

ACTIVATED CARBON USE IN TREATING DIESEL ENGINE EXHAUSTS

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INTRODUCTION

Diesel engines, both stationary and mobile, are major sources of air pollution. Pollutants of concern are solid and liquid particulates, nitrogen oxides (NO_x), toxic hydrocarbon gases, and, in some cases, sulfur dioxide (SO₂). Approaches considered in the past to reduce these pollutants have included modifying the engine design, modifying the fuel composition, recirculating the exhaust gases, and installing a device or system on the exhaust gas stream to remove or modify the undesirable constituents. Of particular concern to the U.S. Air Force are the high levels of NO_x that are present in their diesel engine exhaust gases. Sorbent Technologies Corporation (Sorbtech) engineers, during the past two years, have been examining and developing ways to remove NO_x from these exhaust gases.

The principal NO_x species in diesel engine exhaust gases is nitric oxide (NO). Typical NO levels range from 100 to 1200 ppm. Higher NO levels generally occur with higher engine loads that result in higher engine temperatures.

Both stationary and mobile diesel engines are employed at Air Force sites. Typical stationary engines produce back-up electrical power at critical sites, such as at computer or hospital locations. Mobile diesel engine applications include portable or mobile generators, air heaters, air-conditioners, and incinerators, small and large trucks, and buses. Each engine application presents its own problems because each has different space constraints and each produces gases with different characteristics of temperature, flow rates, and composition.

At least four different methods have been used in the past to remove nitrogen oxides (NO_x) from waste gases. These methods include (1) selective catalytic reduction, (2) selective non-catalytic reduction, (3) reaction of the oxides with water or alkali solutions, and (4) sorption by a solid sorbent. The first two methods are receiving most attention today. In selective catalytic reduction, ammonia is commonly injected into the waste gas stream and the combination is passed across a catalyst to reduce nitrogen oxides to nitrogen and water. Disadvantages of this approach include high cost, narrow temperature range of applicability, and ammonia emissions into the atmosphere. In selective non-catalytic reduction, ammonia or urea is injected into the engine or combustor itself or into the gas leaving the engine where temperatures are very high. Disadvantages of this approach are low NO_x removals and the problems associated with the handling of ammonia or urea. Reaction of the oxides with water or alkali has seen only limited success because of NO, the principal NO_x species in most gases, does not readily dissolve in water or react with alkali in aqueous solutions.

APPROACH

Sorbtech engineers have adopted two separate approaches in treating exhaust gases from stationary diesel sources and from mobile diesel sources. Each approach involves the use of activated carbon, but in different manners.

Few materials sorb NO_x well. An exception is activated carbon under certain conditions. Specially prepared activated carbons can sorb 10 percent or more of their weight in NO_x under ideal conditions. After NO_x is sorbed at a low temperature, heating the carbon to a higher temperature can release it. This process of sorbing NO_x at a low temperature with activated carbon and releasing it at a high temperature has been used commercially in the past. This approach was pursued in treating exhaust gases from mobile sources.

An observation by Sorbtech engineers made possible a second approach for use with stationary sources. It was found that certain activated carbons, when saturated with NO_x, act as a catalyst for the rapid conversion of NO to NO₂, in the presence of oxygen. The resulting gas stream containing principally NO₂, instead of NO, was then observed to be readily treatable with water alone or with alkali solutions. This approach was pursued in treating exhaust gases from stationary sources.

MOBILE DIESEL-ENGINE APPLICATIONS

System Design

The concept for mobile applications consists of two steps: (1) capture of NO_x with an activated carbon filter; and (2) regeneration of the filter after it is saturated. The concept is shown schematically in Figure 1. For mobile applications, Steps 1 and 2 are generally performed at two separate locations. In Step 1, the use of a prefilter is recommended to remove particulates before the saturated carbon bed. Diesel engine exhaust gases usually contain huge amounts of particulates. Not only do large puffs of black particulates occur during engine start-up and during power changes, but smaller, PM-10 particles are emitted during all running conditions. Particle traps can be employed to effectively remove these particulates. A special vermiculite-based filter developed by Sorbtech likewise does an effective job in reducing particulates, particularly PM-10 particles. In Step 2, the carbon bed is regenerated by simply heating the bed. The NO_x released during regeneration is destroyed by reaction with natural gas over a special catalyst developed by Sorbtech. The products of reaction are nitrogen, CO₂ and H₂O.

Figure 2 shows a mobile filter cart designed and constructed by Sorbtech to control emissions from Air Force mobile diesel generators. The cart was designed to be attached to the portable generator unit and to move with it to the usage location. Twenty-four separate activated carbon filters are employed on this cart. When saturated, the individual filters are removed from the cart and are processed in a separate regeneration/NO_x-destruction unit.

Experimental Studies

The effectiveness of activated carbon filters in reducing the levels of NO_x and CO in exhaust gases from a mobile diesel generator was examined in studies at Wright Patterson AFB, Ohio. The results of these studies are listed in Table 1. Two filter designs were considered, one consisting of 9 inches of activated carbon alone and a second consisting of 6 inches of a vermiculite-based sorbent followed by 6 inches of activated carbon. The supplier of the carbon was Calgon Carbon Corporation. The exhaust gas was cooled to 60°-100°F before entering the beds. During each run, the activated carbon bed temperatures increased to 110°-120°F due to heat of adsorption. The total run time was several hours. The residence time and flow rate of gas through the filters were 1.0 second and 40 SCFM, respectively.

The results of these runs showed that average NO_x removals of 54 to 64 percent were achieved. These results agreed well with earlier laboratory results. Laboratory results showed that NO_x removals were a strong function of space velocity. Because lower overall gas velocities will occur with the mobile filter cart, higher NO_x removals with this unit can be expected.

STATIONARY DIESEL-ENGINE APPLICATIONS

System Design

The system developed to cleanse NO_x and other contaminants from stationary diesel-engines exhaust gases is shown schematically in Figure 3. This system consists of four components: a prefilter (to remove particulates); a gas cooling means; an activated carbon bed; and a NO₂ scrubber. The key component in this system is the activated carbon bed that converts NO to NO₂.

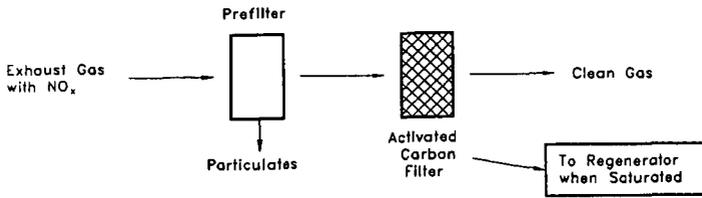
Experimental Studies

A number of carbons were examined for their ability to first sorb NO_x and then convert NO to NO₂. Two materials, one supplied by Calgon Carbon Corporation and one, an experimental char, supplied by the Illinois State Geological Survey proved to be particularly effective.

In one test, for example, an 8.0 gram bed of activated carbon was exposed at 26°C to a simulated exhaust gas having the composition: 460 ppm NO, 50 ppm NO₂, 10 wt% oxygen, and balance nitrogen at a flow rate of 4 liters per minute. The bed was exposed for 60 hours. Figure 4 shows the levels of NO and NO₂ entering and exiting the bed during the 60-hour exposure. In this figure, it can be seen that during an initial period, both NO and NO₂ were sorbed. After this period, however, NO ceased to be sorbed, but instead the NO partially passed through the bed and partially was converted to NO₂. After a time, about 15 hours in this case, an equilibrium occurred in the ratio of NO converted to NO₂ and the level of NO passing through the bed. In this run, a conversion of NO to NO₂ of over 75 percent was achieved.

In separate experiments, the ability of water and alkali solutions to scrub NO₂ and NO from gas streams was studied. Water alone was not effective in removing NO from gas streams, and concentrated alkali solutions were only partially effective. Water alone, however, was effective in removing the majority of the NO₂ present, and alkali solutions removed NO₂ almost completely.

SORPTION



REGENERATION

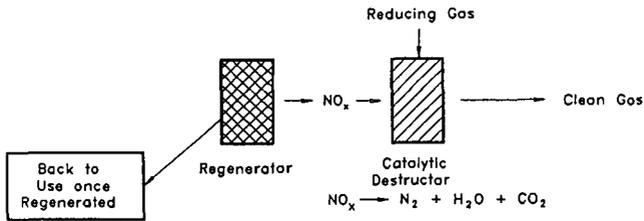


Figure 1. Two-Step Process for NO_x-Control-Mobile Applications

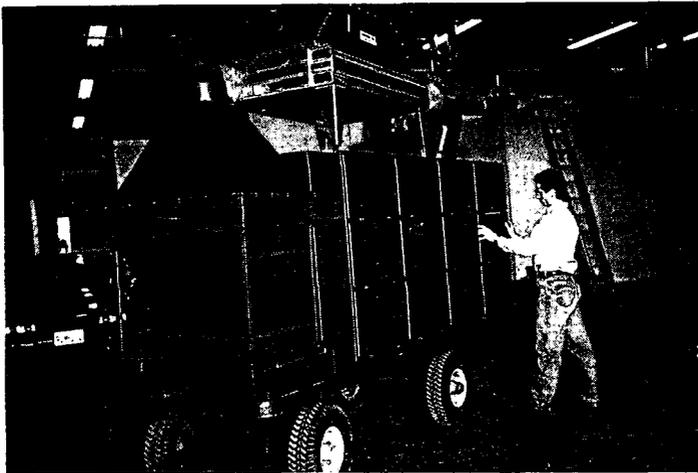


Figure 2. Activated Carbon Beds on a Mobile Filter Cart for Controlling NO_x Emissions

TABLE 1. TEST RESULTS AT WRIGHT PATTERSON AFB
ON MOBILE DIESEL-ENGINE
EXHAUST GASES

Gas Composition			
	Entering Filter	Leaving Filter	Average Removal Rate
9" Activated Carbon			
NO	1000 ppm	320 ppm	68%
NO ₂	200 ppm	120 ppm	40%
NO _x	1200 ppm	440 ppm	63%
CO	200 ppm	200 ppm	0%
O ₂	15%	15%	0%
6" Vermiculite Sorbent + 6" Activated Carbon			
NO	800 ppm	345 ppm	57%
NO ₂	300 ppm	205 ppm	32%
NO _x	1100 ppm	550 ppm	50%
CO	100 ppm	100 ppm	0%
O ₂	16%	16%	0%

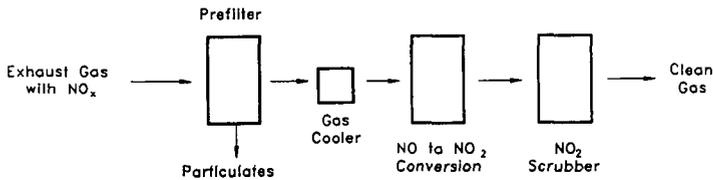


Figure 3. Single-Step Process for NO_x Control-
Stationary Applications

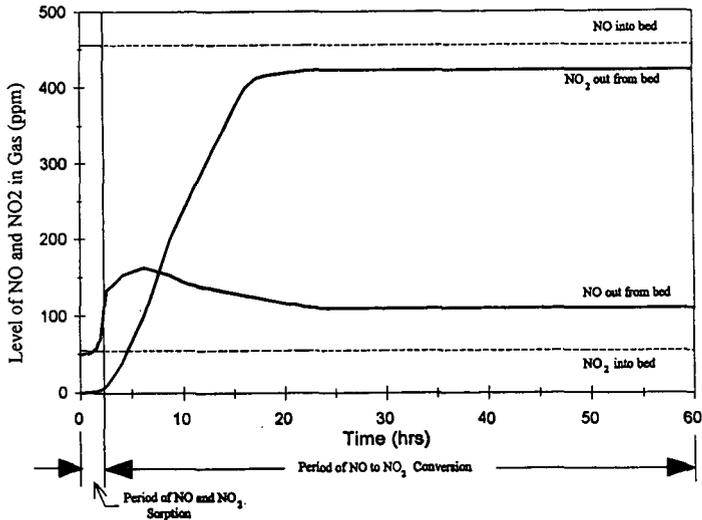


Figure 4. NO to NO₂ Conversion at Room Temperature