Appendix K

Tier 4 Engines Assessment

A. Introduction

During the process of developing these amendments, ARB staff conducted several meetings with stakeholders to gather data and discuss issues. In these meetings, a few stakeholders expressed concern with using Tier 4 engines equipped with diesel particulate filters (DPFs) in their applications. According to these stakeholders, they experienced problems such as the engines losing power when entering into a regeneration mode, or the filters becoming clogged due to a low-temperature duty cycle. There are approximately 2,750 Tier 4 engines in registered portable equipment and most stakeholders have not expressed any concerns. Many stakeholders that expressed concerns about Tier 4 engines do not yet own Tier 4 engines.

During these meetings, the California Groundwater Association (CGA) expressed concerns regarding the operation of Tier 4 engines in drilling applications. Specifically they claimed that the regeneration cycle could cause the engine to de-rate which might compromise multi-day well pump tests required by law, or lead to engine shut down that could cause a loss of equipment in the well or damage to the well itself. In addition, representatives from CGA stated that Tier 4 engines present a potential ignition risk if combustible gases are emitted from a well during drilling. As a result of these two issues, CGA claimed that a 40-year exemption for Tier 3 engines used in drilling operations had been granted under Federal law as published in Volume 78 No. 116, of the Federal Register (78 FR No 116) on June 17, 2013, and they requested the same be done with California regulations. This federal rulemaking was finalized in 40 CFR part 1068.240(a)(3) and extended the use of replacement engines from 25 years to 40 years. ARB decided not to align with these federal requirements. The extension for replacement engines in federal law does not interfere with ARB's authority to adopt regulations that require replacement of engines prior to failure.

Staff used several approaches to assess the validity of Tier 4 engine concerns expressed by stakeholders. These approaches included relating the industry's prior experience with DPFs in on-road applications to off-road applications, analyzing data from stakeholders, visiting stakeholders to better understand their concerns, talking to engine manufacturers and retailers, and investigating a specific issue which had been brought to ARB's attention.

B. Industry Experience in the On-Road Sector

The heavy-duty diesel engines found in the on-road sector use similar and, in most cases, the same emission control technologies as engines used in the off-road and portable sectors. However, on-road emission standards preceded equivalent off-road emission standards by three to four years giving engine manufacturers and end-users time to learn how to properly operate and maintain engines with new emission control technologies. Staff conducted an extensive analysis of DPF performance in heavy-duty on-road applications in 2015. Results are detailed at: https://www.arb.ca.gov/msprog/onrdiesel/documents/DPFEval.pdf.

Staff's overall findings from the on-road analysis were:

- DPFs do not increase the likelihood of truck fires and are manufactured in accordance with federal and state safety requirements

- DPFs are effective in removing more than 98 percent of toxic diesel PM emissions;
- Engines are operating properly, and most trucking fleets are not having problems with their DPFs; and
- Some fleets are experiencing problems with their DPFs, but engine durability issues caused by inadequate maintenance practices are the primary reason for these problems.

The California Council on Diesel Education and Technology (CCDET), a non-profit cooperative group of California Community Colleges, the diesel industry and government agencies, supporting training and education programs for diesel mechanics, has recently published the Preventative Maintenance for Heavy Duty Trucks[1]. This handbook explains the advances in newer heavy duty diesel vehicles technology, the requirement for proper maintenance, steps to properly maintain engines and associated emission control devices, and potential issues that can arise due to improper engine and DPF care. The purpose of the handbook is to exemplify the importance for engine operators to understand how to care and maintain their engines and associated emission control devices. Since on-road and off-road engines use the same emission control devices, each preventative measure recommended in the handbook should also be taken by portable engine operators.

C. Evaluating Industry Data

ARB requested engine performance data from members of the CGA and members of the oil and gas industry. Members from both the water well drilling and oil and gas industries invited ARB staff to drilling sites and equipment yards to demonstrate how the equipment operates during a drilling operation. They also submitted engine performance data indicating average engine load on different types of equipment (mud pumps, drilling rigs, generators, well test pumps, etc.). The engine data reflected low-loads with long periods of idle. The worksite demonstrations of drilling operations verified that low-loads with long periods of idle were unavoidable. For example, an engine powering a drilling rig will only take on load while the engine powering the pipe setting operations is at idle, and vice-versa. These operating characteristics could potentially lead to excess soot loading onto a DPF similar to those experienced by the off-road engines discussed in Section E.

However, to date no fleet from either the CGA or oil and gas industry has operated a Tier 4 engine as part of their drilling operations. Therefore, no data has been collected nor has any situation occurred to validate the aforementioned claims. The CGA's claims are based on predictions of how Tier 4 engines installed with DPFs will perform in water well drilling applications.

Since data does not exist for Tier 4 engines operating under drilling conditions, staff sent surveys through traditional mail and e-mail to fleets with Tier 4 engines registered in PERP. The purpose of the survey was to assess whether or not Tier 4 engines meet fleets' operational needs. Staff received 18 hard copy and 35 electronic surveys from participating fleets, with 45 fleets (~85%) saying their operational needs are met. Of the

[1] CCDET Preventive Maintenance for Heavy Duty trucks: http://ccdet.org/wp-content/uploads/2016/12/preventive_maintenance_handbook_12_2_2016.pdf

8 fleets who were not satisfied with their specific Tier 4 performance, only 3 fleets said their needs were not met due to a loss of power during regeneration.

Although the vast majority of engine operators are satisfied with their Tier 4 engines, ARB recognizes there are certain operating scenarios that can lead to excessive soot loading of a DPF. ARB also recognizes that steps can be taken to prevent excessive soot loading. Engine and equipment manufacturers have recommended the following steps be taken to eliminate excessive soot loading and promote passive regeneration:

1) Properly size the engine for the application. It is of paramount importance to install an engine that is not oversized. This will ensure that under load, the engine will work at load high enough to maintain an appropriate exhaust temperature resulting in passive regeneration of the DPF.
2) The installation of a load bank on generators. If low loads result in excessive soot loading, a load bank can be installed that adds an additional power requirement on the engine resulting in higher load, higher temperature, and passive regeneration.
3) Work with the ARB, engine manufacturer and/or the equipment manufacturer to create combustion management upgrades to the electronic control unit to account for low-load, long-idle types of operations.

D. Visiting Stakeholders

To further investigate claims of low-load, long-idle operations leading to excessive soot loading and ultimately DPF failure, ARB visited an equipment dealer in the San Joaquin Valley who demonstrated two methods to potentially eliminate the possibility of excessive soot loading in Tier 4 engines. The first method was to design an engine that could meet Tier 4 final standards without using a DPF. In theory, without the installation of a DPF, excessive soot loading should not occur. Volvo designed the Tier 4 engine to meet the Tier 4 final certification standards without a DPF by reengineering the combustion physics and installing a Selective Catalyst Reduction (SCR) system. Staff has not yet received operational data on these engines in low-load applications to confirm this has been successful. The second method was an innovative approach to regeneration used on Perkins engines. In lieu of the traditional approach of a Diesel Oxidation Catalyst (DOC)/DPF where fuel is injected upstream of the DOC to instigate active regeneration in the DPF, an electronically controlled valve is installed upstream of the DPF. This valve either opens when engine load and exhaust temperature are high or closes to create backpressure resulting in higher exhaust temperatures. Through this control of exhaust flow, the exhaust temperatures can be held high enough to continually prompt passive regeneration. These two methods demonstrate engine manufacturers' creativity in resolving issues for low-load, long-idle operating cycles using engineering design techniques. After ARB facilitated meetings between engine operators and manufacturers, engine manufacturers have also demonstrated an ability to solve excessive soot loading issues on more traditional Tier 4 technology using a change in the engine's computer programming further discussed in Section E below.

E. Investigation

ARB staff evaluated a specific situation where off-road engines powering rubber tire gantry (RTG) cranes at a port in southern California were having operational issues. These RTG cranes were repowered Tier 4 interim engines which were equipped with DOCs and DPFs. After just 2,000 to 3,000 hours of operation, the Engine Control Module (ECM) indicated a problem with the DOC. These emission control systems are designed by the manufacturer to operate up to 6,000 hours before cleaning is required. After the cleaning was performed on these filter systems, it would only be another 200 to 300 hours before the system indicated the problem had returned. Clearly, these filters were not operating as intended by the manufacturer, so a multidivisional team of ARB staff was brought in to evaluate the situation. It was found that these RTGs were operating for a long time at idle, which does not allow the exhaust system to achieve the exhaust temperatures needed for effective regeneration. The low-temperature duty cycle was affecting the operation of the DOC. After realizing the cause of the problem, ARB worked with the engine manufacturer to develop a solution. The manufacturer was granted an experimental permit to test the solution on one of the RTGs and review exhaust temperature and pressure data to assess the effectiveness of the solution. The engine manufacturer created a combustion management upgrade so that the engines would produce higher exhaust temperatures during idle. This solution has been tested on two engines which each have operated for over 2,000 hours over the past several months with very positive results. ARB staff plans to conduct outreach to companies that may be facing similar problems created by low-temperature duty cycles. Any outreach efforts would inform all affected parties of the issues and possible solutions to ensure Tier 4 engines are programmed properly for their applications.

F. Exhaust Temperature and Operation in Hazardous Locations

Companies in the oil, gas, and water well drilling industries are concerned Tier 4 engines have a maximum exhaust temperature higher than the auto-ignition temperature of hydrogen sulfide and methane that are sometimes released into the environment during a drilling operation. Data from manufacturers indicate temperatures are not sufficiently different between a DPF equipped and non-DPF equipped engine to cause an issue in most applications, which will be discussed in greater detail below. Additionally, the United States Environmental Protection Agency (U.S. EPA) does have provisions for engines to be approved for use at hazardous locations where a risk for auto-ignition may be present. These engines are equipped with devices such as spark arresters and thermal barriers that make them safe for operating at these locations. The use of these engines may be one solution to the concerns raised by industry.

1. <u>Tier 3 and Tier 4 Maximum Exhaust Temperatures</u>

The CGA claims that Tier 3 engines operate with exhaust temperatures significantly lower than those of Tier 4 engines. Therefore, they want their industry to be exempt from any requirements to upgrade from Tier 3 to Tier 4 technology to prevent auto-ignition of gases potentially present at a drilling site. ARB staff has analyzed the potential risk imposed by Tier 4 engines versus Tier 3 engines operating in an environment with hydrogen sulfide and/or methane present.

Stringent Tier 4 final emission standards require engines to be equipped by the manufacturer with a DOC, a DPF, and/or a SCR. Each engine manufacturer choses which combination of control strategies to utilize in order to comply. For instance, engines rated between 50-174 horsepower may be equipped with a DOC, DPF, and SCR. Some engine manufacturers reengineered combustion physics for Tier 4 engines 175 horsepower and greater which lowered diesel PM emissions where only a DOC and SCR were needed. Avoiding the use of a DPF drastically lowers the maximum exhaust temperature of an engine by eliminating the need for active regeneration, which is usually a fuel injection in the exhaust just upstream of the DOC. This fuel injection creates temperatures high enough to combust carbon trapped in the DPF.

One engine manufacturer, who wishes to remain anonymous, submitted data showing that Tier 3 engines can reach maximum exhaust temperatures up to 470 °C. They also showed that Tier 4 engines with DPFs can reach up to 550 °C, while Tier 4 engines without DPFs can reach up to 450 °C. A study done by a different manufacturer shows a Tier 4 engine can reach an exhaust temperature of 650 °C during active regeneration.

The maximum exhaust temperature of an engine is important when considering the auto-ignition temperature of the combustible gases potentially present during operations. The auto-ignition temperature of hydrogen sulfide is 230 °C and 530 °C for methane. Of these two gases, only hydrogen sulfide is heavier than air meaning it disperses at ground level where engines reside and operate. Hydrogen sulfide has an auto-ignition temperature lower than maximum exhaust temperature of both Tier 3 and Tier 4 engines, so the same risk exists for either type of engine.

Tier 4 engines with DPFs may pose more risk in the presence of methane. Tier 4 engines equipped with DPFs have a maximum exhaust temperature higher than the auto-ignition temperature of methane; therefore, there is a higher chance of auto-ignition. However, methane is lighter than air meaning it rises as it disperses. Therefore, measures can be taken to reduce the risk of auto-ignition such as positioning the engine upwind of the drilling site, positioning the engine farther from the drilling site, and the installation of fans to blow air and potentially combustible gases away from the engine. Tier 4 engines without DPFs have an exhaust temperature lower than the auto-ignition temperature of methane, so the risk for auto-ignition is the same as for Tier 3 engines.

2. Engines Approved for Hazardous Locations

The U.S. EPA currently allows engines to be approved for use in hazardous locations per title 29 CFR 1910.307 or 1926.407. These engines are modified to be spark-proof and thermally insulated to keep skin temperatures low. These engines are currently built to meet Tier 3 standards under TPEM flexibility, but that flexibility will soon expire. EPA may add an exemption to The Tier 4 standards in 40 CFR 1039 that would allow engine manufacturers to continue to produce these engines certified to Tier 3 standards. Even built to Tier 3 standards, these engines can cost up to twice as much as an equally sized Tier 4 final engine. They are produced in low volumes, and are intended for use in true Hazardous Locations. Under the proposed amendments, these engines will be exempt from the Portable Engine ATCM and will be allowed to register in PERP until January 1, 2029, after which they may continue to operate under a local district permit.

G. Conclusions

The regulated community's assertions that Tier 4 engines will not work in operations with low-load, long-idle loading cycles and that Tier 4 engines will lead to auto-ignition of combustible gases occasionally released from drilling sites are valid in some instances, but can be avoided altogether if proper work practices are put in place.

Staff understands there are certain applications that require periods of extended idle, and that long-idle times can potentially lead to excessive soot loading of a DPF. Excessive soot loading can be avoided by taking the following actions:

1) Properly size the engine to the application,
2) Conduct regular maintenance on the engine and associated emission control systems consistent with manufacturer suggestions and as documented in the CCDET's preventive maintenance handbook.
3) Choose an engine that does not have a DPF/DOC,
4) Choose an engine with a DPF regeneration technology designed for low-load situations, and/or
5) Work with engine manufacturers, equipment manufacturers, and ARB to develop engineering solutions.

We can conclude Tier 4 engines without DPFs do not pose additional safety risks with regards to auto-ignition of hydrogen sulfide or methane when compared to a Tier 3. Tier 4 engines with DPFs which utilize active regenerations may potentially add risk for auto-ignition of methane compared to a Tier 3. The following safety measures can that can be taken to minimize the risk of auto-ignition include: position the engine upwind of the drilling site, position the engine farther from drilling site, and install fans to blow potentially combustible gases away from the engine.

For instances where fleets want to take additional precautionary measures, fleets may choose to use Tier 3 engines approved for use at hazardous locations. Staff has proposed certain amendments which will allow these engines to be used indefinitely in these potentially hazardous situations.

References

1. CCDET Preventive Maintenance for Heavy Duty trucks: http://ccdet.org/wp-content/uploads/2016/12/preventive_maintenance_handbook_12_2_2016.pdf November 2016
2. Aguila, Memo to the File. Discussion with Stakeholders on Measures to Minimize Auto-ignition Near Drilling Sites from Portable Engines. August 2017