Applied Thermal Engineering 141 (2018) 976–980

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Influence of the idle-up strategy on the thermal management of diesel particulate filter regeneration during a drop to the idle process

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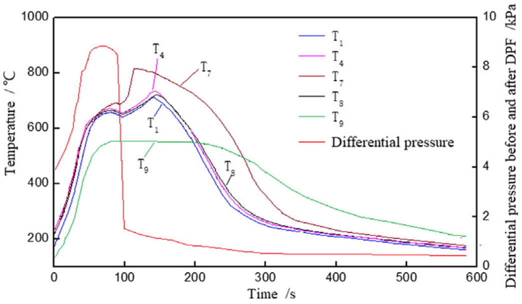
HIGHLIGHTS

- Regenerative temperature field of cordierite ceramic filter was measured.
- Different idle speeds were tested for DPF regeneration during drop to idle process.
- Idle-up strategy was provided to decrease the peak temperature and temperature gradient under drop to idle process.

GRAPHICAL ABSTRACT

As exhaust temperature and particulate combust speed increased after active regeneration, catalyst carrier temperature increased accordingly; after approximately 80 s, carrier temperature reached steady condition, after approximately 20 s, as particulate consumed, pressure difference of DPF inlet and outlet started to reduce; at this point, diesel engine working condition dropped to idle abruptly, exhaust mass flow reduced from 720 kg/h to 180 kg/h, heat generated from particulate combust could not be taken away in time, carrier temperature raised rapidly. Test results showed center area of the carrier outlet have higher temperature increase; center area of the carrier inlet has lower temperature increase. Therefore, attention of DTI progress shall be concentrate on the temperature of carrier outlet, ensure the peak temperature is sustainable for catalyst and its carrier through thermal management.



ARTICLE INFO

Keywords:
Diesel particulate filter
Active regeneration
Drop to idle
Diesel engine

ABSTRACT

The idle-up strategy of diesel particulate filter (DPF) regeneration during a drop to the idle (DTI) process was investigated in this study. This strategy could control the peak temperature and maximum temperature gradient of a cordierite ceramic filter. Experimental results showed that as the engine working condition dropped to idle speed during regeneration with a DPF soot load of 4 g/L, the peak temperature was reduced from 820 °C to 632 °C when the idle speed was increased to 1100 r/min, a decrease of 22.9%, while the maximum temperature gradient was reduced from 30 °C/cm to 10 °C/cm, a decrease of 66.7%. The peak temperature and temperature gradient of the DPF cordierite ceramic filterwith DTI during regeneration were effectively reduced. The idle speed range for the idle-up strategy to decrease the peak temperature and temperature gradient of a cordierite ceramic filter was discussed. The maximum idle speed of the idle-up strategy should not be higher than the speed of common engine working conditions in order to avoid DTI during a regeneration increase at current engine driving speed.

Abbreviations: DPF, diesel particulate filter; DOC, diesel oxidation catalyst; PM, particulate matter; PN, particulate number; HCI, hydrocarbon injection; DTI, drop to the idle; VGT, variable geometry turbocharger; EGR, exhaust gas recirculation; HFM, Hot Film air mass Meter

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https://doi.org/10.1016/j.applthermaleng.2018.06.056
Received 10 January 2018; Received in revised form 8 June 2018; Accepted 18 June 2018

1. Introduction

The wall-flow diesel particulate filter (DPF) has been widely used to remove harmful particulate matter (PM) and has become an indispensable feature of modern diesel engines due to strict regulations on PM and particulate number (PN) emissions [1,2]. However, the PM will clog the DPF after a long running time and affect the normal operation of diesel engines. Too much PM accumulating in the DPF will increase the back pressure, resulting in a deterioration of power and fuel economy. So it is necessary to develop a technology for removing the PM to ensure the efficient long term operation of diesel engines. The trapped PM can be either continuously or periodically removed by regeneration technology. DPF regeneration can be divided into active regeneration and passive regeneration. Active regeneration depends on the oxidation of the soot by O_2 at higher exhaust temperatures, by injecting fuel into the exhaust pipe through hydrocarbon injection (HCI) and using diesel oxidation catalysts (DOC) to oxidize it to raise the exhaust temperature to approximately 600 °C [3]. Passive regeneration depends on continuous oxidation of the soot by NO_2 and other catalysts within a temperature range of 200–500 °C, which uses DOC to oxidize NO from exhaust to NO_2 and change the NOx/PM ratio. Numerous studies have been conducted on both active and passive regeneration characteristics [4–9]. The combination of both passive and active regeneration of vehicle strategies could balance PM control as well as cost.

One key parameter is the accurate estimation of the actual soot loading in the DPF at any time. "Overloading" with soot can lead to DPF damage, whereas "under-loading" results in unnecessary DPF regenerations and therefore CO_2 penalties [10,11]. Bai SZ developed a soot loading model to calculate the soot accumulation in the DPF, which can effectively improve the accuracy of the active regeneration trigger time, and passive regeneration was studied based on this model [12]. Active control measures in exhaust thermal management were used to increase the exhaust temperature, which can ensure that the exhaust temperature before DOC is capable of triggering active regeneration [13]. Exothermic combustion during uncontrolled regeneration sometimes generates excessively hot local zones that melt the cordierite ceramic filter (the melting temperature is about 1250 °C). Therefore, it is crucial to develop a regeneration procedure which circumvents local filter melting as this is the most demanding technological challenge in DPF operation. Yu MT presented guidance about how this peak temperature depends on the DPF design and operating conditions, and a widening of the width of the temperature front, or an increase of the initial DPF temperature close to the ignition temperature before regeneration starts in order to decrease the highest transient temperature following a drop to the idle (DTI) process [14]. K Chen experimentally studied the temperature gradients within the soot layer during DPF regeneration, and found that the amplitude of the temperature difference decreased with an increase in feed oxygen concentration [15]. Transient temperature rises during regeneration of diesel particulate filters were studied and it was found that high temperature excursions in a DPF may be the dynamic response to a shift from the normal driving mode to idle [16].

Diesel engines at middle or high load working conditions have more exhaust discharge, so the timely removal of heat released from DPF regeneration process is needed. However, at the early period of the active regeneration progress, if engine working condition suddenly drops to the idle (DTI), as the exhaust discharge sharply decreases, the oxygen density increases, particulate matter accumulated in the DPF will violently combust and the heat released cannot be removed in time, and thus the DPF might be scarred or cracked due to burning. Therefore, when DTI occurs in the regeneration process, the peak temperature and maximum temperature gradient must both be within the sustainable limits of catalyst and its carrier. This is an important subject of DPF regeneration study. In this study, increasing the exhaust mass flow with the idle-up strategy was presented and verified to remove the heat in time when DTI suddenly occurs, thus controlling the peak temperature and temperature gradient.

Table 1
Test engine specifications.

Project	Specification
Engine type	6 Cylinder in-line/inter-cooling
Bore × Stroke/mm × mm	108 × 130
Swept volume/L	7.14
Compression ratio	18
Rated power/kW	200
Rated speed/r/min	2100
Max torque/N·m	1100
Idle speed/r/min	650
EGR type	Electronic control EGR
Turbocharger	VGT
Emission standard	EURO VI

2. Experiment setup and methods

2.1. Experiment setup

The engine used in these experiments was equipped with the common rail system of BOSCH. Table 1 and Fig. 1 show the related specifications and detailed information about the test bench, respectively. The experiments were carried out by using an Electric dynamometer, Opacimeter, Precision balance, Exhaust gas analyzer, and HFM (Hot Film air mass Meter) to focus on torque and speed, soot emission, soot weight in the DPF, concentration of NOx and O_2, and the mass of intake air, respectively. The details of these equipments are shown in Table 2.

The detailed specification of DOC and DPF are shown in Table 3. The DPF was equipped with 9 thermocouples, whose diameters were 0.5 mm, to measure the temperature field in the DPF. Fig. 2 shows the distribution of the thermocouples, the "Axial size" in Fig. 2(b) is the axial distance from the inlet vertical section to the outlet vertical section of the cylindrical DPF carrier; and the "Radial size" is radial distance from the center to the edge of cylindrical DPF carrier.

2.2. Experiment method

The DPF active regeneration test was by two methods. In the regeneration process, when the engine working condition drops to the original idle speed of 700 r/min, when DTI occurs in the regeneration process, engine idle speed increases to 900 r/min, 1000 r/min, and 1100 r/min. In the regeneration process, with the same soot load, different DTI timings will result in different peak temperatures and temperature gradients in the later period of the regeneration process, as particulate matter accumulation inside the DPF is largely consumed through combustion, and a drop in the engine working condition to idle speed will not significantly increase the DPF carrier temperature.

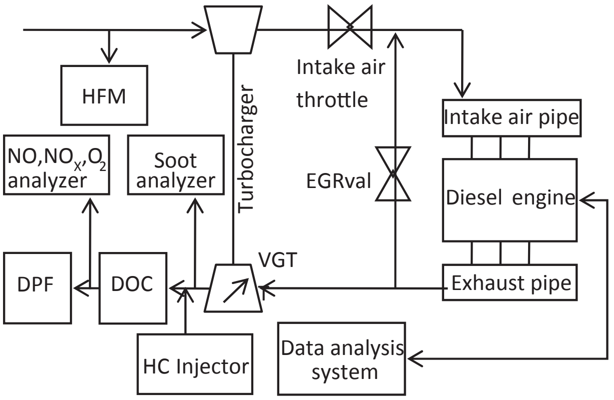

Fig. 1. Schematic of experimental setup.