United States Environmental Protection Agency
Office of Mobile Sources

October 29, 1997

Greg O. Scherer, Manager
Fuels Technology and Product Section
Southwest Research Institute (SwRI)

Dean Schoppe, Manager
Fuels Testing
EG&G-AR

Dear Mr. Scherer and Mr. Schoppe:

I am writing in response to your letter dated March 6, 1997, in which you recommended that the Environmental Protection Agency (EPA) apply revised test equipment qualification criteria in evaluating the suitability of intake valve deposit (IVD) control tests conducted to comply with the requirements of EPA's certification program for gasoline deposit control (detergent) additives (61 FR 35309, July 5, 1996). This response also considers the additional data presented in a letter from Mr. Schoppe dated September 24, 1997, on temperature corrections for Stoddard solvent flow data. Specifically, you recommended that revised pressure valve and fuel injector flow rate specifications be substituted for those found in the American Society for Standards and Materials (ASTM) D 5500-94 procedure entitled, "Standard Test Method for Vehicle Evaluation of Unleaded Automotive Spark-Ignition Engine Fuel for Intake Valve Deposit Formation", which is specified for detergent certification purposes at 40 CFR 80.165. You also requested that EPA temporarily waive compliance with the injector flow pattern specification in the ASTM D 5500-94 procedure until ASTM resolves issues related to its application when injector flow rate is tested with Stoddard Solvent rather than isooctane.

A detailed discussion of these procedural items is attached. The order in which they are addressed follows that in your letter. Until such time as EPA amends the IVD test procedure through a rulemaking or issues additional guidance, this letter may be used by the regulated community as a guide regarding EPA's position on the suitability of the changes recommended in your letter to the ASTM D 5500-94 procedure. As we discussed, this letter will be released to the general public to serve as an announcement to regulated parties. Thank you for your efforts in maintaining the soundness of the ASTM D 5500 procedure. Please contact me if you have additional concerns.

Sincerely,

Jeffrey Herzog
Mechanical Engineer
Fuels and Energy Division

Enclosures

Environmental Protection Agency Position on Suggested Changes to the ASTM D-5500-94 Test Procedure Specified for Use Under the Detergent Certification Program

Item 1:

Subject Requirement:

Section 8.7.1.1 of the ASTM D 5500-94 procedure states that the coolant system integrity must be checked to conform to the following specifications:

Pressure valve opens at ..... 90 to 110 kPa (13 to 16 psig)
Vacuum valve opens at ..... 90 to 110 kPa (13 to 16 psig)

Issue:

You stated that the specification for the pressure valve is adequate and meaningful, but that it is not possible for the vacuum valve to meet the specification listed. You also stated that a reasonable specification for the vacuum valve would be as follows:

Vacuum valve opens at 5.06 to 10.13 kPa (1.5 to 3.0 in Hg)

You recommended that this specification should apply to all (past, present, and future) ASTM D 5500-94 tests conducted.

In a phone conversation on June 23, 1997, Mr. Schoppe related that the replacement specifications suggested in your letter resulted from a review of considerable data from tests run at SwRI and EG&G which showed that the suggested specifications would ensure proper functioning of the vacuum valve. Mr. Schoppe also stated that the suggested specification will be balloted by ASTM in the future for inclusion in a revised ASTM D 5500 procedure.

EPA Response:

It is clear that the vacuum valve specifications in section 8.7.1.1 of the ASTM D 5500-94 procedure are not meaningful since these specifications bracket normal ambient air pressure. EPA believes that the vacuum valve specifications recommended in your letter are based on the best data currently available, and are likely be adopted by ASTM in a revised ASTM D 5500 procedure. Therefore, EPA will apply the suggested vacuum valve specification of 5.06 to 10.13 kPa (1.5 to 3.0 in Hg) to all IVD tests performed to support certification under the gasoline detergent program (pursuant to 40 CFR 80.165) in place of the vacuum valve specifications in section 8.7.1.1 of the ASTM D 5500-94 procedure. Based on a review of additional data which might become available or the approval by ASTM of a different specification, the Agency might consider adoption of a different

vacuum valve specification in the future.

Item 2:

Subject Requirements:

Section 8.5.5.1 of the ASTM D 5500-94 procedure states that the flow rate of fuel injectors must be tested at 310 +/- 1.4 kPa (45 +/- 0.2 psi) using Stoddard solvent or isooctane. The specification for flow testing using isooctane states that each injector must have a flow rate (at 310 kPa, 15.6øC) which conforms to the following:

isooctane 2.03 to 2.09 g/s (0.0716 to 0.0737 oz/s)

Section 8.5.5.1 further states that:

Flow rates shall be adjusted for test conditions of fluid temperature and pressure.

Issue:

You stated that the fuel injector flow rate specifications in section 8.5.5.1 of the ASTM D 5550-94 procedure were produced by ASTM based on data from flow tests on the fuel injectors which were available when the procedure was developed in 1993. Since 1993, you related that the manufacturer of the fuel injectors specified for use in the ASTM D 5500-94 procedure changed their manufacturing processes resulting in a slight alteration to injector flow properties. Subsequently, ASTM developed flow rate specifications which are more appropriate for injectors of current manufacture. I understand that the flow rate specifications recommended for adoption by EPA in your letter were approved by ASTM ballot in June of 1996, and will be included in a revised ASTM D 5500 procedure to be published by ASTM in the future. The revised injector flow rate specifications for flow testing conducted using isooctane are as follows:

isooctane 1.94 to 2.06 g/s (0.0684 to 0.0727 oz/s)

You also stated that in association with the modified flow specifications, ASTM plans to include the following clarification of the procedural specifications regarding the conditions to which the reported fuel injector flow rates must be adjusted:

Flow rates shall be corrected to 15.6øC (60øF).

EPA Response:

EPA agrees that the flow specifications recommended in your letter are appropriate for fuel injectors of current manufacture. However, it is inappropriate to apply the revised specifications to all tests conducted using the ASTM D 5500-94 procedure regardless of whether the injectors used were of earlier or more recent manufacture. The recommended lower bound in the revised fuel injector flow rate specifications is less than the lower bound in the ASTM D 5500-94 procedure (1.94 vs 2.03 g/s). Therefore, injectors of earlier manufacturer which would have

complied with the specification on the lowest acceptable flow rate in the ASTM D 5500-94 procedure would also comply with the revised specification. However, the upper bound in the revised acceptable range of flow rates is less than the upper bound in the ASTM D 5500-94 procedure (2.06 vs 2.09 g/s). Thus, some injectors of earlier manufacturer that conformed to the flow specifications in the ASTM D 5500-94 procedure would not conform with the revised specifications. Consequently, if the revised specifications were applied to tests conducted in the past as suggested, some tests that have already been conducted using the earlier-production injectors might be inappropriately judged to be invalid for detergent certification purposes. Such an action would be unfair, since these tests were conducted in good faith using properly functioning fuel injectors which were in conformity with the requirements applicable at the time. Since some certifiers might currently be relying on tests conducted with earlier-production injectors to substantiate compliance with the requirements for detergent certification, invalidating these tests could necessitate recertification in some case which could result in significant financial hardship for these parties.

To ensure that both earlier and later fuel injector production batches are properly evaluated for their suitability for use in the ASTM D 5500 procedure, EPA believes that it would be most appropriate to provide separate specifications for the two fuel injector variants. Under this approach, the fuel injector specifications in the ASTM D 5500-94 procedure would apply to fuel injectors from earlier production batches, and the revised specifications would apply to injectors from current production batches. In a phone conversation on July 23, 1997, Mr. Scherer related that BMW states that it is not possible to differentiate by lot number or other means between injectors of earlier manufacture which were used by ASTM to produce the flow rate tolerances specified in the ASTM D 5500-94 procedure, and those of current manufacture which were used by ASTM to produce the revised flow rate specifications. Fuel injectors of both earlier and current manufacture conform to the same part number as specified in the annex to the ASTM D 5500 procedure (BMW part number 13 14 1 179 232).

Since it is not possible to apply separate specifications for earlier and current fuel injector production batches, EPA believes that it is suitable to apply broadened acceptance criteria which spans the allowed variability for both injector production variants to tests in which mileage accumulation was initiated prior to the date of this notification. Tests in which mileage accumulation was begun after October 30, 1997, would be required to comply with the specifications suggested in your letter for injectors of current manufacture. Allowing increased variability in the flow rates of injectors used in tests that have already been conducted is necessary to prevent the potential invalidation of tests which used injectors from earlier production batches that conformed to the flow specifications germane to these injectors.

EPA will apply the following fuel injector flow specifications for flow testing conducted using isooctane in evaluating the acceptability of IVD test data for detergent certification purposes in place of the specifications in section 8.5.5.1 of the ASTM D 5500-94 procedure:

For tests in which vehicle mileage accumulation was initiated on or prior to October 30, 1997, the following specifications on injector flow rates will apply:

isooctane 1.94 to 2.09 g/s (0.0684 to 0.0737 oz/s)

For tests in which vehicle mileage accumulation was initiated after October 30, 1997, the following specifications on injector flow rates will apply:

isooctane 1.94 to 2.06 g/s (0.0684 to 0.0727 oz/s)

EPA agrees that the suggested revision to the specifications on the conditions to which the reported fuel injector flow rates must be adjusted resolves ambiguities present in the current ASTM D 5500-94 procedure. In keeping with your suggested revision to the procedure, EPA will continue to require that flow rates reported pursuant to section 8.5.5.1 of the ASTM D 5500-94 procedure be adjusted to 15.6øC (60øF).

Potential Impacts of the Temporary Application of Broadened Acceptance Criteria

The temporary application of broadened acceptance criteria in evaluating the suitability of fuel injectors for certification testing purposes necessitates an evaluation of the potential introduction of test bias and associated impact on the emissions control goals of the detergent program. The application of broadened acceptance criteria will allow injectors from later production batches that have a flow rate as high as 0.03 g/s greater than that specified in the planned ASTM amendments to procedure D 5500 to be judged acceptable in past tests. However, EPA does not believe that this will result in the introduction of significant test bias since the magnitude of the increase in the upper limit of the allowable injector flow rates for later production injectors is minimal and there are factors which mitigate against such variation having a significant impact on test results.

The application of broadened acceptance criteria will also allow earlier production injectors that have flow rates as much as 0.09 g/s lower than that specified in the ASTM D 5500-94 procedure to be judged acceptable for use. The magnitude of this potential difference from appropriate flow specifications raises somewhat more concern regarding potential test bias which might be introduced. However, there are several factors to mitigate this concern. Firstly, EPA believes that most injectors of earlier manufacture were evaluated for use based on the criteria in the ASTM D 5500-94 procedure, which were tailored to the particular flow characteristics of these injectors. If earlier

production injectors did not conform to these specifications, they would have been identified as unsuitable for use and discarded. It was only after current-manufacture injectors were identified as requiring different flow specifications and appropriate specifications were developed by ASTM that industry began applying the revised flow specifications. EPA believes that it is unlikely that a significant number of earlier production injectors continued in use after industry started evaluating the acceptability of injectors based on the flow specification developed for current production fuel injectors.

EPA's experience regarding the various test parameters which influence the results of IVD testing indicates that injector flow has a relatively small effect on test results within the described range of variability, relative to the effect of other testing parameters such as valve temperature (as evaluated by engine coolant temperature). In addition, it is not possible to definitively determine the directional effect that decreased (or increased) fuel flow will have on IVD test results since the important factors to consider have competing effects on test severity. As discussed below, the overall effect that these factors will have on IVD test results is dependent on the deposit forming tendency of the base fuel, the efficacy of the additive used, and unknowns regarding deposit formation processes relative to these factors.

Flowing additional fuel over the intake valves tends to provide more material to form deposits. However, increased fuel flow also tends to decrease the temperature of the valves slightly, thereby reducing the amount of deposits formed. EPA is not aware of data to quantify the differential cooling effect. However, it is reasonable to assume that this effect is very small relative to the magnitude of the difference in injector flow rates considered. The degree to which increased fuel flow increases deposit test results due to the availability of more material to build deposits varies according to the severity of the base test fuel, with the potential impact probably being more pronounced for more severe fuels. However, there are inadequate data to quantify the magnitude of the potential increase in test severity which results from increased fuel flow relative to differences in test fuel deposit forming severity.

If the fuel is additized, flowing greater volumes over the valves will not only bring more material from which to form deposits, but will also increase an additive's deposit control activity since more additive will flow over the valve. Differences in the deposit control characteristics of different additive types and in the efficacy of different detergent packages relative to the base test fuel used will affect the extent to which increased additive flow over the valve tends to reduce IVD test results. Although it is not possible to determine which of these competing mechanisms would predominate in determining the overall effect on IVD test results of increased fuel flow, EPA believes that given that the potential effect of any of these mechanisms is small for the case

considered, the overall impact on test severity would be marginal at most. Therefore, it appears reasonable to assume that the potential impact of the additional variability in injector flow within the range allowed would not result in significant test bias.

The test validation criteria regarding the amount of fuel consumed during the test in section 10.4.4 of the ASTM D 5500-94 procedure will also serve to limit the potential impact on test results of increased variability in injector flow rate. Section 10.4.4 states that average fuel consumption must be between 10.2 km/L and 12.8 km/L (24 to 30 mpg) for the test duration for the test to be valid. The potential impact on test results of allowing broader injector acceptance criteria will also be of limited duration, since tests initiated after October 30, 1997, are required to comply with the flow rate specifications tailored to the characteristics of current manufacture injectors. In addition, since EPA expects that additive manufacturers will retire additive certifications at a rate of 15% per year[1], the potential impact on the emissions control goals of the detergent program of certifications which might be based on tests that were biased to a degree by increased variability in injector flow would be of limited duration.

Considering these factors, EPA believes that the potential impact on the emissions benefits of the detergent program of applying the broadened injector flow criteria is negligible. EPA might consider the adoption of a different flow rate specification for flow testing conducted using isooctane based on a review of additional data, if such data becomes available, or the approval by ASTM of a different specification.

Item 3:

Subject Requirements:

The specification for flow testing fuel injectors using Stoddard solvent in section 8.5.5.1 of the ASTM D 5500-94 procedure states that each fuel injector must have a flow rate (at 310 kPa, 15.6 øC) which conforms to the following:

Stoddard solvent 2.30 to 2.36 g/s (0.0811 to 0.0832 oz/s)

Section 8.5.5.3 of the ASTM D 5500-94 procedure states that the spray pattern of each injector must conform to specified visual inspection criteria.

Issues:

You stated that at the time the ASTM D 5500-94 procedure was finalized, data on appropriate fuel injector flow rates using Stoddard solvent were not available. Consequently, a conversion factor based on specific gravity was applied to the isooctane flow testing specifications to produce the specifications for flow testing using Stoddard solvent. It is now recognized that this means of conversion does not take into account viscosity differences between isooctane and Stoddard solvent, which will

affect the flow rate. You noted that since Stoddard solvent has a higher viscosity, less Stoddard solvent will flow through a given injector in comparison to isooctane.

Your letter dated March 4, 1997, included the results of a program conducted at three different test laboratories which compared flow rates on three sets of four injectors using isooctane and Stoddard solvent. In a follow-up letter dated September 24, 1997, Mr. Schoppe provided additional data to correct the results of this interlaboratory data to 60øF, as required in the ASTM D 5500 procedure. The temperature-corrected results of the inter-laboratory study showed smaller differences in flow rate using Stoddard solvent and isooctane than was predicted by the specific-gravity conversion calculation which formed the basis for the specifications for flow testing with Stoddard solvent in section 8.5.5.1 of the ASTM D 5500-94 procedure.

Based on the temperature-corrected inter-laboratory test data and other testing experience, you suggested that the Stoddard solvent flow rate specifications be changed from the specification in the ASTM D 5500-94 procedure to the following:

Stoddard solvent: 1.89 to 2.01 g/s (0.0667 to 0.0709 oz/s).

You stated that, the suggested specification should apply to all (past, present, and future) ASTM D 5500-94 tests.

You also stated that due to the viscosity differences between isooctane and Stoddard solvent, a proper fuel injector spray pattern cannot be attained using Stoddard solvent. You stated that it is intended that ASTM review the sections pertaining to visual inspection of the fuel injectors and develop a consensus on how to address the problem. Until ASTM makes such a determination, you recommended that EPA not require the visual evaluation of fuel injector spray pattern if the injectors are flow tested with Stoddard solvent.

In a phone conversation with Dean Schoppe on June 23, 1997, Mr. Schoppe related that unless EPA waives this requirement, parties who test injector flow rate with Stoddard solvent will be forced to continue performing a separate evaluation of injector spray pattern using isooctane, resulting in additional cost and logistical difficulties.

EPA Response:

EPA agrees that the Stoddard solvent flow specifications in the ASTM D 5500-94 procedure are unrepresentative and should be replaced with the specifications suggested in your letter dated September 24, 1997. Since the specifications in your letter are based on temperature-corrected results from a matrix of inter-laboratory test data, they are clearly more appropriate than those in the ASTM D 5500-94 procedure which are based on a methodology of extrapolation from isooctane flow specifications that did not take into account the substantial effect of

differences in viscosity between isooctane and Stoddard solvent. Application of the injector flow rate specifications for Stoddard solvent in the ASTM D 5500-94 procedure would allow injectors with inappropriately high flow rates to be used, and would exclude from use injectors with flow rates in the appropriate range, thereby effectively barring the use of Stoddard solvent for flow testing. However, EPA believes that applying the revised flow specifications to past tests is inappropriate since this would potentially invalidate tests which met the qualification criteria applicable at the time. Consequently, in keeping with the discussion in the previous section, EPA believes that the only workable approach in evaluating the validity of past tests is to apply broadened injector flow specifications which encompass both the specifications in the ASTM D 5500-94 procedure and those recommended in your letter.

In place of the specifications in section 8.5.5.1 of the ASTM D 5500-94 procedure, EPA will apply the following fuel injector flow specifications for flow testing conducted using Stoddard solvent:

For tests in which vehicle mileage accumulation was initiated on or prior to October 30, 1997, the following specifications on injector flow rates will apply:

Stoddard solvent 1.89 to 2.36 g/s (0.0667 to 0.0832 oz/s)

For tests in which vehicle mileage accumulation was initiated after October 30, 1997, the following specifications on injector flow rates will apply:

Stoddard solvent 1.89 to 2.01 g/s (0.0667 to 0.0716 oz/s)

EPA cannot at this time waive compliance with the requirement that the fuel injector flow pattern conform with the specifications in the ASTM D 5500-94 procedure. ASTM determined through an industry consensus process, and EPA continues to believe, that a specification on injector flow pattern is useful in limiting test variability. EPA does not believe that requiring parties who evaluate flow rate using Stoddard solvent to conduct an evaluation of flow pattern quality represents a substantial hardship for these parties. A party who wishes to conduct flow rate testing using Stoddard solvent can evaluate flow pattern at their laboratory using isooctane or contract with another laboratory to have the flow pattern evaluated using isooctane. In addition, both injector flow rate and flow pattern testing can be conducted using isooctane. All things considered, EPA believes that it is appropriate to defer further consideration of the issue until input from ASTM is available.

Potential Impact of the Temporary Application of Broadened Acceptance Criteria

Specifying that tests conducted before the release of this notification must comply with the combined range of acceptable flow values discussed above will allow the use of IVD test data

which were collected using injectors that have a flow rate as much as 0.33 g/s above the appropriate limit identified in your letter. This magnitude of increased fuel injector flow outside of the bounds of the appropriate limits raises somewhat more concern regarding the potential impact on the representativeness of IVD test results with respect to ensuring a proper level of deposit control than that discussed in the previous section. However, for many of the same reasons discussed in the section above, EPA believes that the potential impact on the deposit control goals of the program is marginal and would be short-term in nature. In addition, EPA believes that little if any IVD testing was conducted using Stoddard solvent to flow test injectors until the development of the revised flow specifications. Flow tests conducted using Stoddard solvent immediately after the development of the ASTM D 5500-94 procedure would have quickly shown that meeting the stated specification was impractical. The specifications determined to be appropriate through your inter-laboratory study are significantly different and do not overlap those in the ASTM D 5500-94 procedure. Thus, it is highly unlikely that lengthy and costly IVD testing would have been undertaken using injectors flow tested with Stoddard solvent until the appropriate flow specifications were available. Also, it is EPA's understanding that the revised flow specifications have been observed by laboratories which have used Stoddard solvent to flow test injectors in conducting IVD tests intended for detergent certification purposes.

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[1] Regulatory Impact Analysis for the Detergent Certification Program, Docket A-91-77, Item V-B-01.