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NATIONAL VEHICLE AND FUEL EMISSIONS LABORATORY
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OFFICE OF
AIR AND RADIATION

November 22, 2013

CD-13-13 (HDOH)

SUBJECT: Testing of Heavy-Duty Diesel On-Highway Engines with Adjusted Diesel Exhaust Fluid (DEF) Quality

Dear Manufacturer:

The purpose of this letter is to provide guidance to manufacturers of heavy-duty on-highway engines on how EPA expects to determine the physical range of adjustment of diesel exhaust fluid (DEF) quality for certification testing and what measures manufacturers may take to sufficiently restrain the adjustment of DEF quality to limit the need for testing outside the manufacturer's specified range. This letter also serves to provide notice that EPA may begin testing manufacturers' engines with adjusted DEF quality during the certification process. This letter does not represent final agency action. Final decisions regarding the adequacy of means to inhibit the adjustment of DEF quality will occur at the time of certification.

Adjustable Parameter Provisions of 40 CFR Part 86

The provisions that govern adjustable parameters in 40 CFR § 86.094-22(e) authorize EPA to determine which parameters are adjustable for emission testing purposes, the adequacy of the limits, stops, seals, or other means used to inhibit adjustment, and the resulting physically adjustable range for such a parameter. Any parameter on any engine which is physically capable of being adjusted and may significantly affect emissions may be subject to adjustment (40 CFR §§ 86.094-22(e)(1)(i) and (ii)). In determining the parameters subject to adjustment, EPA will give consideration to the likelihood that settings other than the manufacturer's recommended setting will occur on in-use vehicles or engines (40 CFR § 86.094-22(e)(1)(iii)). Once a parameter has been determined to be adjustable, EPA then determines the range of adjustment for emission testing based on whether the means used to inhibit improper adjustment (*e.g.,* physical limits, stops, seals, or other means) are adequate. In determining the adequacy of a physical limit, stop, or other means used to inhibit adjustment, EPA will give consideration to the likelihood that it will be circumvented, removed, or exceeded on in-use vehicles or engines (40 CFR § 86.094–22(e)(2)(iv)). Finally, the resulting physically adjustable range for any such parameter is established based on whether the parameter is determined to be adequately inaccessible or sealed, or is otherwise restrained in adjustment (40 CFR § 86.094–22(e)(3)).

The provisions governing adjustable parameters are of particular relevance for the certification of diesel engines using selective catalytic reduction (SCR) technology to comply with the NO_X emission standard of 40 CFR § 86.007-11. SCR technology in use with certified engines today relies upon injection of an aqueous urea solution, DEF, into the exhaust to control NO_X emissions. DEF is stored in a tank on the vehicle and must be replenished routinely by the operator with DEF meeting the engine manufacturer’s recommended specification. Engine manufacturers predominantly recommend use of DEF meeting the industry-recognized ISO 22241-1 quality standard, which specifies a 32.5 percent by weight urea concentration for the solution. SCR systems are calibrated to the 32.5 percent urea concentration to ensure optimum NO_X reduction during operation. Given the need for operator intervention to replenish the DEF, there exists the possibility that the operator can put fluids other than the manufacturer’s recommended DEF in the tank, either accidentally or intentionally. Using fluids other than the manufacturer’s recommended DEF could contribute to a significant increase in NO_X emissions.

EPA believes a financial motivation exists for operators to refill the DEF tank with fluids other than the manufacturer’s recommended DEF. DEF price varies depending on whether it is supplied via bulk container (e.g., 275-gallon totes or underground storage tanks) or 1 to 2.5-gallon jug. Current prices for bulk DEF at a truck stop are generally less than $3.00 per gallon and jug prices can be $5.00 or more per gallon. Some operators wishing to reduce working expenses may be tempted to refill the DEF tank with fluids that are less expensive. EPA expects that operators that would tamper with DEF quality would most commonly attempt to do so by diluting DEF with water. Dilution of DEF with water can be accomplished cheaply and easily by inserting a garden hose in the DEF tank and turning it on. This type of dilution would cause little to no immediate damage to the SCR system and would not affect performance characteristics apparent to the operator, such as developed power or fuel economy, though it would likely lead to a substantial increase in NOx emissions. Using the cost range for DEF above and assuming 25 percent dilution with water, an operator that drives 100,000 miles a year, achieves a fuel economy of 6 miles per gallon, and whose engine doses DEF at 3 percent of its fuel consumption rate, could save from $375 to $625 per year[1]. In other terms, this equates to the operator eliminating the cost of one out of every 4 gallons of DEF purchased. The trucking industry is a competitive business and owners may be motivated to help their bottom line. For example, the rate of operators violating the Federal Motor Carrier Safety Administration’s hours-of-service rule is estimated by the FMCSA to be approximately 40 to 75 percent of operators.[2] If this is an indication of likeliness to favor cost savings over regulatory compliance, then there is significant likelihood that at least some truck operators would be tempted to dilute DEF.[3]

Given an operator’s ability to physically adjust DEF quality, the increase in NOx emissions that would result if they do so, and the significant possibility that they could be tempted to make such adjustments on in-use vehicles, EPA has previously determined that DEF quality is an adjustable parameter. [4]

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[1] (100,000 miles per year / 6 miles per gallon of diesel fuel) x (0.03 gallon DEF per gallon of diesel fuel) x (cost of DEF) x (0.25 dilution rate)
[2] Federal Motor Carrier Safety Administration, NPRM, Hours of Service of Drivers, 65 FR 25570
[3] Note that such intentional actions by operators would constitute tampering with emission controls, which is illegal under the Clean Air Act, and could result in assessment of civil penalties.
[4] *See* CISD-07-07 (March 27, 2007) and CISD-09-04 REVISED (December 30, 2009).

Range of DEF Quality Adjustment

At the time of certification, EPA will review the manufacturer's engine design to assess the adequacy of the means used to inhibit DEF quality adjustment (*e.g.*, physical limits, stops, seals, or other means) by reviewing the likelihood that it will be circumvented, removed, or exceeded on in-use vehicles or engines. 40 CFR 86.094-22(e)(2)(iv) allows EPA to determine that a physical limit, stop, or other means used to inhibit adjustment of a parameter is adequate based on the effect of settings beyond the limit, stop, seal, or other means on vehicle or engine performance characteristics other than emission characteristics. In previous guidance, we have provided the example of an engine design that incorporates the ability to detect DEF quality and activate engine or vehicle-based performance inducements in a timely manner as one that could represent an adequate restraint on adjustability.[5] We continue to believe that such an approach represents one example of an adequate restraint on adjustability. Manufacturers may, however, devise alternate restraints.

Upon establishing that adequate restraints on adjustability exist, EPA will next review the manufacturer's engine design to determine the physically resulting range of DEF quality adjustment for emission testing. EPA generally considers the range of adjustment for emission testing to span the change in urea concentration from 32.5 percent (unadulterated DEF) to the point at which poor DEF quality can be detected. This point represents the limit for DEF quality adjustment because it is the first point at which a manufacturer is able to implement inducements to prevent sustained engine or vehicle operation with poor quality DEF. Poor DEF quality is any urea concentration at which the engine is unable to comply with the relevant NO_X standard over an applicable test cycle, including operating points within the not-to-exceed (NTE) zone. For example, an engine that first detects poor quality when DEF is diluted with water by 50 percent would be subject to emissions testing at any urea concentration ranging from 32.5 percent (unadulterated DEF) down to, but not including, 16.25 percent (DEF diluted with water by 50 percent). Over the full span of this range, the engine would need to comply with the relevant NO_X standard over all applicable test cycles. In this example, if the engine will exceed the NOx standard on one or more test cycles when DEF quality drops below 24 percent urea concentration, the engine will exceed the NOx standard within the adjustable range for emissions testing purposes. In this case, the manufacturer should improve their detection capability to restrain adjustment between 32.5 percent and 24 percent urea concentration. Such an adjustable range could be appropriate for certification. Manufacturers should describe the DEF quality range of adjustment in their application for certification.

It is possible that in a specific case, EPA may determine that it is acceptable to certify an engine design that detects poor DEF quality such that there is a very small range where poor DEF quality will not be detected and the engine will not comply with a specific emission standard, and where the manufacturer can prove to EPA that the adjustable range where noncompliance is found is so small that it is highly unlikely an operator would adjust to that setting in-use. As in the example above, if the manufacturer improved their detection capability to restrain adjustment between 32.5 percent and 23 percent urea concentration (i.e., the range contains a "non-

[5] *See* 76 FR 32895 (June 7, 2011) for EPA's most recent published recommendations on driver inducements to restrain adjustments to DEF quality.

compliant" setting that represents a one percent span in urea concentration, or a roughly 3 percent increment of dilution with water), the manufacturer might be able to sufficiently demonstrate that such a narrow setting is so difficult for an operator to target in-use that it is highly unlikely that they will attempt to make such an adjustment. EPA notes that a manufacturer is unlikely to be able to make such a demonstration where its engine's level of detection has a noncompliance margin that is large enough to possibly be targeted by consumers. EPA also notes that any evidence of such targeting by consumers, even in situations not including the manufacturer's products, would make such demonstration increasingly unlikely. Any manufacturer contemplating certification of such an engine design should be prepared to justify the claim that there is a low likelihood of such adjustment in-use and approach EPA well in advance of submitting an application for certification.

EPA recognizes that technological challenges exist for detecting poor DEF quality instantaneously. In previous guidance, EPA has described a reasonable time frame for detecting poor DEF quality of one hour. In the test cell, this can be demonstrated by running replicate test cycles, such as the FTP, with poor DEF quality while checking for detection within one hour of continued engine operation. To confirm detection during NTE operation in the test cell, the engine manufacturer should use good engineering judgement to select NTE points or a sequence of operation within the NTE zone which can demonstrate detection over the entire NTE zone. Also in previous guidance, EPA noted its recommendation that the engine should implement appropriate inducements to prevent sustained operation with poor DEF quality and with final inducement occurring within 4 hours of detection.

DEF Quality Detection

For 2012 and earlier model years, EPA has certified engines that demonstrate an approach using NO_X sensor-based strategies for detecting some, but not all, DEF dilution levels. These strategies monitor NO_X concentration in the exhaust stream and determine SCR catalyst efficiency by measuring changes in NO_X across the catalyst. Significant deviations in NO_X conversion across the SCR catalyst from the expected or modeled conversion rate can be an indication of poor DEF quality. In most applications, NO_X sensors have been able to detect poor DEF quality for many, but not all, DEF dilution scenarios. The Agency approved certification for these engines because at the time we concluded NO_X sensors were the best available technology to detect in-use adjustments and other technology was not readily available to detect all DEF dilution levels that would result in non-compliance with the applicable emission standard. Some manufacturers continue to make refinements to their DEF dosing strategies to enable NO_X sensors to detect lesser amounts of dilution. For some manufacturers with excess DEF dosing capability and sufficient control of ammonia storage on the SCR catalyst, it may be possible to eventually achieve this level of performance with only NO_X sensors. Such an approach could be acceptable under the adjustable parameter provisions.

As early as 2007, EPA recognized urea quality sensors as one example for detecting DEF quality.[6] Through direct measurement of urea concentration, these sensors offer the quickest and most accurate measurement of DEF quality across the full spectrum of DEF dilution. They are able to measure urea concentrations at a resolution ranging from 1-5 percent and have response

[6] *See* CISD-07-07.

times as rapid as 30 seconds. In July 2011, EPA anticipated that urea quality sensors may be ready for implementation with 2013 model year engines, but noted that the sensors were still in development for mobile applications and engine manufacturers were still evaluating durability and system integration issues with them.[7] For the 2013 model year, two heavy-duty on-highway engine manufacturers certified their SCR-equipped engines with urea quality sensors. Other manufacturers have indicated that their engines could incorporate urea quality sensors as early as the 2014 or 2015 model year. These sensors will enable engine manufactures to further restrain the adjustment of DEF quality, especially DEF quality adjustment accomplished by dilution with water.

EPA Expectations for DEF Quality Monitoring In-Use

At this time, neither of the above technologies (NO_X sensors or urea quality sensors) can monitor DEF quality continuously. NO_X sensor technology relies on the calculation of conversion efficiency across the SCR catalyst to determine DEF quality. This measurement can't be made unless DEF dosing is occurring, which typically requires a minimum exhaust temperature of 190ºC. Urea quality sensors may have accuracy errors at high DEF temperatures, or, for certain sensor types, when excessive bubbles are present in the DEF tank. Neither NO_X sensors nor urea quality sensors can monitor DEF quality when the fluid is frozen. While these problems prevent continuous monitoring, a manufacturer can design a DEF quality monitoring strategy that prevents maladjustment of DEF while avoiding monitoring under problematic conditions. For example, urea quality signals could be monitored during discrete intervals, such as shortly after DEF refill, or ignored if DEF temperature is too high. Manufacturers should describe their DEF quality monitoring strategy in their application for certification.

Conclusion

For the 2013 model year, two heavy-duty on-highway engine manufacturers have certified engines using urea quality sensors that allow for conformance to the adjustable parameter provisions regarding inhibition of adjustment at all DEF quality levels that would lead to noncompliance. As such, we are now concluding that at least one technology, urea quality sensors, is available that can detect DEF dilution at all levels of concern. EPA believes that given the timing of engine and vehicle design, urea quality sensors can be installed on new vehicles by the 2016 engine model year.

From pre-certification discussions with manufacturers, it appears most heavy-duty engine manufacturers would be able to incorporate urea quality sensors no later than the 2015 engine model year on most if not all of their engines. A small number have indicated they may need additional time to complete their qualification process for a production-ready urea quality sensor and fully implement them on the assembly line. Given this circumstance, we think it appropriate for engine manufacturers to implement urea quality sensors, or otherwise be able to detect poor urea quality in a manner such that it is highly unlikely for noncompliance to occur without triggering the appropriate inducements, no later than the 2016 engine model year.

[7] *See* 76 FR 32895.

Through parallel discussions with urea quality sensor suppliers, we understand that production capacity is rapidly developing to meet anticipated demand from engine manufacturers around this timeframe. However, some level of uncertainty remains about meeting the entire demand for the industry if it comes forward all in one model year. To help alleviate this situation, we encourage engine manufacturers planning to incorporate urea quality sensors to begin implementing them on some portion of their certified engine families in the 2015 engine model years. In pre-certification discussions for the 2015 model year, engine manufacturers should be prepared to describe their plans to the Agency.

Should you have any questions concerning this guidance, please contact Justin Greuel, Director of the Diesel Engine Compliance Center at greuel.justin@epa.gov or (202) 343-9891.

Sincerely,

Byron J. Bunker, Director
Compliance Division
Office of Transportation and Air Quality