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Response and Recommendations of the Engine Manufacturers Association To the GRPE Particle Measurement Program Report

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SUMMARY:

1. EMA believes that the measurement of particles from very low emitting engines poses a particularly troublesome technical issue that needs resolution before government can propose compliance with any future particulate emissions standards.

2. EMA agrees with the report's conclusions that improvements in particle mass measurement methods, such as the revised EPA 2007 procedure, are needed in order to properly characterize PM emissions from low-emitting engines.

3. EMA supports the report's conclusion that any particle number measurement must necessarily exclude volatile/nucleation mode particles since there is no method to reliably and repeatedly estimate numbers of these particles.

4. Although the report indicates that measurement of carbonaceous solid particles in the 20-200nm range may be feasible, there is little new information to be gained from making such measurements.

5. The laboratory demonstrations reported in the PMP document are not sufficient to conclude that the CVS + thermodiluter + CPC system will be reliable, acceptable, or cost effective on a commercial basis. Much more testing, including a necessary series of round robin laboratory tests under commercial certification (type approval) conditions, is needed before government and industry can be confident with any number count results.

6. Prior to development or implementation of any particle number standard, the major technical deficiency of lacking a suitable instrument calibration standard must be overcome.

Response and Recommendations of the Engine Manufacturers Association To GRPE Particle Measurement Program (PMP) Report

The Engine Manufacturers Association (EMA), representing the major U. S. manufacturers of heavy-duty vehicle engines, has reviewed the final report of the GRPE PMP Government Sponsored Work Programs effort to address methods to measure particulate matter emissions from heavy duty and light duty vehicles. EMA offers the following comments on the conclusions of the report and recommends that more extensive methods development and quality assurance testing be completed before any particle number measurement method is established.

1. EMA believes that the measurement of particles from very low emitting engines poses a particularly troublesome technical issue that needs resolution before government can propose compliance with any future particulate emissions standards.

Engine exhaust emissions are a complex mixture of particles and gases. The composition of the mixture is dependent on a number of factors including engine design, fuel characteristics, operating conditions, load, and maintenance state. In addition, particulate matter (PM) emissions rapidly change as the exhaust interacts with ambient air and because volatile and semi-volatile components condense and form particles or agglomerate on solid particles when the exhaust is diluted and cooled

Because sampling and measurement conditions physically change the nature of particulate emissions in engine exhaust, current PM emissions have been methodologically defined. That is, government and industry agreed on a standard set of conditions and sampling methods using gravimetric measurement of filters to define and quantify PM emissions. Through this standardized method, there is at least an understanding of the portion of the actual particulate matter emissions that are being measured and reported as well as a certain level of confidence that the results are comparable. It is important to note that PM measurements from a single engine under the same operating conditions would change if the sampling conditions and analytic methods detailed in the regulations were altered, simply because PM is methodologically defined.

The current gravimetric methods are considered adequate to obtain an index of PM emissions from today's engines. However, the technical boundaries of the current gravimetric filter methods are likely to be exceeded when applied to exhaust from aftertreatment-equipped engines. Advanced diesel and gasoline engines will emit extremely low levels of particles, and current PM sampling and measurement methods will need improvement in order to increase their precision and accuracy to levels needed to accurately detect and estimate PM. Because of the near zero levels of PM emissions from the new systems, any PM measurements will be very sensitive to artifact formation and instrument detection levels, and will be even more dependent on the defined methodology, especially for any number measurement technique.

For example, the PMP research effort used a standard dilution tunnel used for mass measurement to also evaluate instruments to measure particle number. Although the dilution method used in the PMP evaluation has been successfully used for PM mass, it is not immediately clear that it is appropriate for use in PM number measurements. This is because the effects of dilution on particle nucleation and condensation have only minor impacts on particle mass measurement since the nuclei mode particles do not significantly contribute to mass, but may have a significant effect on particle number counts. As demonstrated by recent CRC studies showing that a 10 C degree change in dilution temperature can have an order of magnitude change in number count, much more work is needed to determine the complex effects of the proposed measurement methods described in the report.

The need for accurate and repeatable measurement of PM at near zero levels stretches the boundaries of today's measurement technology. It is critical that regulatory bodies identify and define PM measurement methods that are scientifically validated, capable of producing accurate and repeatable results, and proven to work in a commercial setting. Engine and vehicle manufacturers will not be able to demonstrate compliance or achieve certification (type approval) to future PM standards unless, and until, such validated measurement and certification procedures are developed and codified and are available to manufactures and government agencies on a widespread basis.

2. EMA agrees with the report's conclusions that improvements in particle mass measurement methods, such as the revised EPA 2007 procedure, are needed in order to properly characterize PM emissions from low-emitting engines.

The current gravimetric, filter-based approach to PM measurement is considered adequate to provide a standardized index of PM mass emissions under specified engine operating and exhaust dilution conditions for today's heavy-duty vehicles. However, as noted above, the current method is not adequate to produce reliable and repeatable results under the near-zero PM emissions levels expected from diesel engines equipped with PM aftertreatment equipment.

EMA recognized this fact and not only provided written comments expressing concerns about applying the current PM measurement methods to aftertreatment-equipped engines to the U. S. EPA during the public review of the proposed 2007 heavy-duty on-highway regulations but has also been working cooperatively with EPA on developing a solution. The systematic and random errors associated with the current methods, filter artifacts, and inaccuracies in weighing filter samples at near zero levels create great uncertainty in the results. Consequently, improved methods to determine PM mass are needed.

EMA is working with the US EPA to revise the gravimetric filter methodology and believes that progress is being made. However, The Coordinating Research Council (CRC) is undertaking a new research project (E-66) that proposes a systematic parametric study to evaluate the effects of varying the test parameters within the specifications of the revised gravimetric test procedures proposed by the U. S. EPA. This study will characterize the organic vapor deposition artifact as a function of filter media and examine the magnitude of variability through a range of PM sampling system test parameters to determine potential lab-to-lab variability. E-66 also will examine different filter temperatures and dilution ratios, study the effects of sampling system parameters on the correlation between full flow CVS PM measurement and partial flow PM measurement, and develop an alternate technique that may be applicable for in-use PM measurement.

EMA is not yet satisfied with the changes in EPA's 2007 PM gravimetric filter method and is jointly working with EPA to improve upon it. EMA recommends that the modified 2007 PM procedure cited in the document not be approved or adopted in Europe until industry and regulatory authorities agree on a final set of recommendations derived from ongoing research efforts including results of the E-66 project.

3. EMA supports the report's conclusion that any particle number measurement must necessarily exclude volatile/nucleation mode particles since there is no method to reliably and repeatably estimate numbers of these particles.

As noted above, the measurement of particle mass is complicated, but standard methods do exist to measure particle mass under a specified set of conditions. In contrast, particle number formation is even more complicated, is extremely sensitive to a number of conditions including temperature, dilution, and engine operating conditions, and there is no standardized or acceptable method available to reliably sample and measure total engine exhaust particle number.

In particular, the quantification of particle number is frustrated by the rapid transformation of nucleation mode and accumulation mode particles when volatile particles react with ambient conditions and condense and coagulate to form larger particles or adhere to solid particles in the exhaust stream. New research has shown that the initial formation of volatile particles is dependent on engine operating and load conditions as well as dilution rate, and ambient temperature. Thus, any attempt to measure particle number must address the extreme sensitivity of volatile particles to these conditions, and it is virtually impossible to achieve any degree of control or standardization during the measurement processes. Consequently, even under heavily controlled research laboratory conditions, quantification of particle number from a single engine produces neither repeatable nor robust results.

Additionally, the PM sampling and measurement device itself has a profound effect on measurement results. Because nucleation and accumulation mode particles are so sensitive and transient in nature, particles are lost, entrained, or even formed in the sampling equipment. Thus, even the attempt to measure such particles has the effect of significantly altering the results.

Based on the above, there is no current sampling methodology that can be used to quantify or measure volatile particles in the exhaust. The sensitivity to operating, ambient and sampling environments create uncontrollable variability that makes the measurement of particle number unsuitable for either regulatory control or establishment of a standard. EMA strongly agrees with and supports the conclusion of the PMP Group that any particle number–based measurement system must exclude nucleation and accumulation mode volatile particles.

4. Although the report indicates that measurement of carbonaceous solid particles in the 20-200nm range may be feasible, there is little new information to be gained from making such measurements. Due to the uncertainty and inability to measure volatile particles, the PMP report recommends that the only viable approach to particle number measurement is one which only measures carbonaceous solid particles. The report states that a sampling system that prevents the formation of, or removes, all volatile particles is an option to improve sample repeatability. The PMP Group then recommends a CVS+thermodiluter+CPC system as a means to achieve a number count of solid, carbonaceous particles.

EMA believes that such an approach is redundant and not needed. Our concerns with developing a solid particle count standard and measurement method is that it offers no new information that is not already available through the current mass-based approach.

With the elimination of the volatile particles, the only particles that would be counted are the solid particles that are normally trapped on the filter used in the gravimetric mass measurement. Since the particles are solid and do not rapidly change, one can determine a consistent relationship between particle mass and particle number based on currently available information EMA believes that government and industry should not invent a new methodology to obtain an estimate of particle number simply for the sake of having a number count.. Additionally, recent work by Dr. David Kittleson, at the University of Minnesota, a leading diesel particle researcher, has found that particle number appears to decrease in direct relationship to particle mass when diesel particulate filters are utilized. Based on the above, the establishment of a separate and new solid particle number method does not add any useful information about PM emissions and is unnecessary.

5. The laboratory demonstrations reported in the PMP document are not sufficient to conclude that the CVS + thermodiluter + CPC system recommended in the report will be reliable, acceptable, or cost effective on a commercial basis. Much more testing, including a necessary series of round robin laboratory tests under commercial certification conditions, is needed before government and industry can be confident with any number count results.

EMA applauds the PMP investigation for exploring the performance of many particle measuring instrument systems, and appreciates the evaluations that eliminated for consideration many unsuitable devices. However, EMA believes that a similar effort is needed to thoroughly verify a candidate system for regulatory purposes, if such a system is required. The development and demonstration of a sampling method and selection of analytic instrumentation to estimate particle number under carefully controlled research laboratory conditions is thus far insufficient to demonstrate that the method will produce reliable results under commercial laboratory conditions used for certification. The proposed system may have been demonstrated to work in a research laboratory, but the instrumentation and methods have not undergone sufficient testing and verification under real-world conditions. As indicated in the PMP report, any new measurement systems must meet several criteria before it can be considered acceptable. These include repeatability, reproducibility, robustness, cost, and traceability of results.

The PMP report states that the primary PM number research to date has been on the repeatability of the results in a single lab, and that these results are promising. However, when the data are scrutinized they show a number count range of 1.06E+14 to 1.61E+14, which is a difference of 51.9%. This is a huge difference in measurement terms especially if one were to use this type of data for emissions compliance results where repeatable and reproducible measurements are required. The EMA /USEPA Calibrations Standards Task Force has established variability goals of 2.5% for repeatability and 5.0% for reproducibility. PMP data in Figure 4, Annex 7 indicate that repeatability range from 3.4% to over 30%. Variability of this nature, characterized as good in the report, is unacceptable to test and certification engineers attempting to demonstrate compliance to a standard.

In addition, there has been little or no testing to date to assure reproducibility by testing the same engine in different labs or to assure that the equipment is robust enough to perform in a commercial setting. Only short term, daily repeatability has been assessed. No studies of long term validation have been completed. We understand that ACEA has examined repeatability over a four month period and identified a 35% decrease in PM number under identical test conditions, thus calling into question the stability of measurement methods over the long term.

To investigate reproducibility, a series of round-robin tests must be completed to determine if different labs testing the same engine reach the same results. When previous changes to testing and certification regulations were proposed, extensive and comprehensive round robin testing was completed. For example, before implementation of the transient test cycle in the United States, engine manufacturers were involved is a two year program that tested 6 engines at 7 different laboratories and included numerous testing parameters. Prior to implementation of the U. S. EPA Heavy-duty On Highway PM standard of 0.1 g/bhp-hr, there was a both a European and US round-robin test program that included several different labs and numerous data sets, and in 1994 ISO completed a worldwide series of tests on standard dilution systems that involved 16 labs and numerous replicates to gather information on preferred methodologies.

This round-robin testing is critical to establishing the validity and variability of any proposed testing protocols and must be completed prior to the adoption or implementation of the PMP recommendations.

Furthermore, both the robustness and costs of the instruments and testing need investigation prior to acceptance of any proposed method. The combination of a CVS, thermodiluter, and CPC is an innovative use of instruments, and because they involve newly developed technologies, have not been proven in commercial test cell applications. It is likely that the diluter and CPC instruments require considerable “hands-on” care in order to produce repeatable results. The instruments must be demonstrated to work under commercial laboratory conditions, must prove reliable, and meet performance characteristics if they are to be used for certification to any standard. Engine and vehicles makers cannot afford to experiment with different instruments and methods during the certification process.

Finally, the instruments must be available on a large scale and it must be cost-effective to complete any proposed tests. Again, none of these activities have been completed on the proposed system.

EMA recommends that a series of round robin tests be completed at manufacturers' labs in order to study the robustness of the proposed number count method. This testing needs to be completed, and the results reported and analyzed, prior to the development of any standards or test protocols. This additional testing is necessary to ensure comparable results as well as the usefulness of the method and instruments to the regulated community. In addition, more information on the commercial availability, operating requirements, and costs needs to be collected and evaluated before the proposed method can be accepted and implemented.

6. Prior to development or implementation of any particle number standard, the major technical deficiency of lacking a suitable instrument calibration standard must be overcome.

The results of any number count method must be traceable to an internationally-recognized standard. However, the PMP report concludes that no calibration standard or calibration procedure is readily available. The instruments to be used in the particle number measurement program by government and industry must be capable of calibration on a daily basis at field laboratories around the world. Obviously, a traceable international calibration standard must be developed before any further efforts to implement the PMP report recommendations are made.

Conclusion

The PMP Group report's conclusion that thermodilution and CPC offer the best particle measurement system is premature, and additional technical and product development work must be completed before government can propose or implement a particle standard based on this measurement technology. The uncertainties surrounding the measurement methods, the lack of adequate testing for repeatability, the lack of commercial grade measurement equipment, and the high costs to industry of developing such a measurement system make any proposal regarding particle number measurement premature.

Engine manufactures in the United States are currently working cooperatively to improve PM measurement techniques through the CRC E-66 project, and will be happy to share those results with the GRPE PMP program; results are expected in about one year. This new information will greatly assist in the development of a validated and accurate PM measurement procedure applicable to the near-zero emissions expected in the future.