

WRONG-WAY BEHAVIOR DURING SOOT COMBUSTION IN DIESEL PARTICULATE FILTER (DPF)

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Summary

A major technological challenge in the operation of diesel particulate filters (DPFs) is prevention of melting of the ceramic filters during regeneration (combustion of accumulated particulate matter). Experiments and simulations indicate that during stationary regeneration (fixed feed conditions) the temperature rise is not sufficiently high to cause this melting. Experiments and simulations show that the sudden changes in the feed to the DPF during regeneration may lead to temperature rise in excess of those under stationary feed conditions. Similar to the wrong-way behavior of packed bed reactors, a counter-intuitive high temperature rise may occur in a DPF upon a rapid shift to idle.

Keywords

Diesel particulate filter, wrong-way behavior, DPF regeneration, temperature excursion

Introduction

The emission of particulate matter (PM) or soot by diesel engine is a major health hazard. The most efficient device for its removal is the diesel particulate filter (DPF), which consists of thousands of square parallel ceramic channels with the opposite ends of adjacent channels being plugged. The incoming exhaust gas flows through the porous walls and about 95% of the PM accumulates in the inlet channels.¹ The PM removed either periodically or continuously by combustion. Experience reveals that the exothermic combustion sometimes melts the Cordierite ceramic filter and destructs it. Previous experiments and simulations revealed that the maximum temperature rise under stationary DPF regeneration is not high enough to explain this unexpected melting.^{2,3}

It is essential to gain an understanding what cause this unexpected DPF melting. It is well known that the maximum temperature rise in packed bed reactors under dynamic operation may largely exceed that under stationary operation. For example, a rapid reduction in the feed temperature can lead to a counter-intuitive temperature rise exceeding the initial one (wrong-way behavior). This led us to study if a similar behavior may explain the unexpected excessive temperature rise in the DPF.

Experimental Setup

Infra-red (IR) imaging was used to measure the spatio-temporal temperature during the soot combustion in a mixture of air and nitrogen on a planar catalytic single layer DPF, cut from a commercial DPF. It was held in a

stainless steel insulated reactor with an IR transparent quartz window on its top, at about 3 mm below the window. Five K-type thermocouples were installed at the bottom of the single layer DPF to help monitor its temperature. The spatiotemporal temperature profile was measured by a high speed infrared camera (Merlin, MW18, Indigo Systems) held 50 cm above the quartz window. The IR images were recorded at the rate of 10 per second. The magnitude, shape and motion of the thermal front on the DPF were determined by image analysis software.

Results

Simulations revealed that a sudden decrease of the feed temperature to the DPF leads to a transient temperature increase. Experiments reported elsewhere (4) confirmed the predictions that a decrease in the feed temperature will lead to a wrong-way behavior in the DPF. The largest temperature rise is expected to occur following a rapid shift in the driving mode from regular driving to idle. This decreases the exhaust gas temperature, and flow rate and increases the oxygen concentration. We conducted experiments and simulations to determine what is the response to simultaneous sudden changes of several input variables and to compare these to the sum of the responses generated by single input change.

The experiments revealed that the magnitude of the temperature rise depends on the direction in which the temperature front moves. It is larger when the front moves

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in the direction of the flow in the channel. Moreover, the amplitude of the temperature rise depends on the location of the temperature front when the change in the feed conditions is made. The direction of the moving reaction front depends on the operating conditions. For example, figure 1 describes a temperature front that moved in the direction of the gas flow rate (downstream) while figure 2 of one moving in the opposite direction (upstream).

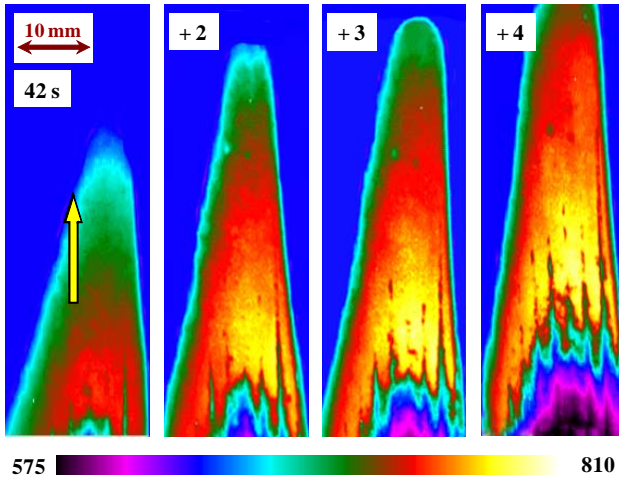


Fig. 1. IR image of downstream moving regeneration front following a rapid shift in $T_1 = 620\text{ }^\circ\text{C}$ to $520\text{ }^\circ\text{C}$ and O_2 from 10 to 15 v. %,

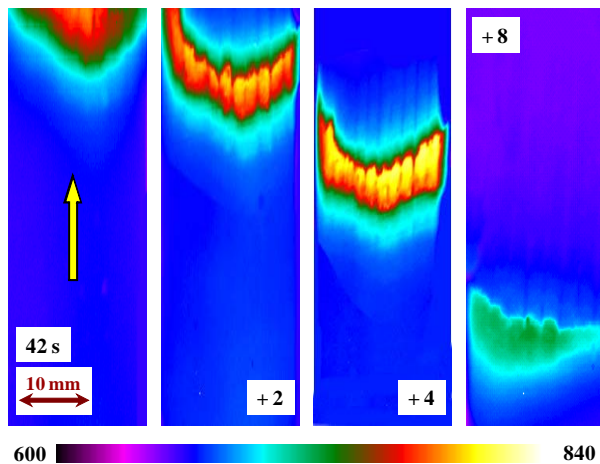


Fig.2 IR image of upstream moving regeneration front following a rapid shift in $T_1 = 620\text{ }^\circ\text{C}$ to $520\text{ }^\circ\text{C}$ and the filtration velocity from 12 to 8.3 cm/s,

The experiments also revealed that the magnitude of the temperature excursion was a monotonic increasing function of the distance that the reaction front moved before exiting the DPF.

A sudden decrease in the feed temperature increases the transient DPF temperature. A sudden increase in the oxygen concentration increases the DPF

temperature. The experiments and simulations showed that following a rapid obtained following feed temperature decrease and oxygen concentration increase the resulting transient temperature is slightly lower than the sum of the transient temperature increases following an experiment in which only one of these inputs is changed.

Figure 1 shows IR images in which the feed temperature was rapidly decreased from $620\text{ }^\circ\text{C}$ to $520\text{ }^\circ\text{C}$ while the oxygen concentration was increased from 10 to 15v. %. The highest transient temperature of $800\text{ }^\circ\text{C}$ was higher than the maximum temperature under the stationary operation ($740\text{ }^\circ\text{C}$). A sudden decrease of only the temperature leads in this case to a temperature rise of $30\text{ }^\circ\text{C}$, while the increase in the oxygen concentration leads to a temperature rise of $40\text{ }^\circ\text{C}$. The sum of both changes ($70\text{ }^\circ\text{C}$) is slightly larger than that when both changes occurred simultaneously.

A change in the filtration velocity may either increase or decrease the stationary combustion front temperature as reported in (2). Figure 2 shows IR images for a case in which the feed temperature and flow rate were simultaneously decreased. The maximum transient temperature of $837\text{ }^\circ\text{C}$ was $75\text{ }^\circ\text{C}$ higher than the maximum temperature obtained under the original stationary state. A rapid change of only the feed temperature would have led in this case to a temperature rise of $51\text{ }^\circ\text{C}$ above that of the original stationary state. A change in only the filtration velocity would have led to a $25\text{ }^\circ\text{C}$ rise. The observed transient temperature rise in this case of $75\text{ }^\circ\text{C}$ is very close to the sum of the two individual temperature rises.

We shall present an extensive set of experiments and simulations that will clearly show that dynamic changes in the driving mode operation can lead to unexpected temperature excursions during the regeneration of the DPF. These have to be considered in the development of the operation and control protocol of a DPF in order to circumvent their occurrence.

References

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