MNM DPF Filter Selection Guide Explanations

Diesel Particulate Filters (DPF)

Overview

Diesel particulate filters applicable to the equipment used in your Metal or Nonmetal mine are designed to filter diesel soot from the hot exhaust. They also replace the muffler. The filter media used in the majority of the commercially available DPFs is made from a porous ceramic material made from either Cordierite or Silicon Carbide. The Silicon Carbide material is more robust, filters slightly more efficiently, but is more expensive.

The filters work by blocking passage of the diesel soot so that much less than 10% of the soot in the engine's exhaust is released into the mine air. Obviously, soot builds up in the filter and something has to be done to remove it. The process of removing the combustible portion of the collected soot is called "regeneration" which is the burning off of the soot by raising the temperature of the filter element so that combustion of the soot occurs. When the soot combusts, the soot which is almost pure carbon is converted to gaseous carbon dioxide (CO_2) and carbon monoxide (CO), which pass through the filter. Diesel soot or DPM is not entirely comprised of combustible carbon but also contains noncombustible ash resulting primarily from the additives used in crankcase lubrication oils, fuel or intake air additives, and from the fuel itself. The removal of the ash from the DPF is called "cleaning" and, although necessary to do, is done much less frequently than regeneration. See the discussion of ash in this document.

DPF regeneration can occur "passively," or naturally when the engine exhaust is hot enough during equipment operation. Some DPFs use a washcoat of specially-formulated catalysts, fuel-borne catalysts (a fuel additive), or both to reduce the exhaust temperature needed for regeneration.

When natural passive regeneration is not possible, the DPF stores the soot during machine operation, and a regeneration must be "actively" performed on a *regular* schedule, for example once every shift. Active regeneration uses electric heating elements and a controlled air flow to regenerate the filter when the equipment is not in use. The commercially available systems for active regeneration either incorporate the electric heating element into the DPF and regeneration takes place on-board the equipment while the equipment is off duty and parked at a designated location, or require the exchange of the loaded DPF for a regenerated DPF. In the exchange scheme, the loaded DPF is taken to a regeneration station located in a designated area (perhaps with other such regeneration stations) that is ventilated and free of combustibles either underground or on the surface. Another system uses compressed air, flowing in the reverse direction from the normal exhaust flow, to blow out the collected soot and ash into a collection bag.

The exhaust temperature dictates whether passive or active DPFs are applicable for a specific piece of equipment. Active systems are universally applicable because they only collect the soot and can be mounted where convenient, but passive systems impose strict requirements on exhaust temperatures and must be mounted as close to the engine exhaust manifold as possible.

You can learn more about regeneration methods here, the effect of a DPF on engine exhaust back pressure and the need to monitor here, and ash removal here, or you can continue to scroll down and keep reading.

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DPF regeneration methods

The soot that is trapped by the DPF can be removed in several different ways. The removal of the carbon soot from the DPF is called regeneration.

- **Passive Regeneration** – Passive regeneration occurs when the soot in the DPF spontaneously combusts (burns off) during the normal work cycle because the exhaust temperatures are sufficiently hot. Techniques have been developed that can lower the temperature required for passive regeneration. The most effective technique is to coat the surface of the filter media used in the DPF with noble metal catalysts such as platinum. This has the undesirable effect of increasing NO_2. In general, the more catalyst used, the lower the regeneration temperature and the greater the conversion of NO to NO_2. MSHA has issued a PIB P02-04
  Other ways to reduce regeneration temperatures which do not increase NO_2 include using fuel-borne catalysts (FBC), fuel-borne catalyst with a light washcoat of platinum on the DPF, and washcoats of a base metal catalyst.
  A rule of thumb has evolved for characterizing exhaust temperatures at which regeneration occurs for passive DPFs of the different systems described above. Specifically it is the exhaust temperature that is exceeded about 30% of the operating time during a shift. It this document it is called the critical temperature and represented by $T_{30\%}$. The exhaust temperatures required for passive regeneration for these techniques range from about 325 to 420^o C (615 to 790^o F)

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Active Regeneration – The term "Active" regeneration refers to the requirement for the active involvement of a person or mechanism to accomplish the DPF regeneration. Active regenerating DPFs must be used when the engine exhaust temperature during the work cycle is not hot enough to burn off the soot being collected. Soot, therefore, accumulates in the DPF and must be removed. Active regeneration is usually performed on a set schedule, usually at every working shift. A set schedule which fits into a regular or natural work pattern such as a shift, or day, or week, is a must to ensure that regeneration is performed *without fail*. The DPFs are sized to collect a full shift-load of soot without creating excessive back pressure on the engine. Several active regeneration schemes, employing temperature-controller electric heaters and controlled low air flows to heat up the DPF to about 800° C to ignite the soot, are currently available:

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- **On-board regeneration** – In this scheme, the electric heater is built into the front/upstream section of the DPF. Regeneration takes place while vehicle is off duty. The controller and compressor can be installed on-board the vehicle or can be a separate unit. If the controller and compressor are on-board, the equipment needs only to be parked in a ventilated area away from combustible materials and where there is a source of electric power. If the controller and air compressor are off-board the equipment, it must always travel to the location of the control unit. If the equipment cannot be parked at the same place at the end of a shift, then additional control units need to be purchased or on-board controller should be considered.
  During regeneration the electric heaters heat the DPF to high internal temperatures (about 800^o C). The outer surface of the filter may get hot and combustion gases very slowly flow from the equipment's exhaust. A regeneration parking area should be designated where the appropriate electrical, fire, and ventilation safety requirements are in effect. Regeneration times can range from under one hour or two (Silicon Carbide media) to eight hours (Cordierite) depending on DPF size, filter media, and regeneration system manufacture. This regeneration time defines the time required every shift or every day that the vehicle must be "out of service."

- **Off-board regeneration** – The DPF is removed from the equipment (this is most easily accommodated with the smaller DPFs used for low horsepower engines) and placed into a filter regenerating system designed for it. Such a system will be connected to a source of electric power, may incorporate a temperature controller, compressed air source and controller, and possibly a catalyst on the outflow to eliminate hydrocarbons and carbon monoxide from the combustion gases. Some regeneration systems blow out the DPM into a collection bag prior to starting the heated regeneration cycle. The regeneration units must be properly located to meet proper electrical, fire, and ventilation safety requirements. Regeneration times are similar to those of the on-board unit.

The equipment down time can be very short, since a newly regenerated DPF can be exchanged for a loaded DPF when the loaded one is removed. The exchange scheme doubles the DPFs required for each piece of equipment.

Active-Passive Regeneration – In some cases, the exhaust temperatures are sufficient to combust most, but not all, of the soot during normal equipment operation. This has been seen to occur in systems incorporating a fuel borne catalyst and/or base metal catalyzed DPFs. In this case, the active regeneration of the DPF is required only after extended periods of operation, say, for example, after 250 or 500 hours and can be performed during the regularly scheduled maintenance. Active-passive regeneration of the DPF uses the same methods as those for Active Regenerating systems described above. Monitoring of back pressure is critical for these systems, because a slight reduction in the operating cycle load can significantly lower the soot burn off rate and reduce the operating time before active regeneration is required.

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Exhaust back pressure

As the DPF collects soot, the passage of exhaust gas through the pores of the filter element is progressively blocked and the pressure required to maintain the exhaust flow increases. This pressure that the engine exhaust must work against is called "back pressure." Engine manufacturers place limits on the exhaust back pressures for their engines. Beyond a certain limit, excess exhaust back pressure increases engine exhaust temperature, CO, and particulate matter (soot) emissions. The additional soot emissions loads the DPF up even faster. Because of detrimental effects of excessive exhaust back pressures on both engine and DPF (discussed below), a back pressure monitoring system must be installed with the DPF.

The exhaust back pressure increases for two reasons:

- short term build up of soot, remedied in the short term by regeneration; and
- long term build up of ash, the noncombustible component of soot, remedied by cleaning.

Need for back pressure monitoring

Overloading the DPF with soot can be detrimental to the life of the DPF. When the DPF is overloaded, spontaneous regeneration in passive DPFs becomes difficult to control and may become too vigorous causing the filter media to melt or crack. For both the protection of the engine and the DPF, all DPF installations *require* a system to monitor engine exhaust back pressure continuously during engine operation. Back pressure monitoring systems can range from those consisting of a simple mechanical gage with the high level marked on the dial to systems using electrical pressure sensors in a sophisticated electronic data loggers and a display multiple alarm set points. Some can incorporate an exhaust pressure measurement into the electronic engine control system to cut back the fueling rate when exhaust back pressures exceed the safe level. Back pressure monitoring systems are offered by most DPF manufacturers as part of the DPF installation and is one criteria to be used for selecting a DPF supplier.

Exhaust back pressure monitoring is also a must because of the slow increase of the back pressure in a regenerated DPF caused by the build up of ash. At some point in the service life of any DPF, the regenerated DPF back pressure will be too high to allow the normal build up of soot without exceeding the back pressure allowed by the engine. When this happens the ash must be removed from the DPF by following the manufacturer's instructions for cleaning. The ash build up will not occur if the regeneration process includes an ash removal step in the routine regeneration process.

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Ash Build-up and Removal

Ash Build-up

Not all of the soot can be removed from the DPF by regeneration which combusts the carbon portion of the soot. A small fraction of the soot is not combustible, the ash. The primary source of ash in diesel exhaust soot are the additives in the crankcase oil. This oil lubricates the cylinder walls, and a small part of it is combusted with the fuel. Additional (repairable) lube oil leaks from worn piston rings or valve guide seals can add significant contributions to ash. Ash is also created by the use of any metal-based fuel additives or by additives to the combustion air.

Unless the engine is consuming lube oil or is a 2-stroke engine, the build up of ash is a slow process and demands no action for several hundred hours or even a thousand hours of operation. Since the life of a DPF is several thousand hours (10,000 or more), the ash must be removed several times during the useful life of a DPF.

Ash Removal (DPF Cleaning)

Ash can be removed from the DPF by several different methods. The DPF manufacturers will provide the hardware, instructions, or a service to remove the ash from the DPFs they supply. The alternatives include back flushing with compressed air into a collection bag or placing it on a special regeneration and cleaning station which uses a vacuum cleaner to reverse flow the air through the DPF as part of the regeneration process. It is not a good practice to reverse the DPF on the engine and use the engine exhaust flow to purge the DPF of ash unless this is done in an open space outdoors and is recommended by the DPF supplier.

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Explanations specific to MNM DPF Selection Questions

Why is it important to have a site champion?

The successful implementation of diesel particulate filters requires the coordination and cooperation of several departments within a mine operation. It was pointed out in a discussion group at MDEC 2003, that the introduction of DPFs will require a "cultural shift" of the entire mining organization, but in particular, those responsible for maintenance and operation of the equipment. The mine management should designate a single person who will be responsible for the selection and implementation of diesel particulate filters at a specific mine and for providing the training to implement the necessary cultural changes. This person should then be given the authority, responsibility and time to perform this function. The list below provides some indication of the variety of people and disciplines involved in the control of DPM.

- Presumably the vehicle(s) targeted (by the **ventilation or health and safety** department) as candidates for DPF installation was/were selected as a result of a survey of area or personal exposures to DPM (Total or Elemental Carbon) and the knowledge of the local ventilation.
- **Engine mechanics** need to be involved to ensure that the engine is in proper working order. These may be either mine employees or contractors.
- **Vehicle and engine maintenance** persons need to be consulted on the placement of the DPF on the vehicle so as to not cause undo impediment to routine vehicle or engine maintenance.
- The **production or operations people** need to be involved because the DPF may require adjustments to vehicle operation and production schedules to accommodate active regeneration systems.
- The **equipment operator(s)** needs to be involved so he/she understands the importance of a DPF to air quality and to learn the importance of back pressure alarms or gages and actions to be taken if exhaust back pressure is exceeded during production.
- Finally the **ventilation or health** department needs to conduct post installation surveys to verify reductions in DPM, and if necessary, when precious metal (i.e., Platinum) catalyzed DPFs are used, verify that the workplace NO_2 concentrations are at safe levels.

It is the responsibility of the site champion to gather together all of these persons who are directly involved with the DPF and fully explain each person's role and responsibility, to solicit suggestions, and gain their acceptance and cooperation. It is the site champion who must maintain and operate with the knowledge of the full picture required for successful implementation of a DPF on a single or several vehicles. Without such a person to coordinate the application of DPFs, successful implementation is less likely.

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Explanation of Engine Questions

Why is the type of engine important?

Two-stroke diesel engines emit exhaust particulate matter (PM) than equivalent 4-stroke engines, and the PM contains lubrication oil. This affects the diesel particulate filters (DPF) in two ways:

- the size or capacity of the DPF must be larger for a 2-stroke engine to provide adequate service time between regenerations for active DPF systems; the larger size increases the cost of the DPF and requires more space for installation.
- the lubrication oil contains ash which cannot be removed by thermal regeneration; frequent maintenance to remove the ash would be required to maintain an acceptable exhaust back pressure.

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Why be concerned with engines that burn oil?

The excessive burning of oil contributes to the engine's particulate matter (PM) emissions reducing the service time between regenerations in DPF systems that must be manually regenerated (active DPF system). Generally, the capacity (and thus the running time between regenerations) of active DPFs are sized for the PM emissions rate for a specific engine model *in good working condition*. The lubricating oil also contains metals which create an ash residue in the DPF that is not removed by simple thermal regeneration. Thus ash accumulates much faster than it should, increasing the back pressure of a fully regenerated DPF, shortening the service life between regenerations in active DPFs, and requiring more frequent maintenance to remove the ash for both active and passive DPF systems.

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Why must the exhaust CO concentration be at an acceptable level?

The carbon monoxide concentration in the raw exhaust is a good indicator of engine condition and/or engine tune. Higher than normal CO concentrations in the engine exhaust at full engine load (torque stall) indicates incomplete combustion of the fuel. Incomplete combustion also causes high diesel particulate matter (DPM) emissions which means the DPF will load up with soot more quickly which will be detrimental to the successful functioning of a DPF. Monitoring engine-out (before any after treatment) CO concentrations in the exhaust forms the basis for emissions-based maintenance.

CO is also a toxic gas and must be controlled so that the workplace CO concentration does not exceed that allowed in §57.5001 (50 ppm).

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Exhaust Temperatures

Why do I need to obtain an exhaust temperature profiles of my equipment?

Exhaust temperature profiling, that is, obtaining a set of exhaust temperature vs. time logs, is needed primarily for determining the DPF regeneration method alternatives that will work on the target equipment. In addition, the DPF supplier can use this information to estimate engine loading and particulate matter emissions to assist in sizing the DPF for the application. Temperature traces or logs need to be obtained for several shifts to provide a valid representation of the variety of situations in which the equipment is used.

The temperature of the engine exhaust is the most critical parameter in determining whether the target equipment can utilize a passive regenerating DPF or must use an active regenerating DPF. With one exception a fuel burning active regenerating DPF active regenerating DPFs cause a greater impact on

vehicle deployment, maintenance, and operation than passive systems. Whether a DPF can successfully regenerate using exhaust temperatures alone, is highly dependent on the length of time the exhaust is above a certain threshold temperature and on the catalyst formulation of the DPF system.
Successful use of a passive DPF also requires that the equipment on which it is installed operate at high loads for **every** shift; ***the equipment cannot be reassigned without a reassessment of exhaust temperatures***.
The amount of operating time during a shift that the engine is heavily loaded provides an indication of the particulate loading of a DPF for a shift and affects the sizing (soot holding capacity) of the DPF for most active DPF systems.
The variability of engine temperatures and loading experienced from shift to shift is of critical importance in assessing whether normal operation can support a passive DPF. If the equipment occasionally works one or more shifts with lighter loads, exhaust temperatures may not be sufficient to regenerate the DPF with the result of excessive exhaust back pressures and potential for destruction of the DPF.
The Compliance Assistant, and most reputable DPF suppliers and manufacturers, insist on having a valid and representative temperature profile for the vehicle targeted for installation of a DPF prior to making a recommendation of a DPF system for the target application.

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What are the differences between getting temperature traces myself and using a DPF supplier or independent consultant? What does the Compliance Assistant suggest?

Below are some things to consider when choosing whether you gather exhaust temperature profiles yourself or let an a DPF supplier or consultant do it.
When you collect temperature traces yourself

- **Disadvantages**
  - You must invest in equipment (a little over $250 for a "kit");
  - You must train personnel to use the temperature logging equipment and software.
  - You must give the person time and responsibility to do this task.
- **Advantages**
  - Collecting exhaust temperature profiles is simple; it is the analysis that is the challenge;
  - You are free to move the temperature logging kit from one piece of equipment to another as needed;
  - You gain a person on your staff and on-site who is trained in temperature logging and can expand to other activities for DPF support;
  - You own all of the data and can share it with all potential DPF suppliers or consultants for analysis;
  - You can collect over more shifts;
  - You can log temperatures after installation, upon redeployment of equipment (a necessity with passive DPFs), and anytime temperatures are needed;
  - You will need to establish exhaust temperature logging capabilities in any case in the long run.

When you contact a DPF supplier or consultant to collect the exhaust temperatures:

- Ask for an on-site visit either to actually perform the temperature profiling and/or to train your personnel to continue after the visit;
- Ask whether you or they supply the temperature profiling instrumentation;
- If the instrumentation is supplied by them, ask how long you can keep it;
- Negotiate for your ownership of the raw temperature data in electronic form compatible with popular spreadsheet programs (separate data collection task from that of data analysis);
- Ask whether the data analysis results in a DPF recommendation and/or consists of exhaust temperature analysis such as histograms, cumulative frequency analysis, moving averages, etc. which provides the basis for DPF selection.
- **Disadvantages**
  - The contractor's time available to remain on-site to collect exhaust temperatures is limited. To continue with gathering additional traces on this or other equipment, *you will have to do it yourself*.

- The contractor may not be able to profile the equipment for sufficient number of shifts to cover the variety of tasks encountered;
- Unless you own the logging equipment, you have no opportunity to profile other equipment or log exhaust temperatures after DPF installation.

- **Advantages**
  - Minimum investment of your time and personnel when the DPF supplier can come on site and collect temperature traces.
  - The temperature profiling can be part of the DPF system purchase with the DPF supplier assuming the responsibility for a successful DPF application.

In sum, the Compliance Assistant believes that the optimum arrangement would be for you to acquire the equipment and collect the temperature data yourself. MSHA or NIOSH can assist you in this task. Also see taking exhaust temperatures myself. You can then provide the temperature profiles to all of the potential DPF suppliers for their analysis and DPF option recommendations.

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DPF System Configuration Details

Passive DPF Systems Descriptions & Considerations

Un-catalyzed DPF

An un-catalyzed DPF consists of Cordierite or Silicon Carbide ceramic filter media that has not been catalyzed; it is bare and hence the nickname of "bare trap.". This DPF will regenerate when exhaust temperatures exceed 450 to 500° C for at least 30% of the engine operating time per shift.

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Considerations for Un-catalyzed DPF

- It is rare that these exhaust temperatures (450 to 500° C) can be achieved with today's modern turbocharged engines. Because the exhaust temperatures are marginal for passive regeneration, there is a risk that a slight or subtle decrease in equipment work load would decrease the exhaust temperature below that needed for regeneration. Back pressures and exhaust temperatures would have to be carefully monitored.
- The CO, unburned hydrocarbons (HC) responsible for diesel odor, and the health impact of the equipment emissions would be reduced if a diesel oxidation catalyst (DOC) were used either before or after the DPF.
- Given the above it is worth considering using a lightly catalyzed (platinum) DPF (without a fuel additive). A lightly Pt-catalyzed DPF would (1) regenerate at a lower exhaust temperature providing a margin of safety and (2) would also remove CO and HC.

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Base Metal Catalyzed DPF

Some DPF suppliers offer a DPF with a Cordierite media coated with a base metals which act to reduce the exhaust temperatures required to initiate and sustain regeneration. The exhaust temperatures need to exceed 400 to 420° C for at least 30% of the engine operating time.

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Considerations for Base Metal Catalyzed DPFs

- Achieving 420° C consistently is not common but achievable in shifts with heavy work loads relative to the available engine horsepower.
- Base metal catalysts do not reduce CO or unburned hydrocarbons (HC). Therefore a diesel oxidation catalyst (DOC) could be added upstream or downstream of this DPF with some health benefit and odor reduction. Such systems are offered by some DPF manufacturers.

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Lightly Catalyzed DPF plus Fuel Additive

The "Lightly Catalyzed DPF + Fuel Additive" is a system consisting of a ceramic filter element that has been given a light wash coat of Platinum- (Pt-)based catalyst. Additionally, a "bi-metallic" fuel borne catalyst is used in the fuel to provide a regeneration temperature of about 360° C, which falls between that of the base metal catalyst and the highly catalyzed DPF.

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Considerations for Lightly Catalyzed DPF plus Fuel Borne Catalyst (FBC)

- Recent (February 2003) data seems to indicate that this system will passively regenerate when the exhaust temperatures are above the 360° C (30% of the time) or 335° C (40% of the time).
- It has also been the experience for some installations that although regeneration is not quite keeping up the soot accumulation, manual regeneration needs only to be done at an interval that corresponds with the scheduled 250-hr maintenance.
- Preliminary MSHA tests at A&CC indicate that the conversion of NO to NO_2 is not significant (in contrast to the heavily catalyzed DPF system discussed below). It is currently unknown to NIOSH whether the build up of the catalytic metals from the fuel additive in the filter element would affect the NO to NO_2 conversion increasing it as the ash accumulates. A cleaning of the DPF to remove the ash would remedy this easily.
- The light coating of noble metal catalyst does reduce CO and hydrocarbons resulting in odor reduction and additional health benefit.
- The fuel-borne catalyst (FBC) must be continuously present in the fuel. Various methods are used to accomplish this. Some manufacturers offer on-board automatic dosing systems which sense the fuel level in the equipment's tank and meter out the appropriate quantity of FBC additive as the fuel level increases upon refueling. Manual dosing can be achieved by metering the fuel during refueling and adding the proper quantity of FBC based on the fuel delivered. The third alternative is to add the FBC to the bulk fuel that is subsequently kept separate from the fuel for other equipment not using this or any other DPF.
- It is very important not to use fuel doped with a fuel-borne catalyst in equipment which is not equipped with a DPF.
- Using a fuel-borne catalyst increases the rate of ash accumulation in the DPF. The dosing level for some FBC additives (the bi-metal FBC in particular) is quite low, which minimizes ash build up reducing the effect on the period between cleaning.

The DPF prevents the fine ash particles of the FBC from being emitted into the workplace air. Although it is an MSHA requirement that the fuel borne catalysts be approved by the EPA, their release into the air is not desirable. Therefore, there is a slight additional diligence needed to ensure that the DPF is not cracked and is filtering properly.

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Catalyzed DPF

A catalyzed DPF system consists of a ceramic media coated with sufficient Platinum (Pt) catalyst to produce soot burning (regeneration) at exhaust temperatures at about 325° C. Substantial amounts of Pt are used, hence these systems are often called "heavily" catalyzed DPFs to distinguish then from the lightly catalyzed DPFs.

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Considerations for Heavily Catalyzed DPF

- The heavily catalyzed DPFs offer the lowest regeneration temperatures of the systems available for mining. The Johnson-Matthey CRT® system designed for city buses has a lower regeneration temperature but has a high conversion of NO to NO_2 that is not controllable nor desirable in underground settings.
- Heavily Pt-catalyzed DPFs obey the principles of chemistry and readily convert the NO in the exhaust stream to NO_2. The conversion rate, which directly affects the amount of NO_2 that is emitted, varies with the DPF temperature and peaks at temperatures slightly above that for minimum regeneration. The NO_2 is consumed somewhat by the soot in the regeneration process, thus the concentration in the tailpipe may vary depending on the amount of accumulated soot in the DPF. Since the compliance level for NO_2 is 5 times lower than for NO, the health effects of NO_2 are more serious. In sum, the above together strongly indicate the need consider seriously the (active) DPF alternatives or to monitor NO_2 in the workplace when heavily catalyzed DPFs are used.
- Several mines have tried the heavily catalyzed system on their equipment because it is the simplest to install and maintain. Because of the lack of data, it is not clear whether NO_2 is a problem.
- If this system does not regenerate reliably, then the only option is to use an active DPF system.
- Link to installation precautions for heavily catalyzed DPF.

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Active DPF Systems Descriptions & Considerations

Systems with off-board regeneration

Off-board regeneration is used to describe an active (regenerating) DPF system in which the DPF must be removed from the equipment for regenerating.

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DPF Exchange or Swapping

Off-board DPF regenerating requires the removal of the DPF for regenerating, usually by placing the DPF in a special regenerating "station" designed for that purpose. Because the time involved in transporting and regeneration usually exceeds the between-shift down time of the equipment, the DPF supplier usually recommends two (or more) DPFs so that when a loaded DPF is removed from the equipment it is immediately replaced (exchanged or swapped) with a regenerated DPF.

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Considerations for Off-board DPF Swapping

The introduction of DPFs requiring active regeneration demands a "culture shift" in mine operations and personnel. Implementation of this culture change is one reason for having a site champion. The implications of an off-board regenerated DPF are the following:

- Because the weight, size, and cost of a DPF increases with engine power, DPF swapping can be limited to equipment with engines of less than about 150 hp.

- DPF swapping produces the least downtime of the equipment of any of the active DPF systems.
- Unless the downtime of the equipment exceeds the regeneration time of the DPF (regenerating times vary between about one hour to eight hours depending on filter composition), you will need at least two DPFs for this equipment.
- DPF swapping requires the easy and convenient access to the DPF on the equipment. Some thought should be given to this factor when designing the installation layout and the design of the DPF connection to the exhaust system. The connection between the exhaust system and the DPF must not leak.
- The logistics (the when, where, and how) of DPF exchange must be carefully thought out. The DPF exchange should be (actually, must be) scheduled and performed regularly; therefore, it must be set up in such a way to ensure that DPF exchange occurs on schedule without fail.
- Transportation of the DPFs between the equipment and regeneration station must be thought about. This factor influences the location of the regeneration station so that transportation of DPFs is minimized to reduce risk of breakage and inconvenience.
- As a consequence of the above, equipment most suited to DPF swapping are the following in order of suitability:
    - utility vehicles (small horsepower, well exposed access to DPF, regular parking place between shifts)
    - production equipment with engines smaller than 150 hp, which park at an established location between shifts, and with easy access to DPF for its removal
    - remote, roaming, or isolated vehicles which are fueled by a visiting fuel truck which would be able to carry a DPF for exchange at every fueling
- The equipment least suited for off-board regeneration (DPF exchange) would be those with any one of the following characteristics: a large engine, no convenient location of DPF for easy access, are parked anywhere at the end of the shift, or are fueled by the operator from any fuel tank that is convenient at the time of need.

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On-board active regenerating DPFs

Active DPF systems in which the DPF remains on-board the equipment during the regeneration process are termed "on-board regenerating DPF systems." Because the DPF remains on board the equipment, the electric heating element must be built into the DPF on the upstream end of the DPF. However, the heater element temperature controller and air compressor or regulator can be either on-board the vehicle or in a separate off-board unit. These two systems are described below. Regeneration requires the vehicle to be out of service for the period of the regeneration which can range from as little as one to as much as eight hours depending on system selected.

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Active on-board regenerating DPFs with on-board controllers

These systems have their temperature controller and combustion air flow source (a small pump) on board the equipment and only require connection to a source of electric power.

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Considerations for on-board controller systems

Here are some things to consider with the on-board controller system:

- All the operator needs to do to start regeneration is to connect the unit to an appropriate source of power.
- The equipment therefore must be parked between shifts at a source of electric power suitable for powering the regeneration unit. This has a number of ramifications:
  - A parking area has to be established that provides the power to as many pieces of equipment that may need it.
  - The parking area should be adequately ventilated to remove combustion gases from the regenerating DPF.
  - The internal temperature of the DPF will reach 800° C or greater during regeneration. Depending on the DPF design, the surface temperature of the DPF may also be extremely hot. Precautions must be taken both in locating the DPF on the equipment and in the parking area to ensure that flammable material is not near or in contact with the DPF during regeneration. Normally this should pose no problem.
- The regeneration control unit, because it is mounted on-board the equipment, is subjected to the vibrations of the equipment on which it is mounted. This has proved to be a weak point in the systems tested in the past by DEEP. Suitable engineering can rectify this problem.

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Active on-board regenerating DPFs with off-board controllers

These systems have their temperature controller and combustion air flow source and controller as a unit separate from the diesel equipment. An umbilical containing heater power, temperature measurement signal, and air hose as a minimum connects the DPF on the equipment to the control unit.

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Considerations for off-board controller systems

Here are some things to consider with the off-board controller system:

- All the operator needs to do to start regeneration is to connect the unit to the umbilical cable from the regeneration controller and start the controller.
- The equipment therefore must be parked between shifts at the site where the regeneration controller *for that DPF system* is located. This has a number of ramifications:

- A parking area has to be established that provides the connection to the regeneration control unit. There must be one regeneration controller for each piece of equipment that requires regeneration at that location.
- If operating scenario for the equipment places it at different locations at the end of a shift then each location needs to be equipped with a regeneration controller for that equipment. For example, if a vehicle works on several different levels and cannot take the time to travel to another level at the end of the shift, a regeneration facility needs to be made at each of the working levels for that vehicle. It may be advantageous in this case to consider on-board regeneration controllers since only a source of electrical power is needed for their operation.
- The parking area should be adequately ventilated to remove combustion gases from the regenerating DPF.
- The internal temperature of the DPF will reach 800° C or greater during regeneration. Depending on the DPF design, the surface temperature of the DPF may also be extremely hot. Precautions must be taken both in locating the DPF on the equipment and in the parking area to ensure that flammable material is not near or in contact with the DPF during regeneration. Normally this should pose no problem.

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Acknowledgments

This document was authored by George Schnakenberg, Jr. in consultation with Aleksandar Bugarski, both with NIOSH, It was reviewed by Larry Patts of NIOSH and James Angel of MSHA. It represents the state of knowledge at the time of writing. Please address any comments about this document to George Schnakenberg, Jr., NIOSH-PRL, P. O. Box 18070, Pittsburgh, PA 15236, 412-386-6655.