Indoor Cats improve quality of exhaust emissions

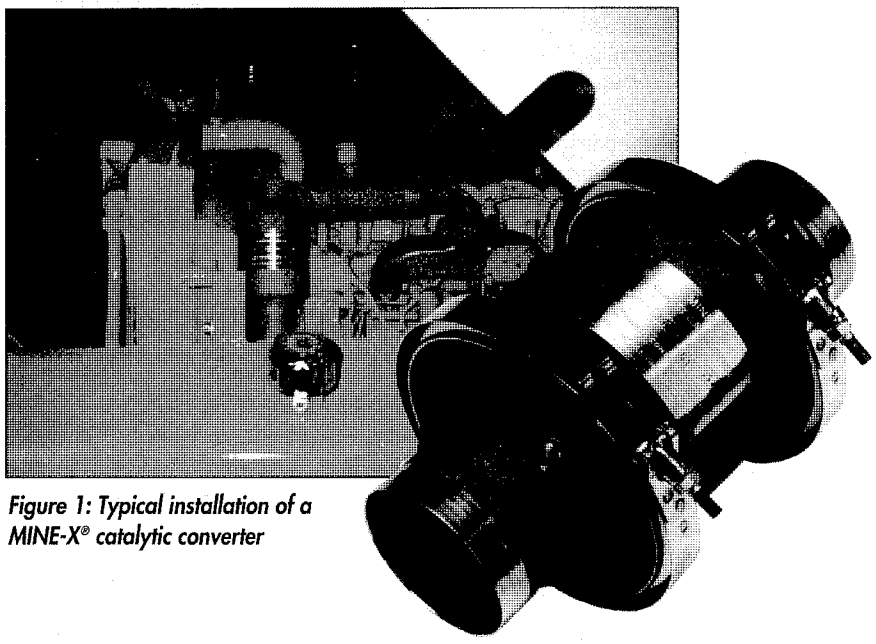


Figure 1: Typical installation of a MINE-X® catalytic converter

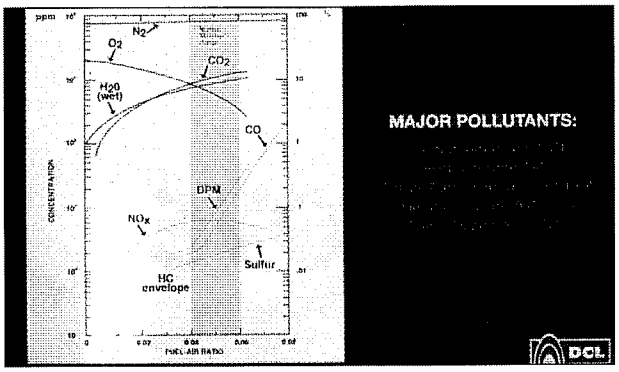
The requirement for emission control systems to be installed as part of drive systems on materials handling equipment is growing in line with increased regulations concerning health and safety in the workplace. Michael Campbell of DCL International Inc. outlines the use of catalytic converters to improve the quality of exhaust emissions.

For over two decades, the automotive industry has struggled to keep up with emission standards by installing emission control systems that are increasingly more sophisticated and expensive. In the meantime, emission control for materials handling equipment has not been a major concern. Without having to meet stringent tailpipe emission standards and faced with pressures to contain costs, OEMs of material handling equipment have seen no need to introduce significant kinds of emission control devices. However, with more strict enforcement of indoor health and safety regulations, combined with the increasing awareness of end-users, the market is slowly changing.

AFTERMARKET

The regulations for indoor health and safety usually set maximum levels of pollutants for the ambient air. This means that even if the IC engine pollutants at the tailpipe far exceed these levels, it is still possible to meet regulatory requirements if there is adequate ventilation, but in many cases this is not sufficient. Installing a catalytic converter provides the end-user with a quick solution to achieving improved ambient air quality and improving worker safety. DCL's MINE-X® catalytic converter combined with proper engine maintenance typically reduces pollutants from gaseous tailpipe emissions by over 90 per cent. As a result, a growing world-wide aftermarket is emerging to provide end-users of materials handling equipment with catalytic converters.

However, simply applying the same



Composition of diesel exhaust

automotive technology to the materials handling industry is not the correct solution. Whereas automobiles feature feedback control systems and emission control devices for meeting stringent emission standards for smog and ozone-causing substances, the objectives for materials handling equipment are quite different. The priority is to control exhaust emissions that have a direct impact on health, such as carbon monoxide. A second objective is to contain costs and maintain the advantage of the IC engine over electrical equipment.

CATALYTIC EXHAUST AFTER-TREATMENT

A catalyst is a material that increases the rate of a chemical reaction but is not consumed in the process. In a catalytic converter, a catalytically active surface is used to promote desired reactions to occur at temperatures present in exhaust gases. The typical catalytic converter consists of a substrate, the packaging elements which protect the substrate in its outer shell, and a means of connecting the center body (substrate and packaging) to the exhaust system. The substrate acts as the mechanical support for the washcoat and catalyst formulations. Cells running axially through the substrate provide small channels through which exhaust gas flows and is exposed to the catalyst.

Currently, there are three basic types of catalytic converters for use with IC engines. For SI engines, either an oxidation catalyst or a three-way catalyst (TWC) may be used. Diesel equipment may use a diesel oxidation catalyst (DOC). Catalyst developers are presently at work developing a lean-NO_x catalyst for lean-burn SI engines, and a lean-NO_x three-way catalyst for diesel.

SPARK IGNITION ENGINES

In an SI engine, exhaust emissions are generally limited to gaseous carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons from unburned fuel, and lube oil materials. Of these, CO poses the greatest health threat. CO reduces the oxygen-carrying capacity of the blood, and can be fatal in sufficient doses. For this reason, exposure limits to CO are legislated in most jurisdictions in North America and Europe.

Three-way Catalyst for Spark Ignition Engines

The MINE-X® three-way catalytic converter converts CO, hydrocarbons, and NO_x to form nitrogen (N), carbon dioxide (CO_2), and water. The basic chemical reactions are as follows:

Oxidation reactions:

$2CO + O_2 \rightarrow 2CO_2$

hydrocarbons + $O_2 \rightarrow CO_2 + H_2O$

$CO + H_2O \rightarrow CO_2 + H_2$

Reduction reactions:

$NO_x + CO \rightarrow N_2 + CO_2$

$NO_x + H_2 \rightarrow N_2 + H_2O$

NO_x + hydrocarbons $\rightarrow N_2 + CO_2 + H_2O$

The series of reactions that occur depend to a large extent upon the operation of the engine. The maximum emission performance is achieved with a stoichiometric air/fuel ratio ($\lambda = 1$). Under stoichiometric air/fuel conditions, the engine exhaust gas will contain about 1 per cent oxygen. With oxygen-poor conditions and NO_x and CO present at near-equal quantities, a high conversion of NO_x and CO occurs. The performance of a TWC system is thus enhanced by the use of an air-fuel ratio controller to maintain the optimum air-fuel ratio. An oxygen sensor in the exhaust provides a rich or lean indication, which, in turn provides a correction signal to the fuel metering device, causing the A/F system to operate in a limited range about the stoichiometric point.

"The priority is to control exhaust emissions that have a direct impact on health, such as carbon monoxide"

Making up the catalytically active surface for a typical three-way formulation is a γ-alumina-ceria washcoat impregnated with a proprietary formulation, normally comprised of precious metals such as platinum, palladium, and rhodium. The γ-alumina is a high surface area substance, approximately 200 m^2/g BET, which provides microscopic pores for active catalyst sites. A high surface area washcoat is desirable to maximize dispersion of catalytic components. This in turn maximizes the surface area of the catalytic components and increases reaction rates. Ceria, present in the washcoat at up to 20 per cent, gives some degree of protection from sintering of the washcoat and also provides a molecular oxygen storage/release mechanism should exhaust conditions deviate from near-stoichiometric.

The TWC with closed loop A/F control has been a standard feature in the automotive industry for the last decade. A TWC, including an air-fuel ratio controller, provides the best available technology for removing CO, hydrocarbons, and NO_x from the exhaust of SI engines. Cost reductions in A/F controllers, combined with more stringent occupational health and safety regulations, are now making use of TWC with closed loop A/F control a more affordable and viable option for SI engines.

Oxidation catalyst for spark ignition engines

For most users of materials handling equipment, the exhaust constituent of most concern is CO so when a reduction of NO_x is not required, an oxidation catalyst may be used. The MINE-X® oxidation catalyst converts CO and hydrocarbons to carbon dioxide and water. The basic chemical reactions are as follows:

$2CO + O_2 \rightarrow 2CO_2$

hydrocarbons + $O_2 \rightarrow CO_2 + H_2O$

The above equations show how CO and HC are oxidized to form carbon dioxide and water. It should be noted that for engines operating near the stoichiometric point, there is not sufficient oxygen in the exhaust to ensure a reasonable level of oxidation of CO and HC. To obtain the required amount of oxygen, the engine may be tuned lean. However, this approach is not favoured by many end-users due to the subsequent loss of horsepower and the difficulty in maintaining the lean condition. An alternative is to inject secondary air into the exhaust upstream of the catalyst by one of various methods. These include the

use of an air check-valve, an air-pump, or a venturi device.

The oxidation catalyst is highly effective at removing CO and hydrocarbons from the exhausts of SI-powered materials handling equipment. Unlike the three-way catalytic converter, an air-fuel ratio-controller is not required to maximize performance. This makes the oxidation catalyst ideal for applications where CO accumulation is the problem and a reduction of NO_x is not required.

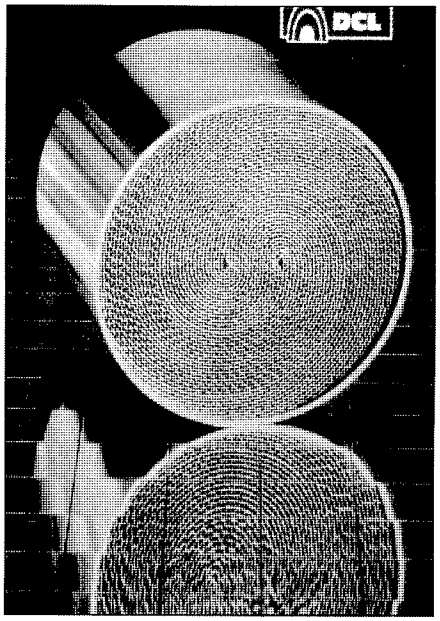


Figure 2: A metallic substrate offers low back pressure due to its large open frontal area

DIESEL ENGINES

Exhaust gas from diesel engines contains the following harmful components: CO; hydrocarbons; diesel particulate matter (DPM); nitrogen oxides, including nitric oxide (NO) and nitrogen dioxide (NO_2), and sulfur dioxide (SO_2). Diesel particulate matter consists of the combined solids and liquids in the diesel exhaust. The constituents of DPM are inorganic carbon (soot), adsorbed liquid hydrocarbons from unburned fuel and lubricating oils, sulfates and other inorganic oxides. The adsorbed liquid hydrocarbons are called the soluble organic fraction (SOF) of the diesel particulate matter. It is this soluble organic fraction of the total diesel particulate matter which is the target for oxidation in the diesel catalyst. The percentage of the diesel particulate matter composed of SOF will vary with the engine, but can reach as high as 60 per cent or more. Sulfur compounds in the fuel will convert to SO_2 and SO_3 during combustion, which will form sulfuric acid (H_2SO_4) in the presence of water vapor and contribute to the DPM. Aldehydes, a derivative of hydrocarbons present in diesel exhaust, are the source of the characteristic harsh odour associated with diesel engines.

Oxidation catalyst for diesel engines

The MINE-X® Diesel Oxidation Catalyst (DOC) contains a catalytically active surface where carbon monoxide (CO), hydrocarbons (HC), and the soluble organic fraction of diesel particulate matter (SOF) react with oxygen in the hot exhaust to form carbon dioxide and water vapor. The basic chemical reactions for a DOC are as follows:

$$2CO + O_2 \rightarrow 2CO_2$$
$$\text{hydrocarbons} + O_2 \rightarrow CO_2 + H_2O$$
$$SOF + O_2 \rightarrow CO_2 + H_2O$$

Although similar to oxidation catalysts for SI engines, the DOC is designed to selectively oxidize CO, HC and SOF while suppressing the oxidation of SO_x; a contributor to the DPM.

The use of low sulfur fuels improves the performance of the DOC. When using high sulfur fuels, the formation of elevated levels of SO_2 may lead to catalyst poisoning. SO_2 can be adsorbed onto the active sites, inhibiting further reactions from occurring. Another problem with high sulfur fuels is that with high exhaust temperatures, H_2SO_4 formation may become significant. By using low sulfur fuel, both of these effects can be reduced.

Diesel engines burn leaner and have better combustion efficiencies than their SI counterparts. For this reason, diesel engines produce much less CO, and therefore the accumulation of CO is less of a problem. The main benefit of DOCs is their reduction of hydrocarbons and SOF, and the consequent reduction in diesel odour and particulates. Even in a well-ventilated building, diesel odour can be an irritating problem in the immediate vicinity of the diesel-powered equipment, especially for the equipment operator. By diminishing the irritating nature of the diesel exhaust, working conditions can be improved.

MAINTENANCE AND DURABILITY

The durability of a catalytic converter is to a large degree optimized in the design of the washcoat and catalyst formulation, as well as in the coating process. However, other factors such as engine maintenance, fuel quality, and catalyst temperature also impact on catalyst durability. With long periods of excessively high exhaust temperature, the physical microscopic pore structure of the washcoat will collapse and catalyst activity reduced. To avoid this problem, the maximum recommended operating temperature for a catalytic converter is 1,350°F (730°C). With poor engine performance, phosphorus present in the lubricating oil as tricresol phosphate will deposit on the catalyst surface as a P_2O_5 film or polymeric glaze. With the pores blocked, the reactant molecules are prevented from accessing the catalytically active sites and the reaction does not occur. Use of a lube oil with low phosphate ash together with good engine maintenance reduces this problem. In the case of diesel engines, soot (dry carbon particles) will also be deposited on the catalyst surface over time. Soot will physically block the catalyst and reduce its activity. Soot accumulation can be monitored by periodically measuring the pressure-drop across the catalyst and comparing it to the measurement made after initial installation. The catalyst can be physically rejuvenated by washing the ash and soot out, or by blowing it out with an air hose and exposing a fresh face to the exhaust flow. This operation may be required after one to three years.

"...the DOC is designed to selectively oxidize CO, HC and SOF while suppressing the oxidation of SO_x"

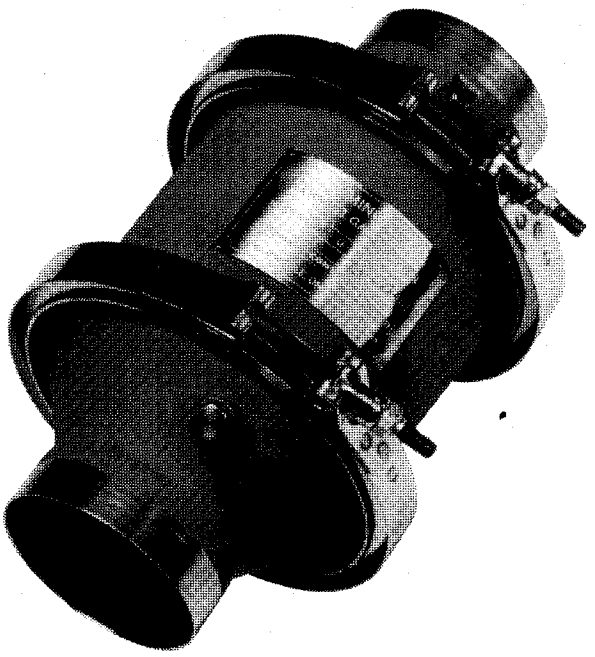
CONCLUSION

The accumulation of harmful exhaust products from IC-powered materials handling equipment poses a serious health concern in indoor environments. To mitigate this problem, harmful exhaust emissions can be reduced by the installation of a catalytic converter such as the MINE-X® exhaust purifier. For the past decade, Diesel Controls has been supplying catalytic converters for materials handling equipment, mostly for the after-market. Given the obvious benefit of lowering tailpipe emissions to affect an improvement in ambient air-quality, this after-market is now showing an enormous growth. Today, in response to the increasing demands for this product from end-users, distributors and OEMs of materials handling equipment are now purchasing catalytic converters for direct installation on some of their vehicles. ■

MINE-X®

Defines advancement in Exhaust Purification

MINE-X® Exhaust Purifiers Offer:



- Up to 95% carbon monoxide reduction
- Up to 90% hydrocarbons reduction
- Up to 50% reduction in diesel particulate matter
- High mechanical and thermal durability
- Short warmup period after cold engine starts
- Allow diesel, gas and propane powered equipment working indoors or in enclosed spaces to meet OSHA and MSHA requirements
- Available for forklift trucks, construction machinery, mining equipment and small engine applications
- Lowest back pressure
- Low maintenance & easy installation
- Standard and custom designs available

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