstream the blower and a valve of precision (5) is installed downstream. The system is protected by an air filter (2). To stabilize the flow, we placed a duct (8) with a length 50 times larger than the diameter. To avoid separations of flow, the diverging angle upstream the filter (9) is lower than 7°. In order to control the essential parameters of our system we installed sensors of flows (7), relative pressure (13) and temperature (11). The propeller anemometer located at 2mm of the rear face of the filter is fixed on 2 perpendicular automated traverse devices. A computer manages automatically the traverses and the acquisitions (15). We can see on figure 2 that the rear face of the filter is aligned with the rear face of the caning (10) in order to allow the probe a complete screening of the filter.

ACCURACY AND SETUP

Accuracy

The experimental tool that we have setup is completely autonomous. The anemometer moves by squaring the filter. In order to obtain a cartography of velocity profile with a very great accuracy, horizontal and vertical displacements are equal to the hydraulic diameter of the channels of the filter. The result obtained with an empty filter is presented on figure 3. We visualize very well the contour of the filter, the unit elements, the joins between unit elements as well as the periodicity of the open and closed channels.

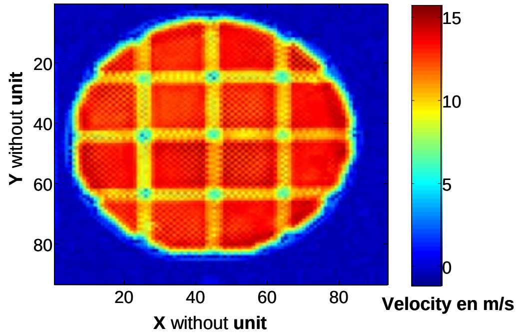
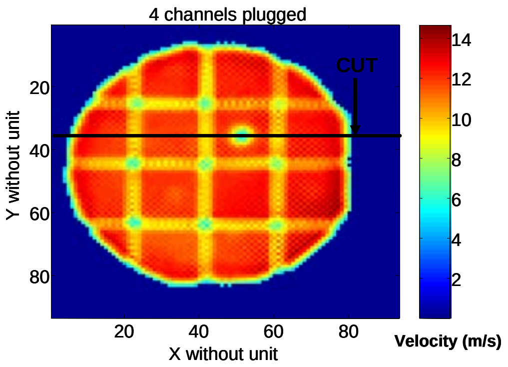


Figure 3: Cartography of an empty filter

Figures 4 end 5 present a filter with 4 channels closed. We can observe that the velocities decreased from 13 to about 4.5 m/s. The velocity is not zero because the diameter of the propeller anemometer is 9 mm. This is not a problem for our study because we want to localize the oxidation of soot and the scale of this phenomenon is about several channels.



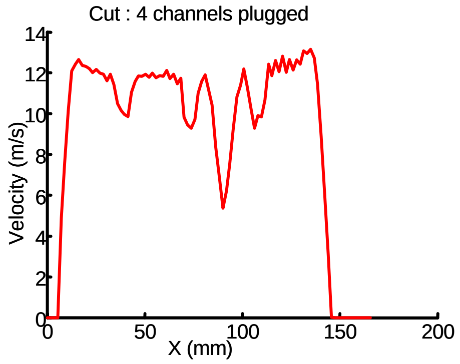
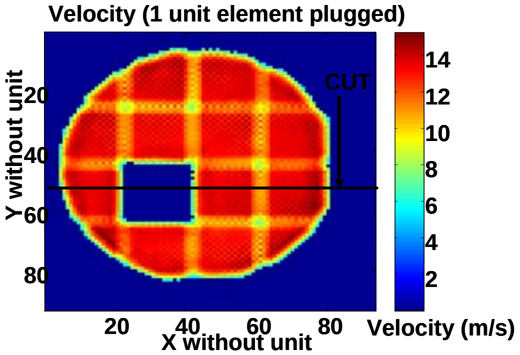


Figure 4: cartography of 4 channels plugged Figure 5: Cut of 4 channels

Setup

In order to know the localization of soot oxidation, we set up an experience which indicates if we have to carry out our tests (empty filter, loaded or partially regenerated) at constant pressure or constant flow rate.

Figure 6 shows a filter with a unit element completely closed so, no flow passes through this part of the filter. Figure 7 presents comparative cuts of velocity profile. The blue curve represents the cut of reference (without soot, not plugged). In this case, le flow rate is 350m^3/h and the pressure drop is 12mbar. The red curve is a cut of the filter with one element completely closed. The pressure drop in this case is 12 mbar (constant pressure). The black curve represents the same test than the red curve but at constant flow rate.



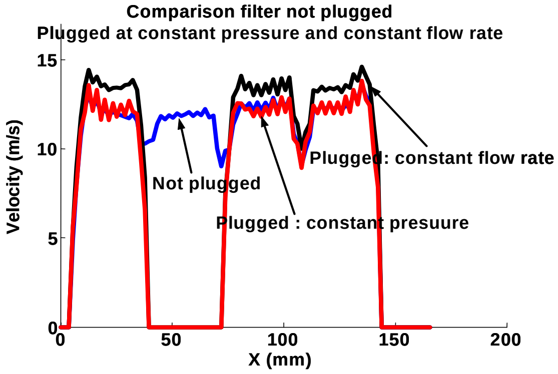


Figure 6: Cartography (1 unit closed) Figure 7: Cut for setup

We can notice that for the test at constant flow rate, we observe perfectly the area where they are no flow but on the other hand, we can see an offset between black and blue curve where the filter is not plugged. This indicates that working at constant pressure leads to errors of measurements. Test at constant pressure, as for it, preserves the velocity (good superposition between blue and red curves where the flow passes through the filter).

RESULTS

LOADING

Figures 8 show the distribution of soot in a filter for different loading.

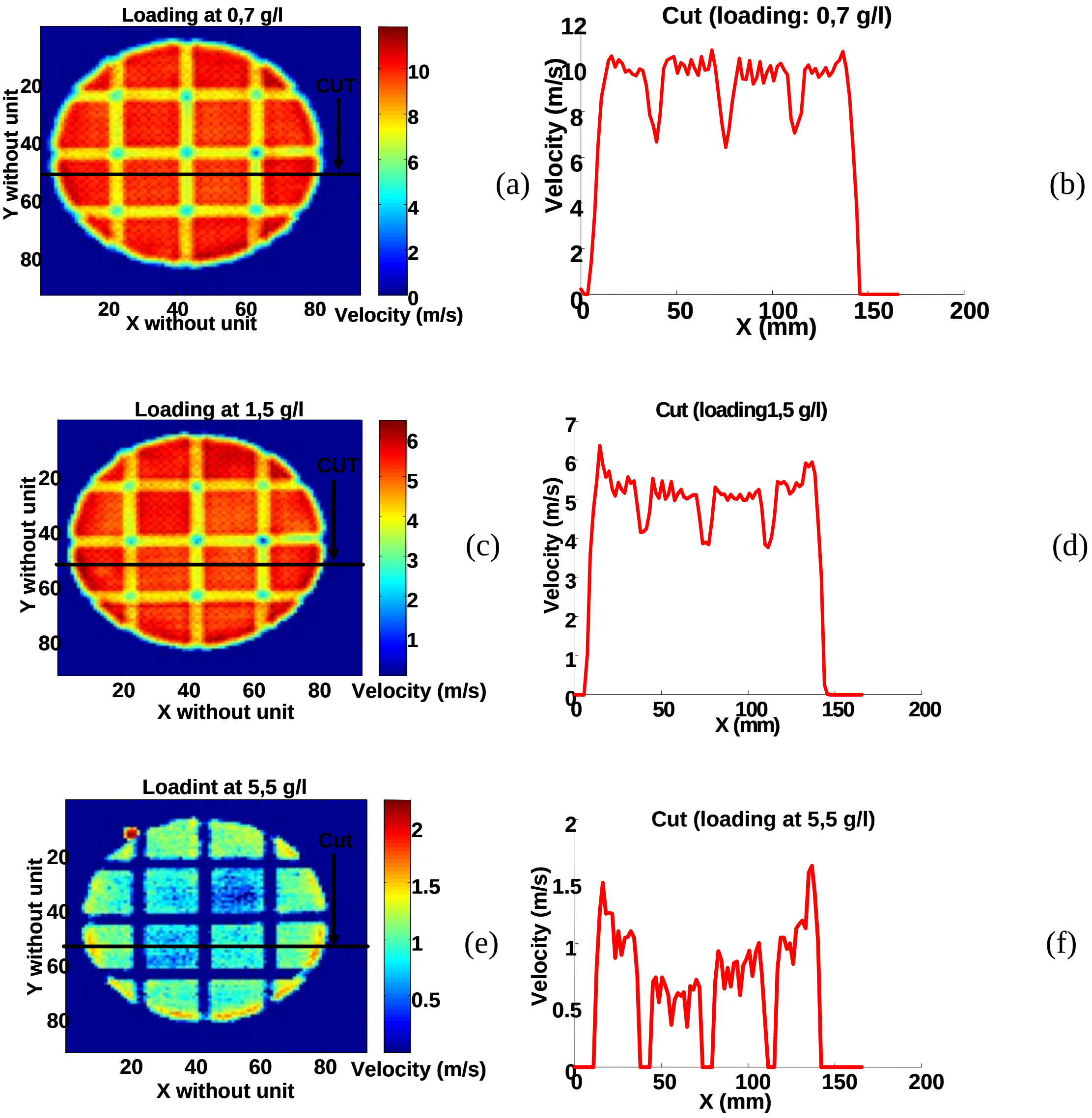


Figure 8: distribution of soot in a filter for different loading

A loading at 0,7 g/l (figures 8 a,b) represents a short loading (about 20 minutes).We can consider that the soot is being deposited inside the wall (beginning of bed-filtration). We note (figures 8 a,b) a completely uniform velocity profile. Then the loading at 1,5 g/l (figures 8 c,d) indicates an important decrease of the velocity. In this case, soot begins to be deposited on the surface of the wall. The radial distribution of soot becomes more or less uniform. We can observe a concentration of soot a little more important at the centre than in periphery of the filter. Thus, soot is more concentrated at the centre of the filter. Loading at 5,5 g/l (figures 8 e,f) shows a non-uniform velocity profile. This means an important amount of soot is concentrated at the centre of the filter.

Figure 9 presents the evolution of the mean velocity at the rear face of the filter for different soot loading.

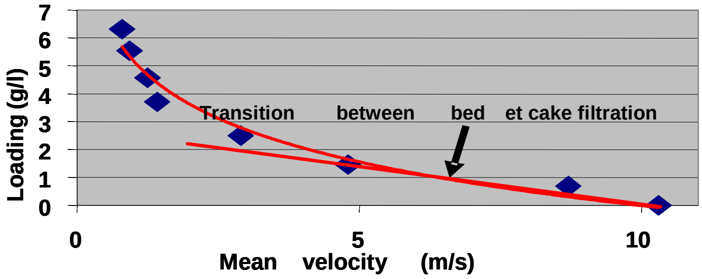


Figure 9: Evolution of the mean velocity for different soot loading

We can observe that the correlation between the soot loading and the mean velocity is not linear. The transition during the loading seems to be representative of the transition between bed and cake filtration. The bed-filtration is the depth filtration (or filtration in mass). The particles are deposited inside the walls of the filter. The cake-filtration appears when the captured particles form a continuous layer on the surface of the wall. The cake-filtration allow to the filter to have the better efficiency of filtration. On the other hand the pressure drop of the filter increases strongly with the thickness of the cake. The ideal operation point is at the transition between bed and cake-filtration. At this transition, the pressure drop is the lower for the better level of filtration efficiency.

REGENERATION

Figure 10 shows the evolution of the amount of soot oxidized for different upstream temperature of the filter. The protocol of controlled regeneration allow us to choose the amount of soot that we want to oxidize with a great accuracy. Thanks to this protocol, we can observe the space and the temporal behaviour of the regeneration.

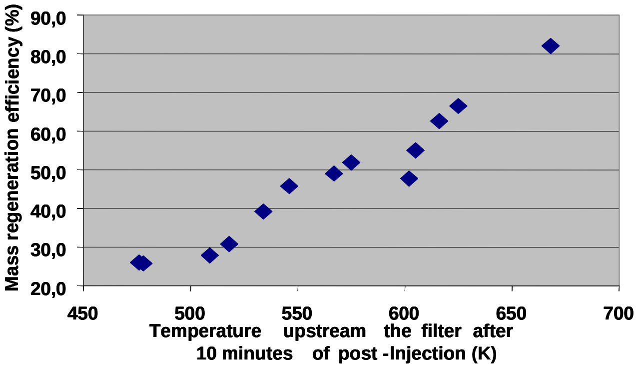
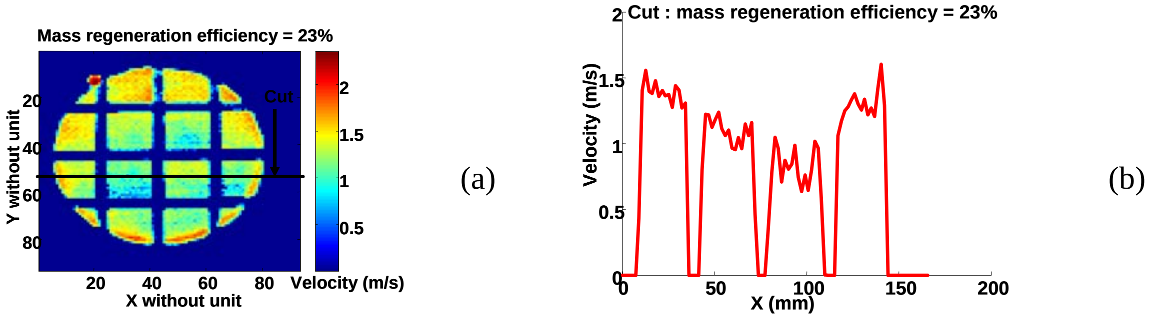
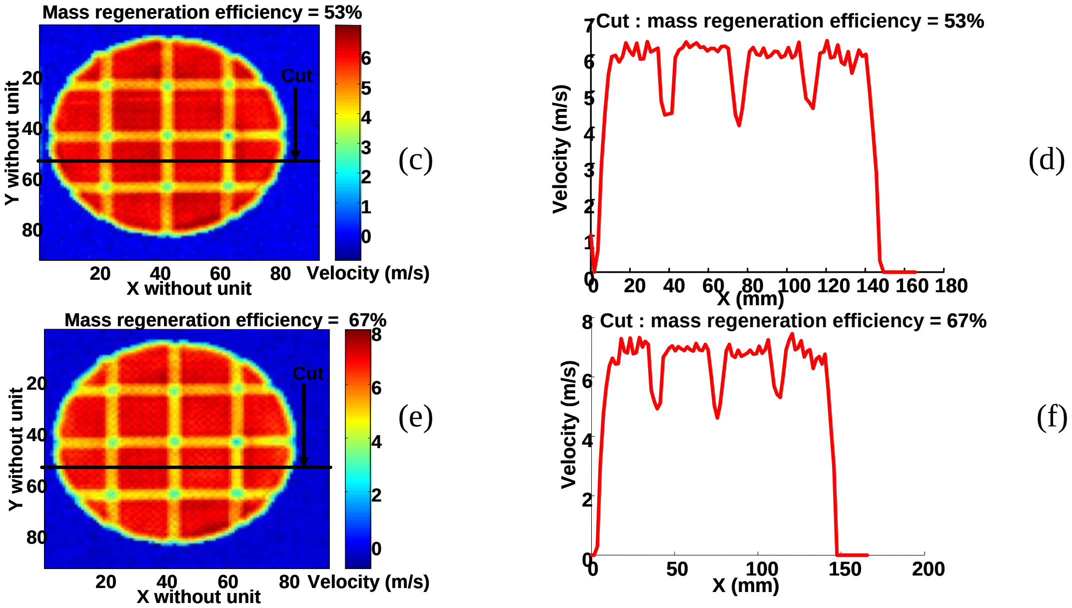


Figure 10: Mass regeneration efficiency for different upstream temperature of the DPF

Figures 11 show the evolution of the regeneration for different amount of soot oxidized.





Figures 11: Evolution of the regeneration for different amount of soot oxidized

Figures 11 indicate that the oxidation of soot tends to start where the soot is the most concentrated in the filter. So soot burns in a uniform manner, as soon as the amount of remaining soot in the filter is uniform. Thus, regeneration is most effective where the filter is the most loaded.

Figure 12 shows the evolution of the mean velocity at the rear of the filter for different mass efficiency and figure 13 shows the evolution of the pressure drop efficiency for different mass efficiency.

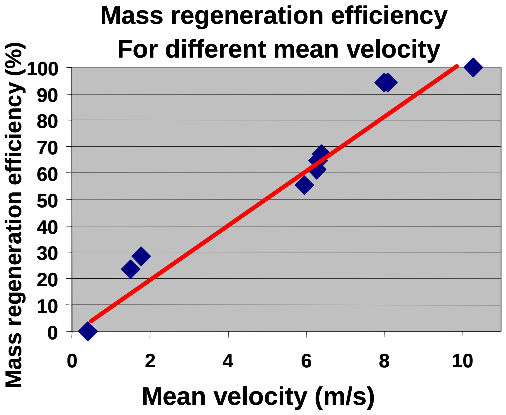


Figure 12: Mass regeneration efficiency for different mean velocity

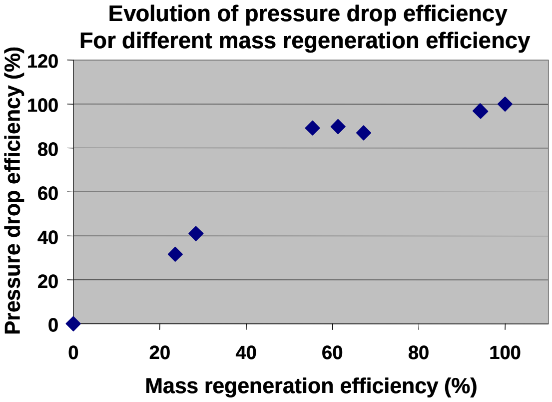


Figure 13: Mass regeneration efficiency for different pressure drop efficiency

The evolution of the pressure drop efficiency for different mass regeneration efficiency doesn’t present a direct correlation. On the other hand, the evolution of mean velocity for different mass regeneration efficiency seems to be linear.

CONCLUSION

An experimental study on the behaviour of partial regeneration was carried out. Before this study, we visualized the behaviour of the loading for different amount of soot in DPF.

Thanks to our system of measurement of velocity at the rear face of the filter, we observed a uniform velocity profile when the filter is empty.

During loadings with a little amount of soot (soot inside the wall), the velocity profile of the filter remains uniform. On the other hand, due to our experimental test bench, we can observe rapidly a non uniform velocity profile when the soot is deposited on the surface of the wall. This indicates us, during the loading, that they are more soot accumulated at the centre of the filter than in periphery.

The evolution of the mean velocity at the rear face of the filter for different soot loading allows us to determine the transition between the bed and the cake filtration.

The protocol of regeneration that we use allows us to oxidize the amount of soot that we want with a great accuracy. Results show us a good correlation between the amount of oxidized soot and the mean velocity at the rear face of the filter.

We observe, during controlled partial regeneration, that the soot distribution tend to be uniform rapidly. So, soot begins to be oxidized where the amount of soot is the most important. Then the remaining soots burns in a uniform manner in the filter. The evolution of the velocity profile at the rear face of the filter for different mass regeneration efficiency is not the same than for the mechanism of loading. So, loading a filter completely then emptying it partially doesn't give the same result than loading it partially.

So, we can think that the protocol of partial regeneration that we use modifies the organization of soots inside the filter. Today we don't how. Thus a better knowledge of the soot distribution inside the filter will be necessary to understand this phenomenon.

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