Field evaluation of a passive diesel particulate filter at a limestone mine

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Abstract

The Mine Safety and Health Administration (MSHA) has promulgated rules to limit the exposure of metal/nonmetal underground miners to diesel particulate matter (DPM). These rules have resulted in many types of control technologies being implemented including diesel particulate filters (DPF). The passive type DPF is the most desirable because it requires little maintenance and it regenerates while the vehicle is operating. One problem with passive DPFs is that many vehicles cannot develop the sustained exhaust temperatures needed to initiate DPF regeneration, and thus it is required that the DPF be catalyzed to decrease the temperature needed for regeneration. In some past studies, such catalyzed filters have been shown to cause an increase in the nitrogen dioxide concentrations in the exhaust, resulting in a potential health hazard. In this study, a lightly catalyzed DPF along with a fuel-born catalyst were employed to help reduce the DPM emissions from a 980F loader used for cleanup in a stone mine. After 30 days of use, the filter continued to regenerate successfully at the exhaust temperatures generated by this loader, substantially reduced DPM concentrations emitted in the exhaust, and did not cause a measurable increase in nitrogen dioxide levels that could be attributed to the device.

Introduction

The Mine Safety and Health Administration (MSHA) has promulgated rules to limit the exposure of metal/nonmetal underground miners to diesel particulate matter (DPM) (MSHA, 2001, 2005). In May 2008, the personal exposure limit was lowered to 160 µg/m^3 total carbon (TC) (MSHA, 2005). In an effort to comply with this rule, mines are attempting to implement control technologies to decrease DPM concentrations in the mines. One type of control technology being tried is passive diesel particulate filters (DPFs).

DPFs employed on equipment in underground metal/nonmetal mines are usually a ceramic or silicon carbide wall-flow monolith type. The soot is collected and stored in the filter, and if the filter is not periodically cleaned, it will fill up and plug. Such plugging causes a high backpressure on the engine, which could damage the engine and possibly result in a filter fire. The filter either has to be replaced or the soot needs to be removed from the filter before the backpressure gets too high.

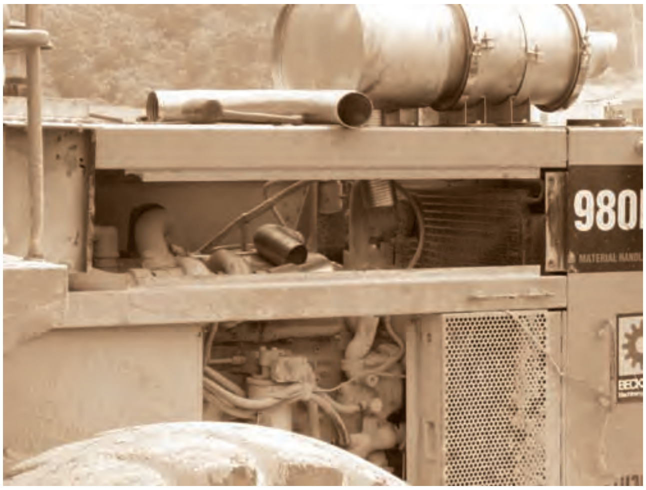
The soot can be removed from the filter by regenerating it, which entails oxidization of the soot and the formation of CO_2. Uncatalyzed filters must reach a temperature above 500°C (930°F) to regenerate, while a catalyzed filter can regenerate at temperatures between 250° and 300°C (480° and 570°F).

Two filter regeneration schemes are in practice today. An “active” filter relies on an outside source to generate the heat to clean the filter. In this case, the filter has to be removed from the machine and be regenerated at a regeneration station or, if not removed, the filter has to be plugged into a power source at a regeneration station for a certain time period. A “passive” filter regenerates while the vehicle is operating, with the heat needed to initiate the regeneration process generated by the engine exhaust. The “passive” filter is obviously the preferred choice because the vehicle is not taken out of service and little maintenance is necessary. Passive filters, however, usually have to be catalyzed for regeneration to occur at the temperatures produced by most vehicles, and this catalyzation can cause an increase in NO_2 emissions, which could result in a health hazard. Even if a catalyzed filter is employed, not all vehicles can generate exhaust temperatures high enough to initiate filter regeneration.

Several studies (laboratory and field) have shown that the ceramic filters can reduce DPM efficiently. They have reported more than a 75% reduction in total DPM and more than a 90% reduction in elemental carbon when using ceramic filters for a short period (Roegner et al., 2002; Bugarski et al., 2003; Bugarski et al., 2005; MSHA, 2005). These studies have also shown an increase in nitrogen dioxide when using certain catalyzed filters, but they gave little information on the implementation and regeneration characteristics of these filters when operating in real mining conditions. Limited information also exists on the conditions under which passive filters regenerate, on the filter backpressure after extended use or on other implementation issues (such as a decrease in machine

FIGURE 1

The passive dpf installed on a loader.



operator visibility) when installing and operating these DPFs under real mining conditions.

In this study, the operators of a limestone mine retrofitted a loader used for clean-up operations with a passive DPF that was lightly catalyzed (lightly catalyzed filters are loaded with 0.11 to 0.53 kg/m^3 (3 to 15 g/cu ft) of platinum compared to around 1.76 to 2.82 kg/m^3 (50 to 80 g/cu ft) of platinum for catalyzed and heavily catalyzed filters) and used a fuel additive to initiate regeneration at low exhaust temperatures. This filter was selected because studies have shown that it will regenerate at regeneration temperatures are representative of a heavily catalyzed filter. This same filter was shown in an isolated zone study to reduce elemental carbon by more than 90% and yet not substantially increase atmospheric NO_2 concentrations (Bugarski et al., 2003). In this study, the filter's performance was monitored for more than one month under actual mining conditions.

Methods

Installation of DPF. A CleanAir Systems DPF system (described in the next section) was installed on a 980F Cat Loader (CAT 3406 engine, 310 hp, Tier 0). Two 305 by 381 mm (12 by 15 in.) DPF filters were used in the system. The mine mechanics disconnected the OEM muffler and installed the DPF. The DPF was affixed to the top of the loader as seen in Fig. 1.

The engine exhaust temperature and backpressure were logged every 15 seconds. The temperature and backpressure were recorded with a CleanAir HiBack exhaust monitoring system and were downloaded every day for the first week to ensure that the filter was regenerating and that excessive backpressure would not pose the potential for engine damage. After two weeks, the backpressure (collected every 15 seconds) was downloaded for those two weeks and finally was again downloaded at the end of 30 days. Although data were downloaded at select intervals, backpressure and temperature data were collected every 15 seconds of equipment operation for the entire 30-day test.

CleanAir Systems DPF system. The CleanAir Systems DPF system (CleanAir Systems, Santa Fe, NM) uses a Corning cordierite wall-flow monolith filter element wash coated with a proprietary platinum-based catalyst. The system is used in conjunction with a fuel additive (Clean Diesel Technology, Stamford, CT, Platinum Plus DFX-DPF), which is a bimetallic catalyst that contains both platinum and cerium allowing it to be used effectively at a dosage level substantially lower than other fuel-borne catalysts. Theoretically, the DPF system, with this fuel-borne catalyst, should passively regenerate during a duty cycle, which results in exhaust temperatures over 300°C (570°F) for extended periods (at least 30% of the operating time) of the cycle. According to the manufacturer, this catalyzed filter/fuel additive system does not promote conversion of NO to NO_2.

Tailpipe measurements. After installation of the filter, the loader was tested while loading material from an embankment outside the mine. This loading operation simulated a high load condition for the engine. The vehicle was run at this high load for 1 minute for each sampling (one sample for gases and one sample for particulate). During the simulated loading operation, an ECOM KL exhaust emissions analyzer was used to measure tailpipe exhaust gasses and exhaust opacity. The ECOM tailpipe probe was placed in the exhaust upstream of the DPF and a smoke dot was collected. (A smoke dot is an opacity-measuring method whereby the exhaust is collected on a paper filter and the color of the dot formed is correlated to a number between 0 and 9, with 9 being the darkest or having the most soot.) The ECOM probe was next inserted upstream of the DPF, and the exhaust was measured for nitrogen dioxide. Both the smoke dot and nitrogen dioxide measurements were repeated downstream of the DPF.

After the DPF was operated for 30 days, the exhaust downstream of the filter was measured again to see if there would be a difference after 30 days of filter use.

Vehicle. The loader used in this study was used to clean up muck piles in the mine. It would typically be used for 4 to 10 hours per day, five to six days per week. During the month of testing, it was run for approximately 125 hours.

NIOSH researchers were at the mine every day for the first week and then about once per week after that. The data were downloaded and reviewed, and the vehicle operators were asked about any problems while using the dpf (e.g., visibility issues).

Results and discussion

Visibility. The filter was installed on top of the loader as seen in Fig. 1, and this location could decrease the miner's visibility. In this case, the operators (there were two different operators) of this vehicle did not have a problem performing their operational duties, and they recorded no significant problems with visibility. There is no guarantee that this dpf will not affect a machine operator's visibility when retrofitted on other vehicles or if this vehicle were used by another operator (e.g., a smaller person). Visibility is a concern when retrofitting some dpfs, and this needs to be addressed any time a filter is retrofitted to a particular vehicle.

Tailpipe measurements. On the first day of installation, the Bacharach smoke dot number was 9 upstream of the filter and 0 downstream of the filter, as seen in Fig. 2. The Bacharach smoke number measures the color of the exhaust collected on a paper filter. A smoke dot number of 9 would be a dark black. The smoke dot number of 0 would indicate no color. Because elemental carbon (EC) is black and no color was seen after the filter but dark black was observed before the filter, the filter seemed to eliminate most of the EC. EC has also been shown to correlate to blackness on a filter in other studies. In a study in an isolated zone, when the smoke dot number was reduced significantly, it was shown that EC was also reduced significantly when sampling before and after dpfs (Bugarski et al., 2003). One technique for determining EC concentrations measures the blackness of the filter by adsorption (Noll and Janisko, 2007). The reduction in EC by the dpf is not surprising because this filter has been tested and found to be 99% efficient in filtering EC (Bugarski et al., 2003).

The tailpipe nitrogen dioxide increased from 20 to 25 ppm. This amount of increase (5 ppm) could not be attributed to the filter device because it could be due to engine variation. For example, in a previous study, when tailpipe measurements were taken from a LHD mining vehicle in an isolated zone of a metal mine, the NO_2 concentrations ranged from 12 to 17 ppm (a difference of 5 ppm) between three runs from the same vehicle under the same conditions (engine under torque converter stall and sampling upstream of control technology) (Bugarski et al., 2003). In fact, when the authors measured NO_2 downstream of the dpf in this study after 30 days, it was 19 ppm (see below), which is less than the measurement before the dpf. The increase from 20 to 25 ppm NO_2 is likely attributed to engine fluctuation.

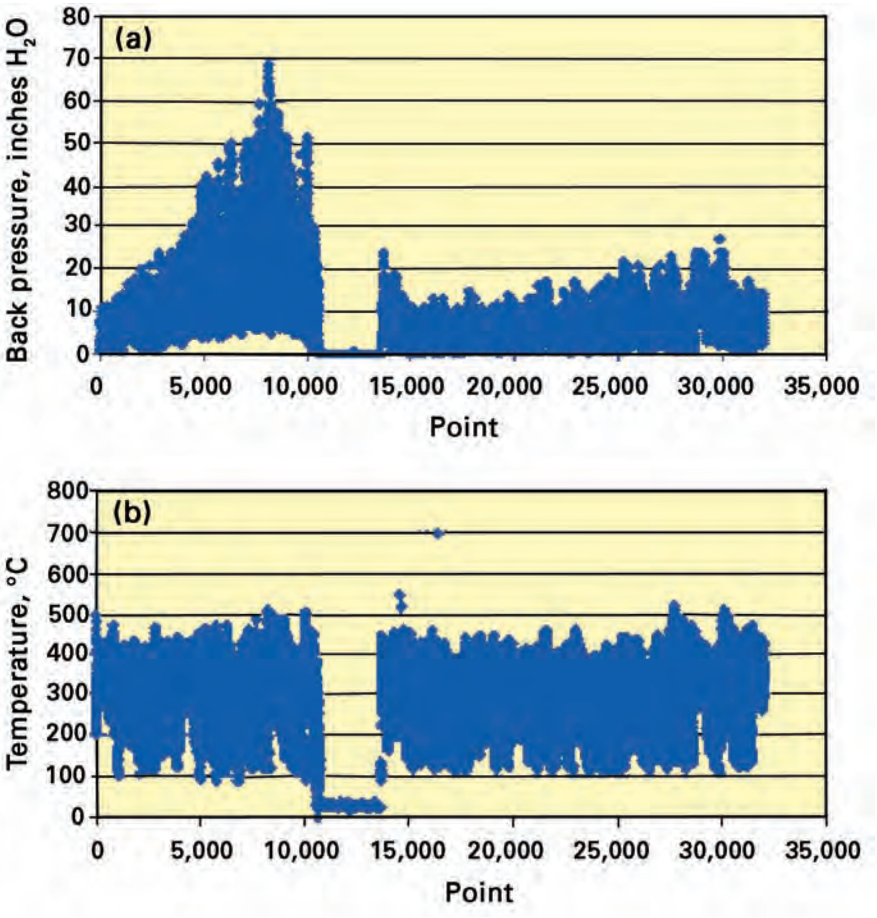
After 30 days of use, the smoke dot number downstream of the filter remained 0 (as seen in Fig. 2) and the tailpipe nitrogen dioxide was 19 ppm. EC continued to be effectively filtered and nitrogen dioxide was not higher than the reading before the filter even after 30 days of use.

FIGURE 2

The results from the Bosch smoke test before and after the dpf installation.

FIGURE 3

(a) The backpressure vs. point (a point was taken every 15 seconds) and (b) temperature of the dpf vs. point.



Backpressure and exhaust temperature. Figure 3 shows the backpressure and temperature trace of the exhaust near the filter. The backpressure would build up and then decrease, indicating that regeneration was occurring at the exhaust temperatures produced by this loader. When the filter was green (unseasoned), the backpressure occasionally rose to 17 kPa (70 in. of water) (but did not remain long at this pressure); however, after a week of use, the filter regenerated when the backpressure reached approximately 7.5 kPa (30 inches of water). The filter manufacturer recommends that the machine fuel be treated with twice the dosage of the fuel additive when the filter is first installed. This recommendation was not followed for this test because there was not enough fuel additive delivered at the start of the filter trial (this could be the reason for the backpressure rising to 17 kPa [70 inches of water] during the first week of filter use). The filter should initially be degreened to achieve optimal performance without subjecting the engine to higher backpressures.

Figure 3 also shows the temperature trace of the filter. This loader filter temperature was above or at 300°C (570°F) for about 65% of the time (calculated from the temperature data). These temperatures are above those recommended to initiate the regeneration process with this filter and were reached by a cleanup loader. The engine of a cleanup loader is not worked as hard as that of a production loader and will not produce exhaust temperatures as high as those of a production loader. Therefore, the production loaders in this mine should be able to produce the exhaust temperatures necessary to regenerate this DPF.

Cleaning or replacing the filter. NIOSH recorded data from this filter for 30 days of loader operation. The filter remained on the vehicle for several weeks after this 30-day test period. The mine reported that after six to seven weeks of use, the tailpipe downstream of the filter began to show signs of a light blackness indicating that the filter probably needed cleaning as a result of ash accumulation, which is a result of the filter regeneration process.

Conclusion

This passive DPF performed well on this loader and probably would perform well for most of the loaders in this mine (based on their projected duty cycle). The DPM concentration generated by this loader was substantially reduced and nitrogen dioxide increase could not be attributed to the dpf. Little maintenance was required for this filter because filter regeneration was accomplished at the exhaust temperatures generated by the loader.

A fuel additive is necessary for this filter to regenerate at its inherent operational exhaust temperatures, and occasionally the filter will need to be cleaned to remove the ash buildup resulting from filter regeneration. Before retrofitting this DPF on a mining vehicle, visibility, regeneration (exhaust temperature profiles), backpressure and filter capacity should be considered. Exhaust temperature profiles are important because the dpf may not work properly on a vehicle without the appropriate temperature profile. The filter needs to be sized large enough so that excessive backpressure is not created. Operator visibility could be different for each vehicle fitted with such a filter and should be considered on a case-by-case basis. Economic issues associated with the use of this filter were not examined during this study.

Disclaimer

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