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Optimization of Partial Filter Technology for Diesel Engines

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ABSTRACT

Diesel particulate matter collection results of a new design for a non-blocking diesel particulate filter are presented. Engine/dynometer testing with partial flow dilution tunnel DPM sampling show the device is capable of greater than 50% DPM trapping efficiency. Parameters in the design of the device such as, the quantity and type of filtration media is shown to directly impact on the trapping efficiency of the device. Preliminary durability results show minimal effects on device performance. In addition, history effects due to engine mode on DPM trapping performance are discussed

INTRODUCTION

Regulations on the reduction of particulate matter have become stricter with regard to new and older engines. New on-road engines are currently required to meet the EPA 2007 regulations for low PM emissions (0.01gPM/bhphr) with similar regulations for off –road engines in 2010 [1, 2]. For new engines meeting the 2007 regulations, full flow cordierite filters are used to trap the DPM. This type of filter requires a systems approach to provide the required temperature needed to regenerate the collected soot and prevent harmful increases in exhaust backpressure.

Older engines will also need to reduce their DPM engines. Retrofitting of systems to cover all operating engine modes is difficult. To retrofit a passive full flow device onto a vehicle it is necessary to review its operating duty cycle to ensure that sufficient temperature and time at temperature are met to achieve regeneration of the device. It is often difficult to predict the duty cycle of a vehicle or machine making it possible for a full flow filter to overload with soot and cause harmful increase in backpressure or excessive temperatures that can damage the filter if the soot should ignite. We present the results of a new filter technology that addresses the problems of soot overloading and harmful backpressure increases. A device is shown that it can meet CARB level II requirements for a 50% PM reduction.

The device, partial flow trap (PFT), consists of metal fiber fleece sandwiched between metal foils that are formed into alternating trapezoidal ducts with varying cross section area (Figure 1). The design of this device is discussed in paper [3] and a complete device is shown in Figure 2.

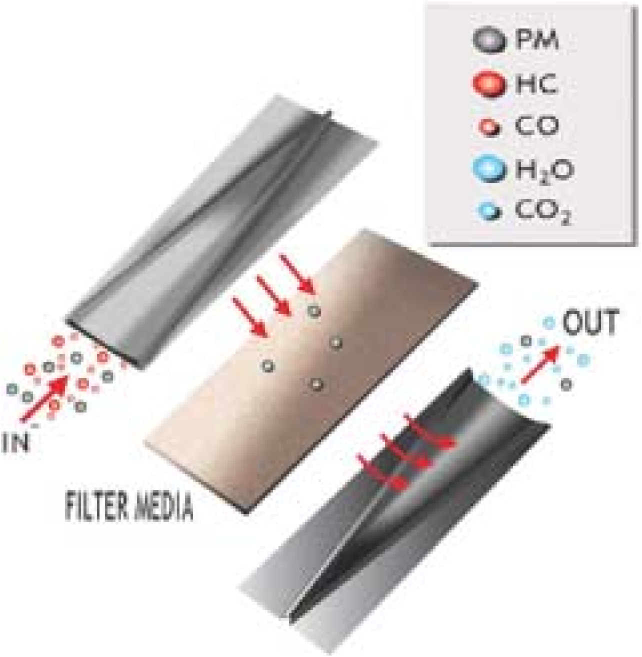

Figure 1: A cell of the partial flow trap

The varying cross sectional area of the duct causes a gas velocity change that creates a differential pressure drop across the filter media, and thus causes exhaust flow to diverge through the filter media and allow DPM trapping. As PM is accumulated on the filter media the pressure drop across the filter media increases and the amount of exhaust flow through the media is reduce. This self- regulating feature of the device prevents excessive soot accumulation in the filter media and results in a finite amount of DPM trapped. By tailoring the quantity of filter media in the device uncontrolled regenerations with excessive exotherms are prevented. Regeneration of the device may be assisted with the application of a catalytic coating on the individual filter fibers. In a previous paper [3], the authors presented both simulated and measured results from the optimization of several geometric parameters. This paper presents experimental results relating the filtration media volume to PM efficiency, and durability results from both field and laboratory aged devices. Furthermore the sensitivity of the device to the testing sequence is discussed.

Figure 2: Close-up view of PFT substrate showing the alternating tapered trapezoidal ducts and filtration media

EXPERIMENTAL SETUP

Engine testing was used to get practical experience on manufactured PFT devices. The PFT devices were installed on an EPA Tier 0 naturally aspirated diesel engine, 2.2L, 37 kW (n=2800 rpm) (Figure 3). The engine was fuelled with ULSD fuel with a maximum sulphur content of 15 ppm. All devices were evaluated using the ISO 8178 C1 test cycle.

Figure 3: Test Stand General View

PM mass reduction was evaluated with a Sierra BG-2 Micro-Dilution Test Stand. The sampling time was 70 to 600 sec on a 70mm filter to allow for measurable mass collect at the different modes. Particulate masses collected ranged between 0.4 to 2.7 mg. These mass values were normalized to the power rating of the mode.

The PFT filter devices studied during the engine testing are shown in Table 1 and the ISO test cycle in Table 2.

Table 1: Relative Fleece volume of Devices

No	Device Type	Fleece Relative Volume
1	Device A	0.52
2	Device B	0.78
3	Device C	1.38
4	Device D	1.58
5	Device E	3.00

Table 2: ISO 8178-C1: Test Engine Parameters

Mode	Engine Speed	Torque	Time	Speed	Exhaust Temp	Engine Output
		%	min	rpm	°C	g/bhp-h
1	Rated	100	18	2800	522	0.122
2	Rated	75	18	2800	386	0.049
3	Rated	50	18	2800	281	0.025
4	Rated	10	12	2800	172	0.006
5	Intermediate	100	12	1700	446	0.111
6	Intermediate	75	12	1700	310	0.032
7	Intermediate	50	12	1700	216	0.014
8	Low idle	0	18		89	0.002

RESULT & DISCUSSION

QUANTITY AND TYPE OF FILTRATION MEDIA

This test was designed to examine the PM filter efficiency as a function of fleece volume. Five devices with were tested using the ISO test modes (Figure 4). The result shows a direct dependence of total trapping efficiency on the fleece volume.

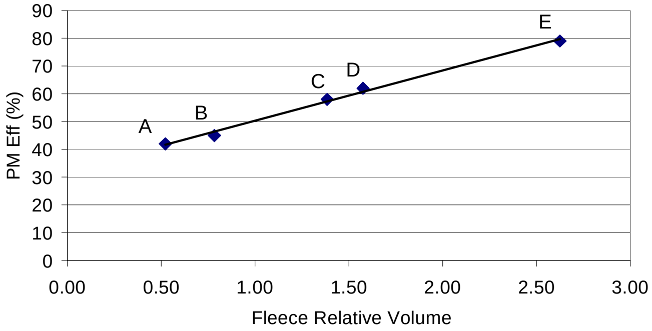

Figure 4: Total PM Devices Efficiency vs. Relative Fleece Volume. Result obtained through the ISO 8178-C1 Tests (A, B, C, D, E- Devices from Table 1).

DURABILITY TEST

Two durability tests are reported here. The first is a 100-hour test where Test modes 2 and Mode 7 of the ISO 8178 C1 cycle are alternated every hour. This test is designed to simulate regeneration and accumulation on the device and determine where the PM collection efficiency will stabilize (Figure 5).

For Mode 2 the device PM trapping efficiency stabilizes after 50 hours. The average device efficiency at the Mode 2 test point was 43-46%. Mode 7 goes through a maximum at 20 hours of 35% PM trapping efficiency and then gradually decreases. It appears that after 80 hours some efficiency was recovered. Further testing is required.

The consistency of the results indicates that combustion does occur at a sufficient rate to maintain PM efficiency beyond the certification test period, which is normally less than 50 hours of operation.

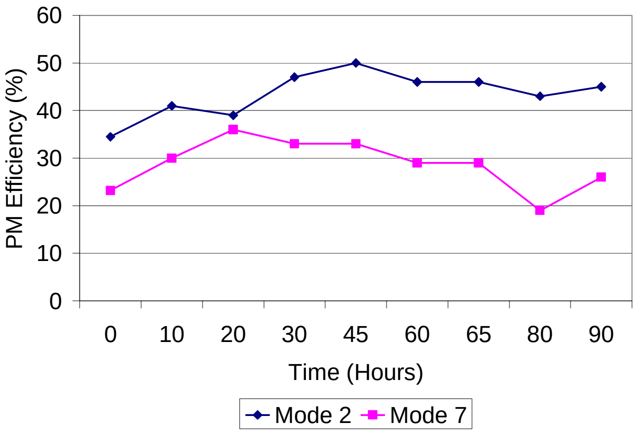

Figure 5: PM efficiency dependence on time (Device A). Switching between Mode 2 and Mode 7 every hour

The second test is long-term field test (Figure 6). The field test was performed on a Volvo L50 Wheel Loader vehicle with an EPA Tier 1 engine. The vehicle was operated for a period of 500 hours and returned for testing on the laboratory test engine. Results of the ISO 8178 cycle showed a PM reduction of 35%.

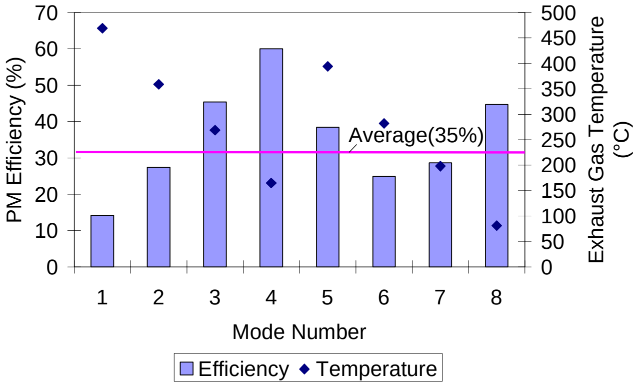

Figure 6: Long-term field test (~ 500 hours) ISO 8178-C1 test (Device A).

The device recovered after field service initially demonstrated a reduction in PM performance of about 15% when compared to new (Figure 7). Backpressure at Mode 2 ranged from 6.1”H2O prior to aging to 7.4”H2O after aging. Larger differences in efficiency were observed at modes one and two. In order to determine if the deterioration was permanent or temporary the device was continuously operated at mode 2 for a period of 75 minutes. After 15 minutes of operation the PM efficiency increased dramatically and after 30 minutes it had stabilized at 45%. This is comparable to the initial performance at this condition and indicates that the impairment was temporary in nature. A possible cause for this impairment could be extended operation at very low engine load. Further testing to determine the actual cause is required. In view of this observation it also becomes necessary to observe the history effect on the performance of the PFT.

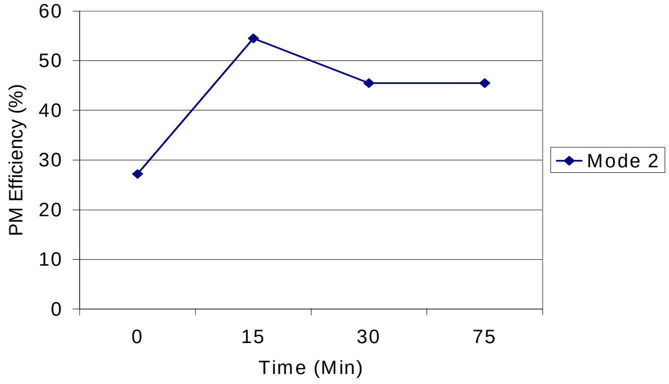

Figure 7: PM trapping efficiency recovery on field test unit

HISTORY EFFECTS ON DPM TRAPPING PERFORMANCE

A question of interest is will the PM efficiency with the device change with the engine mode? It was not clear if the dynamic nature of the device would cause variation in the PM efficiency over the test cycle. This is investigated by varying the order of the test modes in the ISO 8178 C1 cycle. The modes were selected in a random manner and the test is designated Randomized ISO cycle and then compared to the regular ISO cycle.

The Regular ISO cycle weighted PM efficiency was 55% (Figure 8). Randomized ISO cycle has the following sequence: Mode 5,4,1,7,2,6,3,8. Weighted PM efficiency has the same value- 55% (Figure 9). The result shows that over the entire test cycle the average PM collection efficiency has not changed. However comparing the individual modes between the two tests show variation, a result of soot loading from previous modes tested. Modes 1, 3, and 6 have similar PM efficiency between the two tests. Modes 2,4,and 8 have higher PM trapping efficiency on the random test. The remaining modes 5,7 have lower efficiencies on the random test.

This effect is not observed during testing of conventional wall flow particulate filters. However wall flow filters do exhibit variable pressure loss as a function of the mass of accumulated carbon [4]. It is likely that the modal differences in PM efficiency are related to the short-term history of the PFT. At some modes the PM collection rate exceeds the combustion rate resulting in a net accumulation of PM. During subsequent modes this accumulation may temporarily prevent the collection of additional PM until it has been combusted. This effect is present in both the standard and randomized test cycles and the cycle average reflects this.

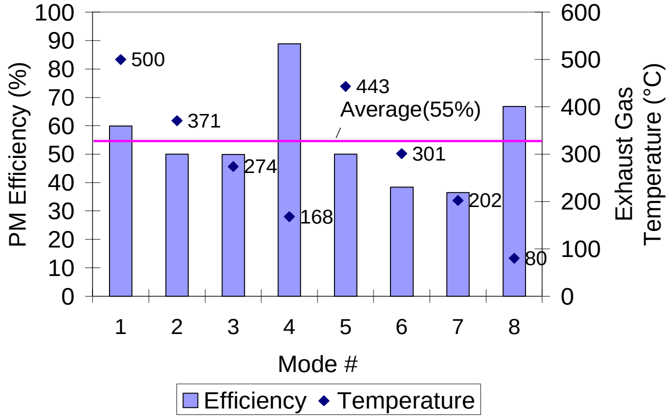

Figure 8: Regular ISO 8178-C1 Test. Device PM Efficiency and Exhaust Gas Temperature vs. Mode number (Device B).

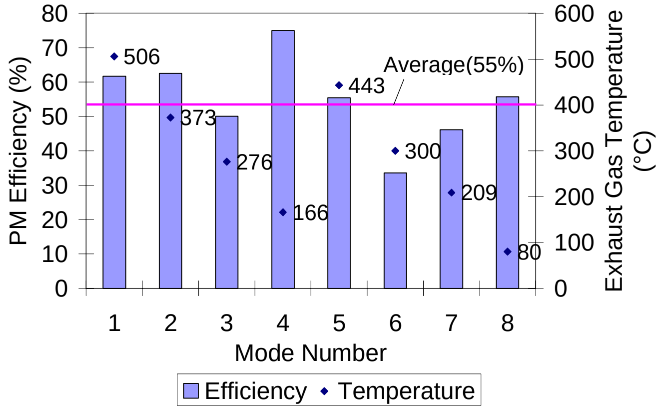

Figure 9: Randomized ISO 8178-C1 Test. Device PM Efficiency and Exhaust Gas Temperature vs. Mode number (Device B).

CONCLUSION

In this paper, we have demonstrated PM trapping efficiency of this device is a strong function of the volume of filter media used in the device. CARB Tier II requirements can be met at 55% PM trapping efficiency. After 500 hours of field operation the device is able to maintain 35% trapping efficiency. Exposing this device to Mode 2 conditions was able to recover the efficiency after 15 minutes of operation. Further tests are needed to understand the aging behavior of this device. The results in this paper indicate that higher values of trapping efficiency could be achieved by increasing the media volume.

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