
Investigation of MOBILE5a Emission Factors:

Evaluation of IM240-to-FTP Correlation and Base Emission Rate Equations

HEALTH AND ENVIRONMENTAL SCIENCES

API PUBLICATION NUMBER 4605

JUNE 1994

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Health and Environmental Sciences Department

API PUBLICATION NUMBER 4605

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JUNE 1994

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ABSTRACT

The U.S. Environmental Protection Agency's (EPA's) on-road motor vehicle emission factors model, MOBILE5a, is being used increasingly as a regulatory and public policy tool. It is used to determine compliance with motor vehicle related control programs such as enhanced inspection and maintenance (I/M) and highway conformity determinations; its outputs were also used to formulate EPA's Complex model for reformulated gasoline. Although MOBILE5a outputs are used for a broad array of purposes, the methods used to develop inputs to the model are largely undocumented. This report evaluates and documents the methods used by EPA to generate the exhaust base emission rate (BER) equations for MOBILE5a, which were developed from data collected with the IM240 test procedure at an operating I/M lane in Hammond, IN. EPA had to convert the IM240 data to a Federal Test Procedure (FTP) basis prior to developing the BER equations because the exhaust relations in MOBILE5a are based on emissions measured according to the FTP. This study critiques the adjustments used to correct the IM240 emissions test procedure for variations in fuel and temperature relative to those specified for the FTP, and it reviews the correlations between emissions based on the IM240 test procedure and emissions measured on the FTP. In addition, the methods used by EPA to develop emission control system deterioration rates for MOBILE5a were assessed and recommendations for alternative methods to estimate in-use exhaust emission rates were made. The evaluation revealed that suspect statistical and analytical techniques were employed in the development and application of the IM240-to-FTP conversion procedure. Further, the methods used to generate exhaust base emission rate equations from the converted IM240 data resulted in a significant overprediction of emission rates at vehicle odometer readings above 75,000 miles.

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EXECUTIVE SUMMARY

The Clean Air Act Amendments (CAAA) of 1990 mandated a wide array of reductions in mobile source emissions. The revised provisions specified more stringent certification standards for new vehicles, changes in inspection and maintenance (I/M) program requirements, implementation of gasoline regulations, new categories of emissions standards and a host of other changes. The primary tool used to track the effect of these changes on the emissions of the in-use vehicle fleet is the MOBILE series of models developed by the U.S. Environmental Protection Agency (EPA). Over the years, the role and influence of this model have expanded considerably. Its original purpose was to support the development of mobile source emission inventories. It is now used to determine compliance with I/M program requirements, support conformity determinations, and estimate the benefits of changes in selected fuel factors such as oxygenate content and volatility. Its outputs were also used to develop some of the components of the "Complex" model that EPA uses to evaluate the emissions performance of gasoline under the reformulated gasoline regulation.

The American Petroleum Institute (API) contracted with Sierra Research, Inc. (Sierra) to prepare an evaluation of the MOBILE model. The original scope of that effort was to assess how the MOBILE4.1 and MOBILE5a versions of the model account for I/M effects and how MOBILE5a modeled the impact of California low-emission vehicles. The results of that study were published in a June 1994 companion report entitled "Investigation of MOBILE5a Emission Factors: Evaluation of I/M Program and LEV Program Emission Benefits". Subsequent to the completion of that investigation, API amended the contract and issued a revised statement of work authorizing additional effort to be directed at determining how the exhaust base emission rate equations were developed for MOBILE5a. This report summarizes the findings from that evaluation.

With the release of MOBILE5a, EPA made a significant departure from the historical process of vehicle emissions data collection and analysis. In previous versions of the model,

the exhaust base emission rate equations (i.e., "emission factors") were developed from test data collected according to the Federal Test Procedure (FTP). The FTP is conducted in a controlled laboratory environment with a standardized test fuel (i.e., Indolene). However, for MOBILE5a, the base emission rate equations for 1981 and later model year vehicles were developed from data that were collected at an I/M lane in Hammond, IN, over the IM240 test cycle. Since most of the exhaust relations (e.g., temperature corrections, speed corrections, etc.) contained in MOBILE5a are based on the FTP, it was necessary for EPA to convert the IM240 data to an FTP basis prior to developing the base emission rate equations. API requested an evaluation of the IM240-to-FTP conversion process because the available documentation of this procedure is limited and because MOBILE5a plays an important role in many regulatory and policy decisions. In addition to assessing the procedure by which the IM240 data were converted to an FTP basis, this study also investigated how the converted data were then utilized to derive inputs to the emission factors preprocessor model, TECH5, which computes the base emission rate equations for MOBILE5a. Finally, an evaluation of IM240 data collected in Mesa, AZ, was performed to serve as a cross-check of the IM240-to-FTP conversion procedure.

After a review of the analytical procedure used by EPA and its contractor, it became clear that questionable statistical techniques were employed in the development and application of the IM240-to-FTP correlation equations for MOBILE5a. First, the development of correlations between the FTP and the IM240 involved a data replacement procedure that resulted in the IM240 data being regressed against itself for one-third of the hydrocarbon test scores for a key technology group, resulting in misleading R^2 values. Second, the application of regression residuals to the correlation equations (which is not appropriate for this type of analysis) inflated average FTP values by approximately 20%.

The evaluation of EPA's derivation of base emission rate equations from the "FTP-equivalent" IM240 data indicated that the data were treated in a subjective and inconsistent manner. Individual emitter category emission rates (an input to TECH5) were generated in

a completely different fashion than emitter category growth rates (also an input to TECH5), analysis methods differed by emitter category, and modifications to the methods to account for technology differences were not applied consistently when the emission and growth rates were estimated.

This study required that Sierra obtain the data used by EPA and its contractors and replicate each of the procedures involved in the IM240-to-FTP conversion process and the development of base emission rates from the converted data. Completing these tasks reinforced the findings of the earlier analysis about the lack of documentation for many of the key inputs for both MOBILE and the "TECH" models. Numerous phone calls to EPA staff were required to understand the motivations behind methodologies employed, why data points were deleted or modified, etc. While EPA staff were generally helpful, there were significant time lags between questions and responses as staff members had to review their work or try to remember what they did. It is clear that large portions of MOBILE5a and its supporting model, TECH5, are undocumented.

The summary below highlights the major findings of the study.

IM240-TO-FTP CORRELATIONS

The IM240-to-FTP conversion was a multi-step procedure consisted of (1) adjusting the Hammond "lane" IM240 scores to account for differences in fuel and temperature between individual vehicle IM240 and FTP tests, (2) developing correlation equations relating the IM240 and the FTP, and (3) applying those correlations to all of the IM240 data collected at the Hammond lane. Main points of the IM240-to-FTP conversion process developed by EPA are summarized below.

Fuel and Temperature Adjustments

The fuel and temperature adjustments were developed from a subset of vehicles tested in the Hammond program. Those vehicles received an IM240 test at the lane on tank fuel, and

then were brought to a local laboratory for additional testing. One of the tests performed at the laboratory was an IM240 that was conducted with Indolene over the FTP temperature range. This testing provided a basis for the fuel and temperature adjustment factors that were applied to all lane IM240 scores prior to performing the IM240-to-FTP conversion. In developing the adjustment factors, data were stratified by "season" (i.e., March and April; May and June; July through September; and October through February) and by lane IM240 emission level.

Significant findings from the evaluation of the fuel and temperature adjustments include the following.

- Although 380 vehicles were in the original data base, test scores from 332 vehicles were used to develop the fuel and temperature adjustment factors. EPA was unable to identify the vehicles and reasons for deleting test points in this analysis (i.e., the final data set used for the analysis was not documented).
- A regression analysis performed for this study did not indicate a better statistical fit when the data were stratified by season. Although seasonal adjustments are logical from an engineering perspective (i.e., fuel RVP and ambient temperature at the lane should be similar for each season), the value of applying those adjustments is questionable and the results do not justify their use.
- The fuel and temperature adjustments were developed by taking the ratio of the mean of the laboratory IM240 scores and the mean of the lane IM240 scores (by season and emitter class); the basis for this approach is not documented. Because the adjustments were ultimately applied to individual data points, taking the mean of the individual vehicle lane/lab ratios (by season and emitter class) would be more appropriate.
- As a sensitivity analysis, alternative fuel and temperature adjustments were developed in this study. The results from that analysis indicated very little change from the factors developed for MOBILE5a.

The effect of the seasonal fuel and temperature adjustments on the hydrocarbon (HC) IM240 scores is summarized in Figure ES-1 for 1983 and later multipoint fuel-injected, closed-loop

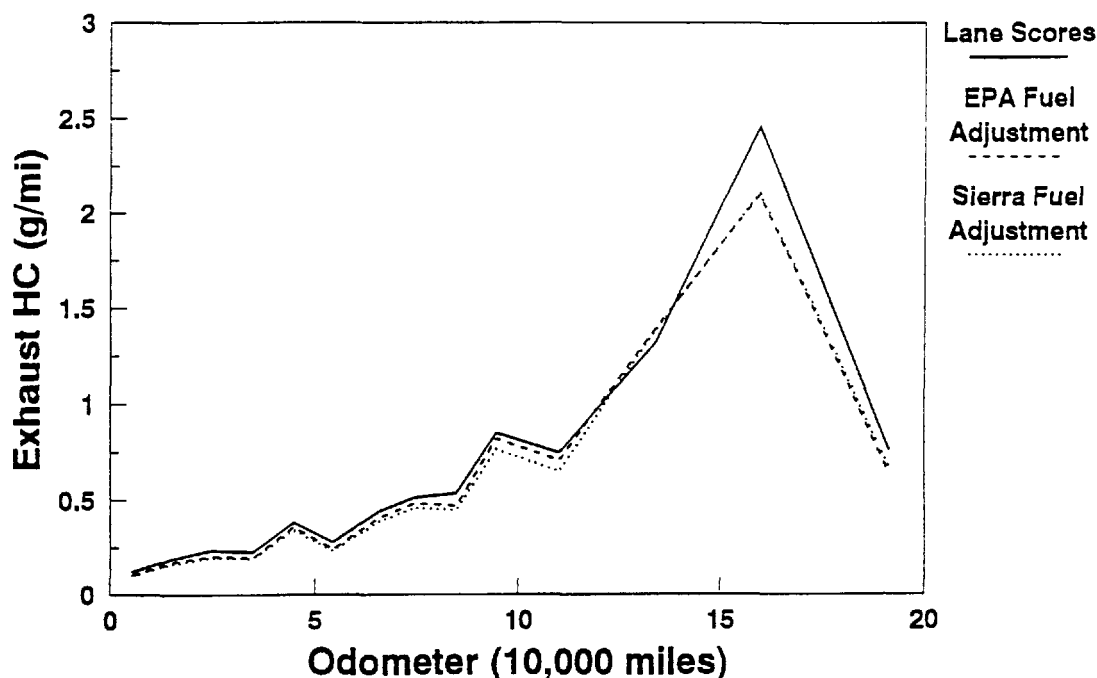


Figure ES-1. Effect of Seasonal Fuel and Temperature Adjustments on 1983+ MPFI/CL IM240 HC Emission Rates, EPA vs. Sierra Adjustments

(MPFI/CL) vehicles. As seen, the application of fuel and temperature adjustments had only a moderate impact on the lane IM240 scores, and very little difference is observed when comparing the results of EPA's analysis and the alternative analysis prepared for this study. Given the small effect and the additional variability incorporated by applying these adjustments, it may have been more appropriate to forego the fuel and temperature adjustments and simply develop the IM240-to-FTP correlations directly from the lane IM240 scores.

Development and Application of Correlation Equations

The IM240-to-FTP correlations were developed by regressing FTP data (developed in the lab on Indolene) against IM240 data that were also collected in the lab on Indolene. (Hence the need for the fuel and temperature adjustments described above, which are used to get the

lane IM240 scores on a lab/Indolene basis.) Two data bases were used for this analysis: (1) a subset of the Hammond vehicles that had lab/Indolene FTP scores and lab/Indolene IM240 scores, and (2) a group of vehicles tested at EPA's Ann Arbor lab that had both lab/Indolene FTP and lab/Indolene IM240 scores. Prior to developing the correlations, the data were stratified according to model year group and technology type.

For HC and carbon monoxide (CO), the correlations were performed in log space, while the oxides of nitrogen (NOx) correlations were based on a linear model. Because the IM240 test procedure does not include a cold start (i.e., the test is conducted with the vehicle in a warm stabilized condition), the correlations developed for HC and CO included a "cold start offset" term; since the cold start mode has less influence on NOx emissions, an offset was not included in the NOx correlations. The HC and CO correlations were developed according to the following equation:

$$\text{Log}_{10}(\text{FTP} - X) = b + m * \text{Log}_{10}(\text{IM240})$$

where X represents the cold start offset, and $\text{Log}_{10}(\text{FTP} - X)$ was regressed against $\text{Log}_{10}(\text{IM240})$ to generate a slope (m) and an intercept (b).^{*} The value of X was determined by taking the mean of the cold start offset (i.e., FTP Bag 1 - FTP Bag 3) for "normal" emitters in the correlation sample.

When the correlation equations were applied to the fuel- and temperature-adjusted IM240 data, EPA added randomized residuals to the equations prior to taking the anti-log, i.e.,

$$\text{Log}_{10}(\text{FTP} - X) = b + m * \text{Log}_{10}(\text{IM240}) + \text{res}$$

^{*} EPA has used "ZML" to represent the intercept term and "DET" to represent the slope in the limited documentation available on the IM240-to-FTP correlations. However, that notation may lead to some confusion, since ZML and DET are generally used to represent the base emission rate zero-mile level and deterioration rate, respectively. Thus, the more generic "b" and "m" are used to represent the intercept and slope in this report.

where "res" represents regression residuals from the correlation sample. According to EPA staff, the reason for applying residuals is because emission data generally demonstrate considerable scatter, and adding residuals back into the correlation equations re-introduces that scatter.

Several items are worth noting with respect to the method used to develop and apply the IM240-to-FTP correlations for MOBILE5a:

- For vehicles with FTP scores less than X, the value of (FTP - X) was negative. Because it is not possible to take the logarithm of a negative number, the IM240 score was used in place of (FTP - X) when (FTP - X) was less than 0.01 grams/mile (g/mi) for HC and less than 0.1 g/mi for CO. When this occurred, the IM240 score was essentially being regressed against itself. Although the contractor memo outlining this procedure indicated that "three or four cars were affected in most technology groups," this actually occurred for 82 of the 266 1983+ MPFI/CL vehicles in the HC correlation. Clearly, when one-third of a sample is regressed against itself, the correlation is likely to improve, and the R^2 values reported by EPA to support the IM240-to-FTP correlations are extremely misleading. Although this example was the most extreme case of data replacement, it also occurred for CO and other technology groups.
- Including randomized residuals in applying the HC correlation equations resulted in a 20% increase in average emissions. This results from the differential impact of the log transformation approach on negative versus positive residuals. Thus, although the residuals may have been applied randomly, the net effect was to increase FTP values. This is shown graphically in Figure ES-2.
- An alternative correlation methodology was developed for this study. That analysis resulted in FTP values similar to those that would have been obtained from EPA's correlations if residuals had not been applied.

Clearly, some questionable statistical techniques were employed in the development and application of the IM240-to-FTP correlation equations for MOBILE5a. First, replacement of (FTP - X) values with IM240 scores resulted in misleading R^2 values. Second, application

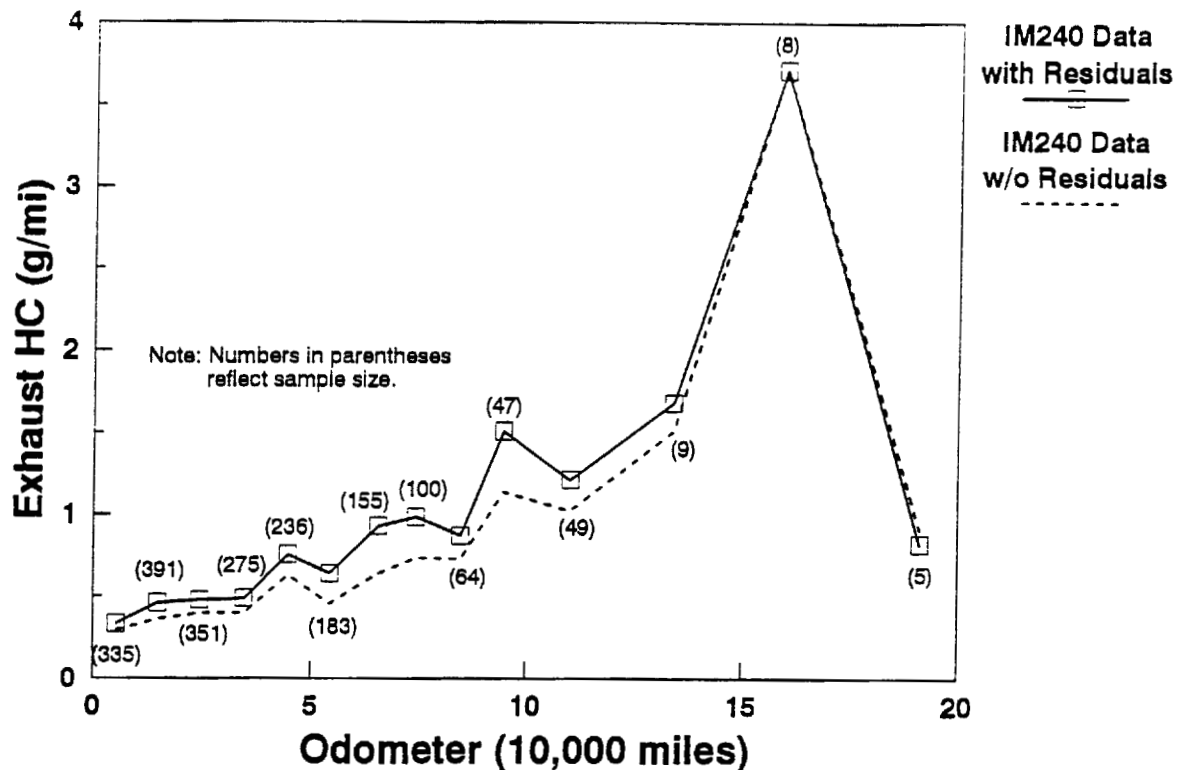


Figure ES-2. Effect of Adding Residuals to IM240-Converted, FTP-Based 1983+ MPFI/CL Exhaust HC Emission Rates

of residuals, which is not appropriate for this type of analysis, inflated average FTP values by approximately 20%.

DERIVATION OF EMISSION CONTROL SYSTEM DETERIORATION RATES

Following the IM240-to-FTP conversion procedure, the resulting "FTP-equivalent" data were used to develop the non-I/M exhaust base emission rate equations for MOBILE5a. A comparison of the Hammond data for 1983+ MPFI/CL vehicles and the 1992 HC base emission rate developed for MOBILE5a is presented in Figure ES-3. (1983+ MPFI/CL vehicles were chosen for the comparison because that model year group/technology comprises 81.5% of the 1992 model year fleet.) As seen in the figure, close agreement between the data and the MOBILE5a predictions is observed up to 50,000 miles, but there is

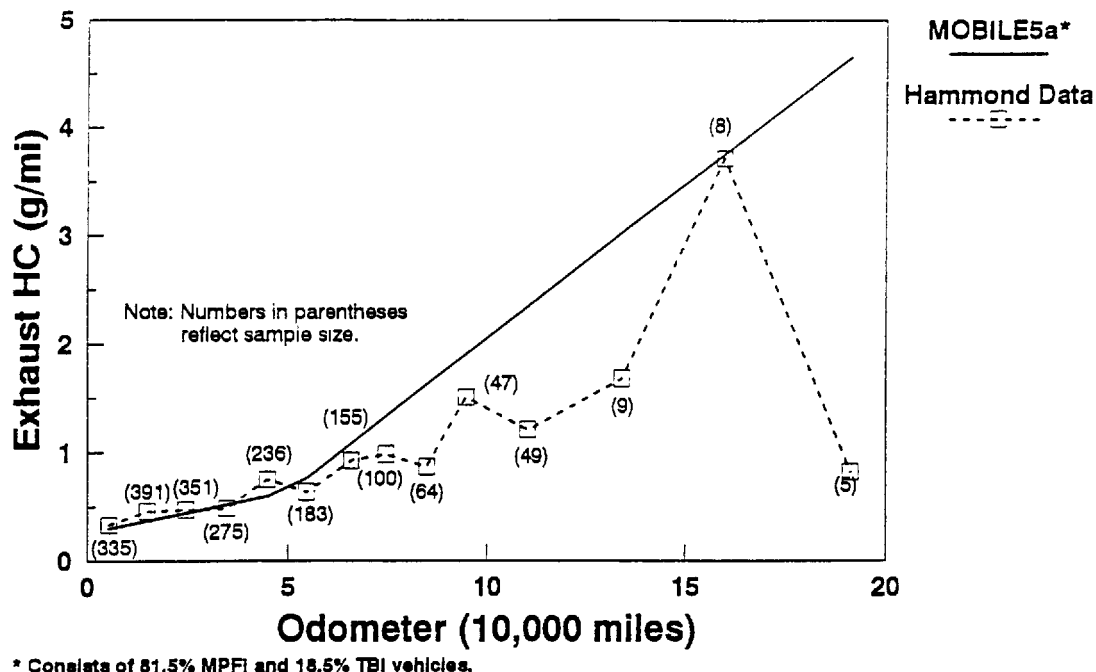


Figure ES-3. Comparison of MOBILE5a 1992 Model Year HC Base Emission Rate Equation to the Hammond 1983+ MPFI/CL Data

a significant over-prediction of emissions by MOBILE5a at higher mileages (similar trends are also observed for CO and NO_x and for the throttle-body fuel-injection technology). The results depicted in Figure ES-3 led to a more thorough evaluation of the procedure used by EPA to develop base emission rate equations for MOBILE5a. A summary of that evaluation is described below.*

* Note that the evaluation performed for this study was focused at the development of HC and CO base emission rate equations. Resource constraints did not allow for a thorough assessment of EPA's development of NO_x base emission rate equations for MOBILE5a.

MOBILE5a Methodology

The base emission rate equations (i.e., zero-mile levels and deterioration rates) developed for MOBILE5a were generated from the emission factors pre-processor model, TECH5. The function of TECH5 is detailed in Section 3 of this report, but a brief review is useful to understand some of the findings presented below. TECH5 uses a "regime" approach to develop emission rates (as a function of vehicle mileage) by model year group (i.e., 1981-1982 and 1983+*) and technology (i.e., MPFI/CL, closed-loop throttle-body injection (TBI/CL), closed-loop carbureted (CARB/CL), and open-loop). Four emitter groups (or regimes) are defined in TECH5: normals, highs, very highs, and supers. Emission rates (by model year group/technology) are determined by multiplying the emission rate of each emitter category by the fraction of each emitter category making up the fleet at mileage intervals corresponding to vehicle age. Thus, two primary inputs to the TECH5 model are the emitter category emission rates and the emitter category population growth rates. Once the model year group/technology emission rates are developed, model year specific emission factors (which are input to MOBILE5a) are generated by weighting the emission rates of each group by its expected fraction of the fleet.

In developing inputs for TECH5, EPA attempted to incorporate both vehicle age and mileage into the analysis. The reasoning behind this approach is that EPA felt uncomfortable with basing emission control system deterioration rates solely on mileage accumulation (which was generally done in previous emission factors development). EPA's rationale in support of this approach is that many vehicles accumulate mileage quickly, and the deterioration rates from those vehicles are likely to be lower than if mileage was accumulated at a more standard rate. Thus, to account for vehicle age as well as mileage accumulation, 1981-1982 data were combined with 1983+ data. However, as described below, the data were treated

* It is generally recognized that the early 1980s model years have different emissions characteristics than later model years because they represent the first widescale introduction of closed-loop, three-way catalyst technology. For example, this distinction is made by the California Air Resources Board in its development of emission factors for light-duty vehicles.

inconsistently for the development of emitter category emission rates and population growth rate:

- For the development of emission rates by emitter category, EPA performed an analysis with a covariance procedure that used data from 1981+ model years to establish a deterioration rate (as a function of vehicle mileage) for 1981+ model years, while the zero-mile level for each model year group (i.e., 1981-1982 and 1983+) was allowed to vary. It is interesting to note that this approach resulted in higher HC and CO emissions being predicted by TECH5 for 1983+ MPFI/CL vehicles than 1981-1982 MPFI/CL vehicles. This is illustrated for HC in Figure ES-4, which implies that from an emissions perspective, auto manufacturers would have been better off maintaining the designs introduced in 1981.

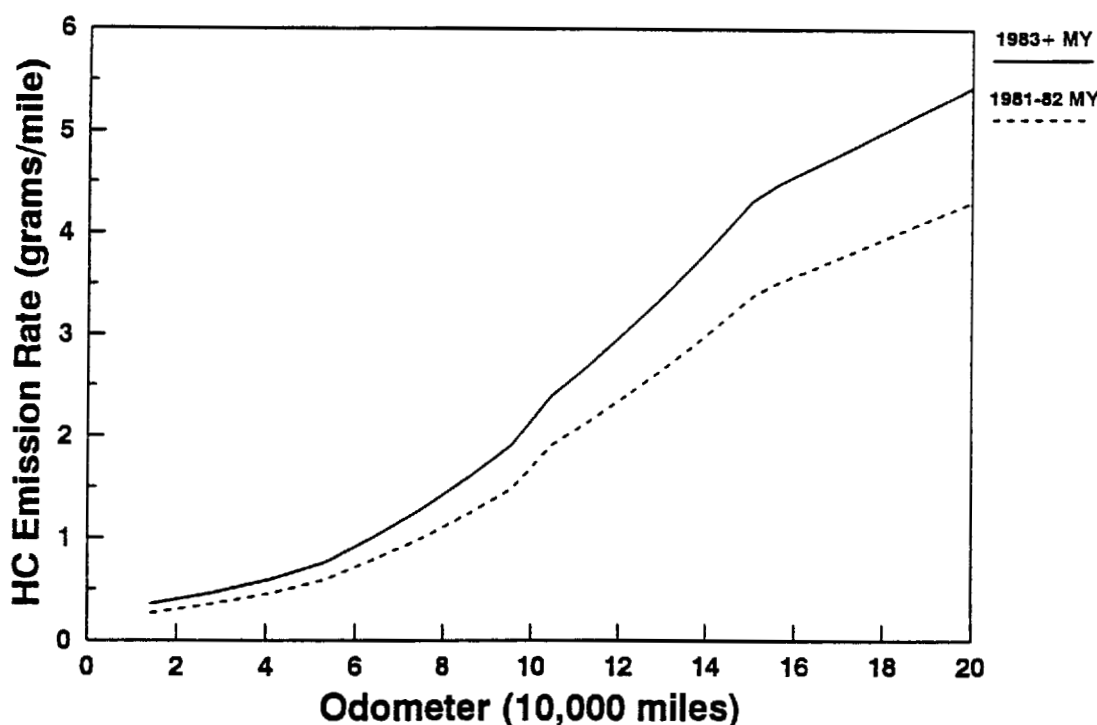


Figure ES-4. Comparison of TECH5 HC Emission Estimates for 1981-1982 and 1983+ Model Year MPFI/CL Vehicles

- Emitter category population growth rates were also developed by combining data from 1981+ model years. However, the procedure used was much different than that outlined above for the emitter category emission rates. Data from 1987 and later model years were used to establish the growth rates for vehicle mileage below 50,000. For mileage above 50,000, data from the 1981-1986 model years were used for the TBI/CL, CARB/CL, and open-loop technology groups; 1984-1986 model years were used for the MPFI/CL vehicles. EPA used the 1984-1986 model years for MPFI/CL vehicles because earlier model years represented "prototype" technology for this class of vehicles. It is unclear why the same reasoning was not also applied to the other closed-loop technologies or for the development of the emission rates for MPFI/CL vehicles.

In addition to inconsistent treatment of data in TECH5, the methodology used by EPA to develop emitter category growth rates overstates the number of high-emitting vehicles in the fleet relative to the data. This is shown in Figure ES-5, which compares the [very high + super] emitter fractions as a function of vehicle odometer developed for TECH5 versus the Hammond data for MPFI/CL vehicles. The "87+ (<50K); 84-86 (>50K)" line represents the data that were used for TECH5 (i.e., 1987 and later model years were analyzed for mileage below 50,000 and 1984-1986 model years were analyzed for mileage above 50,000); the "87+ (<50K); 83-86 (>50K)" line is the same as above except that the model year coverage was extended to include the 1983 model year for mileage above 50,000; and the "1983+" line represents data from all 1983 and later model years. (The 1983 model year was considered in this analysis because that model year historically has been used as a breakpoint between "developmental" and standard technology.) It is clear that TECH5 is over-estimating the number of very highs and supers in the fleet beyond 75,000 miles.

A final point related to EPA's development of emitter category growth rates for MOBILE5a is that a different method was used for super emitters. For that category, the data were stratified into three model year groups: 1987+ for mileage below 50,000; 1983-1986 for mileage from 50,000 to 100,000; and 1981-1982 for mileage above 100,000. Further, because of the limited number of super emitters in the fleet, all technologies were combined.

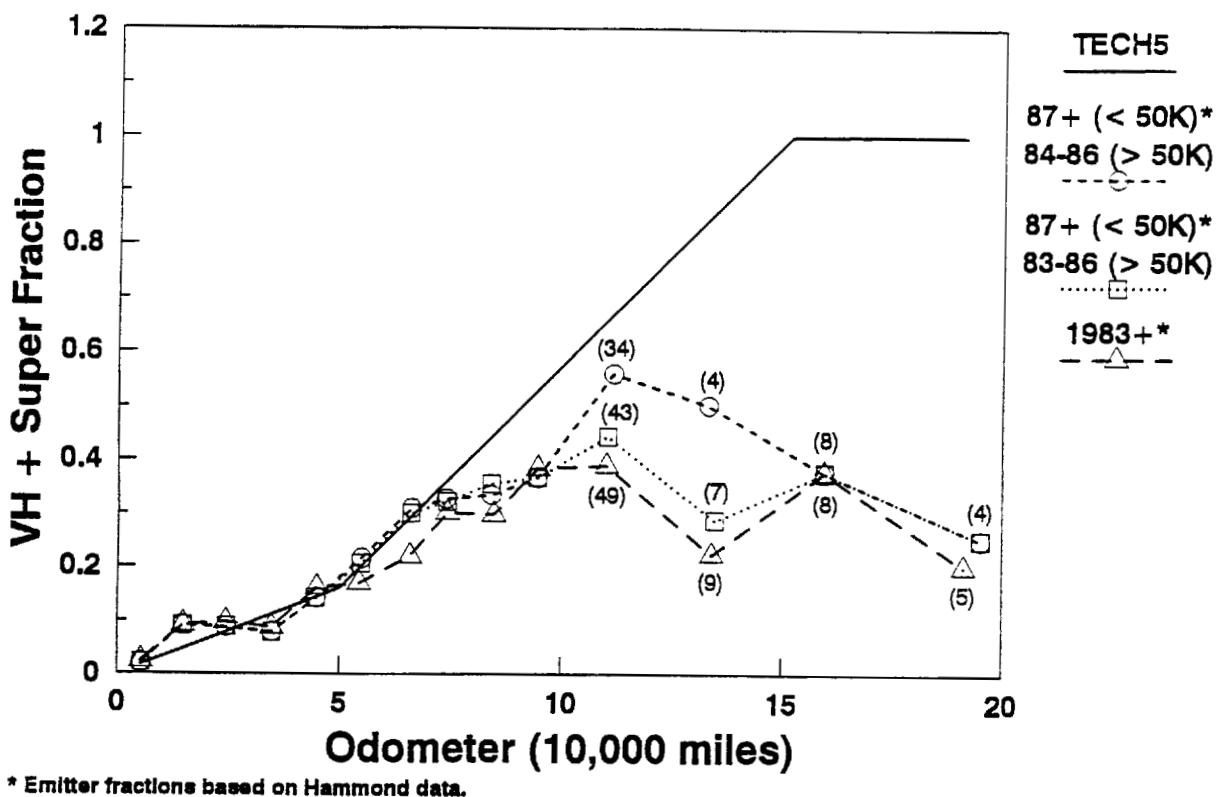


Figure ES-5. Comparison of [Very High + Super] Emitter Fractions - TECH5 vs. Hammond Data for MPFI/CL Vehicles

This approach resulted in a step function increase in the number of super emitters at 100,000 miles from 1.7% to 3.7%.

Based on a review of the procedures that EPA used to develop the emitter category emission rates and growth rates for MOBILE5a, it is apparent that the data were analyzed in a subjective and inconsistent manner. Emission rates were generated in a completely different fashion than emitter growth rates, analysis methods differed by emitter category, and modifications to the methods to account for technology differences were not applied consistently when the emission rates and growth rates were estimated.

Alternative Methodology

Because a number of assumptions used by EPA to develop the base emission rate equations for MOBILE5a appear somewhat questionable, an alternative analysis was performed in which HC and CO base emission rates were developed for 1983 and later MPFI/CL vehicles. Although not a detailed analysis, the evaluation provides an alternative to the MOBILE5a approach. The alternative method generally follows that developed by EPA and demonstrates that with just a few seemingly minor changes (i.e., basing the emitter category emission rates on 1983+ model years, and developing the emitter category growth rates with a regression technique that more appropriately reflected the influence of high mileage vehicles), the resulting base emission rates are significantly impacted. This is illustrated in Figure ES-6, which shows the HC emission rates predicted by TECH5 and the alternative analysis. As seen, the emission rates calculated by the two methods deviate substantially at mileages above 50,000. The 1983+ MPFI/CL vehicle mean emission rates by vehicle mileage calculated from the Hammond data are also shown in the figure. These show much better agreement with the alternative analysis. Clearly, the base emission rates developed for MOBILE5a represent a worst-case scenario for emission control system deterioration.

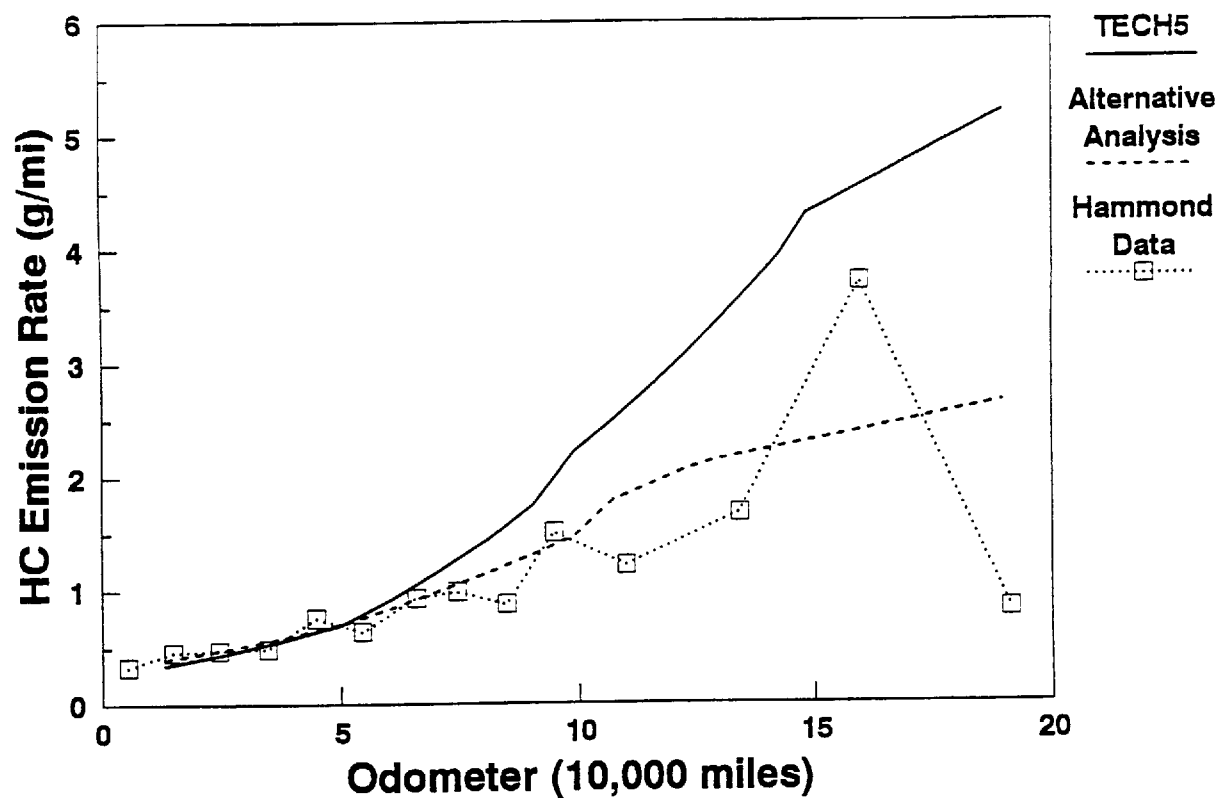


Figure ES-6. Comparison of MPFI/CL Exhaust Emission Rates - TECH5 vs. Alternative Analysis Methodology

Section 1

INTRODUCTION

BACKGROUND

EPA's emission factors model, MOBILE5a, is being used increasingly as a regulatory tool for evaluating the impacts of policies and motor vehicle control programs. For example, MOBILE is used to evaluate compliance with enhanced I/M regulations and for conformity determinations. Further, output from the model was used in the development of the Complex model which will be used by refiners to determine if particular fuel formulations comply with the reformulated gasoline performance standards. Because of EPA's reliance upon the MOBILE series of models, the American Petroleum Institute (API) contracted with Sierra Research, Inc. (Sierra) to perform an evaluation of MOBILE5a, with particular emphasis on how inspection and maintenance (I/M) programs are modeled. Subsequent to the completion of that effort^{1*}, API amended the contract and issued a revised statement of work authorizing the following work:

- critique of the fuel and temperature adjustments developed by EPA to correct data collected using the IM240 emissions test procedure for variations in fuel and temperature relative to those specified for the Federal Test Procedure (FTP);
- explanation and critique of the correlations between emissions based on the IM240 test procedure and emissions measured on the FTP that were developed by EPA;
- evaluation and critique of the methodology used by EPA to develop the emission control system deterioration rates for MOBILE5a; and
- assessment of the degree to which MOBILE5a predictions overestimate or underestimate actual in-use data and recommendations for alternative methodologies to estimate in-use exhaust emission rates.

* Superscripts denote references listed at the end of this report.

This report documents the additional analyses noted above and summarizes the results that were presented in the technical memoranda submitted to API during the course of this study.

ORGANIZATION OF THE REPORT

Immediately following this introduction, Section 2 provides a discussion of the IM240-to-FTP correlation. This includes an analysis of the fuel and temperature adjustments employed by EPA to account for variations between the lane conditions and the laboratory FTP tests, an evaluation of the correlation procedure used by EPA, and a recommended alternative to that approach. Section 3 compares the exhaust emission and deterioration rates from MOBILE5a to the data that were used to develop those rates. In addition, IM240 data from EPA's I/M test program in Mesa, AZ, are compared to those collected in Hammond, IN. New correlation equations relating the IM240 results to the FTP for the Arizona data are also presented in Section 3, and the resulting FTP values are compared to the Hammond, IN, data.

Section 2

IM240-TO-FTP CORRELATIONS

BACKGROUND

With the development of MOBILE5a, EPA made a significant departure from the historical method of using its Emission Factors data base to develop exhaust base emission rate equations (i.e., the non-I/M emission rates input to the model). In previous versions of MOBILE, data used for the base emission rates were collected through a process often referred to as "surveillance" testing, where vehicle owners are randomly contacted (usually by letter) and asked to give up their cars for a week of testing. Over the years, EPA has become concerned that the vehicles they receive for surveillance testing are not representative of the in-use fleet, particularly with respect to the fraction of poorly maintained, high-emitting vehicles. This has been primarily attributed to a sample selection bias, e.g., if vehicle owners know that their car has been poorly maintained or has been tampered, they will not voluntarily submit it for emissions testing.

To overcome sample bias concerns, EPA used IM240 emissions data collected during the initial two years of an inspection and maintenance (I/M) program in Hammond, IN, to develop the exhaust base emission rate equations for MOBILE5a.* It was felt that this approach would provide an unbiased sample because vehicle owners had to participate in the program. However, because all of the exhaust emission relations (e.g., temperature corrections, speed corrections, etc.) contained in MOBILE are based on FTP testing with certification fuel (Indolene), a means to convert the IM240 data collected at the lane on tank fuel to an FTP/Indolene basis was needed. This conversion process was a multi-step procedure, consisting of the steps listed below.

* Vehicles were tested in their first I/M "cycle" and therefore the data represent emissions from a non-I/M fleet.