V. SELECTIVE CATALYTIC REDUCTION (SCR)

A. Technology Overview and Description

OVERVIEW

SCR technology has been used on stationary engines for nearly 20 years. More recently, it has been applied to select mobile sources as OE or retrofit technology on trucks, marine vessels, locomotives, and construction equipment. SCR technology, like LNC technology is a catalyst-based strategy that can reduce NO_x in the oxygen-rich exhaust of a diesel engine. SCR technology employs the use of a reductant to facilitate the catalytic NO_x reduction process. SCR technology can reduce NO_x emissions anywhere from over 25% to over 90%. Certain SCR designs can also reduce HC and CO emissions from 30% to 90% and PM emissions from 15% to 50%, as well as reduce diesel smoke and odor. The emission reductions achieved are influenced by the SCR system design, the engine application, and the operating duty cycle.

SCR technology has performed well in OE and retrofit applications and has demonstrated outstanding durability. SCR technology is a vehicle/equipment specific application and care must be taken in designing and applying this technology. Collecting data on the engine operating modes ("engine mapping") is needed both to screen candidate applications and to properly calculate the rate of reductant dosing needed. The emergence of NO_x sensors may reduce, or even eliminate eventually, the need for engine mapping. In the U.S., SCR has started to emerge as a retrofit strategy in selected on-road and offroad applications. An SCR system with 25% NO_x reduction and greater than 25% PM reduction has been verified by CARB for limited offroad engine applications (see www.arb.ca.gov/diesel/verdev/verdev.htm). SCR technology can be used in combination with a DPF, a DOC or a Selective Non-Catalytic Reduction (SNCR) system.

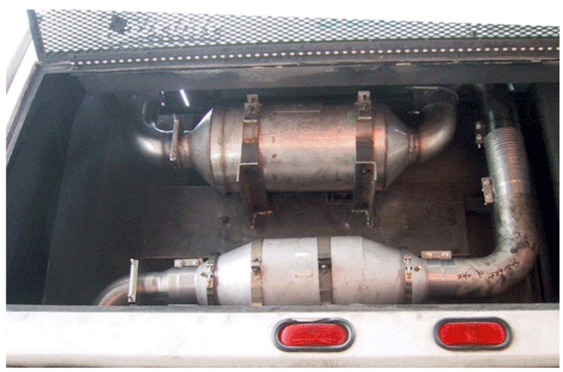
SCR systems have been successfully applied to a variety of on-road and offroad applications and have demonstrated impressive durability. SCR systems on heavy-duty trucks have operated effectively for up to 350,000 miles or more. In marine applications, SCR systems performed effectively in the range of 10,000 to 40,000 operating hours.

Problems have been experience in fitting SCR systems on some on-road vehicles. In addition, there have been start-up issues with the SCR system that required some modifications or adjustments. On rare occasions, operators have complained of an ammonia smell resulting from excess ammonia emissions. This issue is typically addressed by adjusting the reductant dosing.

Once start-up issues have been addressed, SCR technology appears to generally operate effectively with out adverse impact on vehicle/equipment performance or fuel economy. In some applications, SCR systems can add 30% to 60% to the weight of the normal muffler system, but other than requiring installation hardware of sufficient strength, no other impacts have been reported. The requirement for a reducing agent does have a slight impact on engine operating costs (a cost in the range of 4% of the vehicle/equipment operating fuel cost).

TECHNOLOGY DESCRIPTION

An SCR system is designed to catalytically reduce NO_x emissions in the oxygen rich environment of diesel exhaust. The SCR catalytic formulation is coated on a ceramic or metallic catalyst support encased in a stainless steel cylinder. Both precious metal and base metals can be used for exhaust temperatures in the 230°C to 430°C range. For higher temperatures, (360°C to 590°C) zeolite catalysts may be used; precious metal catalysts can be used for low temperatures (175°C to 290°C). Like other catalyst-based emission control technologies, an SCR catalytically converts pollutants without being consumed. To reduce NO_x emissions, the SCR system needs a chemical reagent, or reductant, to help convert the NO_x to nitrogen. The reductant used in mobile source applications is typically urea or aqueous ammonia. The reductant is added at a rate calculated from an algorithm that estimates the amount of NO_x present in the exhaust stream. The algorithm relates NO_x emissions to engine operating conditions (e.g., engine speed/load). NO_x sensors are emerging that will enable more precise reductant injection to optimize NO_x control.



Courtesy of Omnitek

SCR systems installed as muffler replacements provide comparable noise attenuation to the mufflers they replace. In large marine applications, it has been reported that the SCR provided up to a 30-35 db noise reduction benefit.

SCR systems need a supply of the reductant, which is typically stored on board the vehicle or equipment and is refilled as needed. Typically, monitoring/warning systems are included as part of the SCR system to alert the operator or mechanic that the reductant supply is getting low or that there is a problem with the reductant injection system. Also, a readily accessible source needs to be available for storing and dispensing the supply of the reductant when the on-board supply is depleted.

B. Emission Reduction

As exhaust gases pass over the SCR catalyst, chemical reactions occur that reduce NO_x emissions from over 25% to over 90%. The NO_x control efficiency is a function of: 1) the SCR catalyst design, 2) the effectiveness of the reductant delivery system to match the proper dosage to the amount of NO_x in the exhaust, 3) the engine application, 4) the operating temperatures, 5) the duty cycle (e.g. steady-state or transient), and 6) the sulfur level in the fuel. Where an oxidation function is added to the SCR system, CO and HC emissions can be reduced from 30% up to 90% and PM emissions reduced by 15% to 50%. Also, diesel odor and smoke will be reduced. Excess ammonia emissions or "ammonia slip" can be emitted out of the tail pipe if the injected reductant is not consumed by the catalytic process. This issue can be effectively controlled by properly metering the reductant and/or by placing a DOC downstream of the SCR catalyst to destroy any excess ammonia.

C. Status and Availability

As noted SCR technology was first introduced in stationary source applications in Europe in the mid-1980s and in the U.S. in the late 1980s. In the 1990s, SCR began to be evaluated as a control strategy for mobile sources. A demonstration project in Europe involving line-haul trucks demonstrated that SCR technology could achieve greater than 80% NOx control over for over several hundred thousand miles of vehicle operation. SCR systems are expected to be installed on on-road heavy-duty engines to help meet the Euro 5 standards in 2008. SCR technology has also been identified as a candidate technology to meet the EPA on-road HDE 2007/2010 standards.

SCR technology has also been installed on buses, construction equipment, marine vessels and locomotives. For example, since the mid-1990s SCR technology has been installed on over 100 marine vessels in Europe including ferries, tugboats, and cargo vessels. The capacity of the engines equipped with SCR systems ranged from 450 to over 10,000 kW. In the U.S., SCR systems have been retrofitted on refuse trucks, rubber tire excavators, dump trucks, freight transport vehicles and large gantry cranes.

AVAILABILTY

SCR systems are available from several manufacturers. Each system is designed for a specific engine/vehicle/equipment application, and is typically custom-configured for the application.

D. Selection and Use Criteria

SCR technology is an engine specific technology. Care should be taken in assessing candidate vehicles/equipment for possible SCR installation. The factors to consider include:

- Proper exhaust temperature window to support SCR technology.
- Adequate space is available to install the SCR system.
- Operating duty cycle to support application of SCR technology.
- Sulfur level in the fuel.
- Available infrastructure for re-supplying the reductant on the vehicle/equipment.

Exhaust Temperature Window – Depending on the type of catalyst or combination of catalyst used, the exhaust temperature for applying SCR technology is very broad. However, there may be instances where the operating temperature window for a given vehicle/equipment application is too low or too high for a particular SCR system design. Close coordination with the SCR system supplier is needed to insure that the SCR design or designs will function effectively given the operating temperature window for the candidate engine application.

Adequate Available Space – The dimensions of an SCR system are often larger than the existing muffler so finding adequate space to allow for proper installation without interfering with vehicle/equipment operation can be challenging. SCR technology manufacturers, however, continue to make progress in reducing the size of SCR systems. This design improvement is enabling SCR technology to be considered for a growing number of applications. Space must also be found to install the on-board reductant supply containing and injection system.

Operating Duty Cycle of the Application Appropriate for SCR Retrofit – A need exists with SCR systems to precisely match the amount of reductant introduced with the level of NO_x in the exhaust. Transient operations, where the engine operating parameters and in turn the level of NO_x emissions can change frequently and rapidly, is a particularly challenging application for an SCR system. In new engine applications, the issue of transient operation can be addressed by designing and melding the engine control system and the SCR technology into an integrated system. In retrofit applications, SCR technology is more easily applied to vehicle/equipment applications in which the operating duty cycle tends to be more steady-state. In that regard, many offroad engine applications tend to have less transient operation than many on-road applications, making those offroad engines good candidates for SCR

Sulfur Level in the Fuel – See "Fuel Requirements" below.

Reductant Supply Infrastructure – A supply of the reducing agent must be available on-board the vehicle/equipment at all times. If the reductant is not available the SCR will not function. Therefore, an infrastructure must be available to replenish the supply on the vehicle/equipment with fresh reductant. Currently, centrally fueled vehicles/equipment or vessels with large on-board reductant storage facilities are better candidates for SCR. For offroad equipment, which typically operate in one location and/or is centrally fueled, maintaining a reductant supply which is readily available when needed is very feasible.

E. Installation and Vehicle Modifications

The application of SCR technology requires care in evaluating candidate applications, preparing the engine for retrofit, monitoring SCR system performance, and performing proper engine and SCR system maintenance.

As with other retrofit technologies when selecting candidate vehicles/equipment for SCR retrofit, engines that burn excess lubricating oil, require frequent maintenance, or have a record of problems should be rejected. Reviewing maintenance records and/or communicating with fleet managers and senior technicians will help identify vehicles that should not be included in the program. The vehicle should be evaluated to determine whether adequate space exists for the SCR unit, the on-board reductant supply container, and the reductant injection system.

Courtesy of DieselNet

Engine mapping is an important step both in screening candidate vehicles/equipment and in designing the reductant delivery system to match the particular engine operating conditions, optimization of SCR systems for maximum NO_x reductions, and to minimize any ammonia slip from the system. Typically, engine mapping is performed by the technology supplier. The process of developing an engine "map" requires that an engine (of the same model as that for which the SCR system is to be installed) be installed on an engine dynamometer and operated over the full range of speed-load conditions to obtain data on NO_x emissions at different engine speed-load points. This information is essential for proper design of the urea (or other reductant) injection system. The amount of reductant to be injected is established during the engine mapping process.

Courtesy of Bosch

The SCR system is typically installed by the technology provider. Normal installations take about a day, although additional time may be needed with complex installations such as where available space is tight or difficult to access.

F. Fuel Requirements

The catalyst used in SCR systems will benefit from the use of low sulfur fuel in terms of improved performance and minimizing sulfate production when precious metal catalysts are utilized. Low sulfur fuel is not a prerequisite, however, for using SCR technology. The SCR technology verified by CARB is approved for applications using conventional on-road diesel fuel, that typically fall in the 350 to 500 ppm sulfur range.

G. Maintenance

The principal maintenance item for SCR systems is to ensure that the on-board supply of reductant is always available. This requires refilling the storage container at regular intervals. Also, steps should be taken to ensure that the dosing control unit and delivery system are performing as required. Monitoring technology is available both to alert the operator or technician that the reductant supply is getting low and that a reductant dosing problem has occurred. Also, a readily available reductant storage facility will need to be established and maintained to refill the on-board reductant tanks when needed.

H. Costs

SCR technology costs vary greatly depending on the engine size, the vehicle application and whether engine mapping is needed or is already available. CARB, in 2000, estimated the cost of an SCR system to be in the range of $50 to $60 per horsepower. For a 275 horsepower engine, this cost would translate into a range of $13,750 to $16,500 and for a 750 horsepower engine into a range of $37,500 to $45,000. CARB also estimated the installation costs at anywhere from $500 to $5,000 depending on the application and whether engine mapping was required. Operating costs for SCR system include the cost of the reducing agent. The cost of the urea will vary depending on the quantity purchased. The fuel equivalent cost of reducing agent such as urea typically runs in the range of 4% of the cost of fuel consumed.