

Category 1 and Category 2 engines are produced in much greater volumes than Category 3 engines which allows manufacturers to more easily amortize their research and development costs. Third, because Category 3 engines generally operate on residual fuel, this provides an additional constraint on what can be achieved through in-cylinder control.

While this final rule primarily addresses Category 3 engines, we intend to use the future rulemaking as an opportunity to reconsider Tier 3 emission standards for Category 1 and Category 2 standards. We proposed Tier 3 standards for these engines on December 11, 1998 (63 FR 68508, December 11, 1998), but chose not to finalize the Tier 3 standards at that time. Given the current and expected advances in emission-control technologies for land-based diesel engines and the need to coordinate standards for all categories of marine engines, we believe this will be the appropriate context to reopen the proposed Tier 3 standards. In the future rulemaking we would also be able to consider applying compliance provisions such as onboard NO_x monitoring to Category 1 and Category 2 engines. This may be especially appropriate for certain applications, such as ferries and tugboats that operate closest to metropolitan areas.

3. What Technologies Will EPA Consider in the Future Rule?

As discussed above, the future rulemaking will focus on technologies we believe can be used to reduce NO_x emissions by significantly more than 30 percent below Tier 1 levels for Category 3 marine diesel engines. These emission-control systems are expected to include a combination of optimized in-cylinder controls and advanced technologies such as selective catalytic reduction and water. These advanced technologies are discussed below. Although we do not believe it is appropriate to set standards for Category 3 marine engines based on these approaches at this time, we believe that remaining technological and operational issues can be addressed in the future. Technologies that could be used to achieve emission reductions beyond the Tier 2 standards for Category 1 and Category 2 marine diesel engines were discussed in an earlier proposal (63 FR 68508, December 11, 1998).²⁹

a. Water-based technologies. We believe that significant NO_x control of approximately a 50-percent reduction can be achieved in the future, once certain technical and practical challenges are overcome, by introducing water into the combustion process in combination with appropriate in-cylinder controls. Water can be used in the combustion process to lower maximum combustion temperature, and therefore lower NO_x formation, with an insignificant increase in fuel consumption. Water has a high heat capacity, which allows it to absorb enough of the energy in the cylinder to reduce peak combustion temperatures. Data presented below and in the Final Regulatory Support Document suggest that NO_x reductions significantly more than 30 percent below the Tier 1 standards can be achieved, depending on the ratio of water to fuel and on the method of introducing water into the combustion chamber. These data are primarily based on developmental engines; however, given enough lead time, we believe that introducing water into the combustion process may become an effective emission-control strategy.

Water may be introduced into the combustion process through emulsification with the fuel, direct injection into the combustion chamber, or saturating the intake air. Water emulsification refers to mixing the fuel and water prior to injection. This strategy is limited by the instability of suspending water in fuel. To increase the effective stability, a system can be used that emulsifies the water into the fuel just before injection. Another option is to stratify the fuel and water through a single injector. The Final Regulatory Support Document presents data on these approaches showing a 30–40 percent reduction in NO_x with water fuel ratios ranging from 0.3 to 0.4.

More effective control of the water injection process can be achieved through the use of an independent nozzle for water. Using a separate injector nozzle for the water allows larger amounts of water to be added to the combustion process because the water is injected simultaneously with the fuel, and larger injection pumps and nozzles can be used for the water injection. In addition, the fuel injection timing and the amount of water injected can be better optimized. Data presented in the Final Regulatory Support Document show NO_x reductions of 40 to 70 percent with water-to-fuel ratios ranging from 0.5 to 0.9 if a separate nozzle is used for injecting water. Direct water injection has been installed on medium-speed Category 3 engines on

more than a dozen vessels, and there are plans for using it on additional vessels. These vessels are primarily ferries and roll-on roll-off (ro-ro) vessels operating in European waters where there are economic incentives for reducing NO_x emissions. In addition, they make relatively short trips, so water storage is not a significant issue.

Other strategies for introducing water into the combustion process are being developed that will allow much higher water-to-fuel ratios. These strategies include combustion air humidification and steam injection. With combustion air humidification, a water nozzle is placed in the engine intake and an air heater is used to offset condensation. With steam injection, waste heat is used to vaporize water, which is then injected into the combustion chamber during the compression stroke. Data on initial testing, presented in the Final Regulatory Support Document, show NO_x reductions of more than 80 percent with water-to-fuel ratios as high as 3.5.

We believe that the results from initial testing of water introduction strategies is encouraging. We will continue to evaluate this technology in the future. However, we believe there are still outstanding technical issues concerning the use of water-introduction technologies for widespread application on marine engines. These issues are discussed below.

A primary concern with the use of water in the combustion process is the effect on PM emissions. The water in the cylinder reduces NO_x, which is formed at high temperatures, by reducing the temperature in the cylinder during combustion. However, PM oxidation is most efficient at high temperatures. At this time, we do not have sufficient information on the effect of water emulsification and injection strategies on PM emissions to quantify this effect.

Fresh water is necessary for any of these water-based NO_x-reduction strategies. Introducing salt water into the engine could result in serious deterioration due to corrosion and fouling. For this reason, a ship using water strategies would need either to produce fresh water through the use of a desalination or distillation system or to store fresh water on board. Cruise ships may already have a source of fresh water that could be used to enable this technology. This water source is the “gray” water, such as drainage from showers, which could be filtered for use in the engine. However, the use of gray water would have to be tested on these engines, and systems would have to be devised to ensure proper filtering. For example, it would be necessary to

²⁹ Further analysis of potential Tier 3 standards for Category 1 and Category 2 marine diesel engines may be found in the Draft Regulatory Impact Analysis associated with this proposal which is available in Air Docket A–97–50.