

Technical Report

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Recommended Specifications
for I/M Type Analysis Systems
Used to Pass or Fail Vehicles

by

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NOTICE

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Standards Development and Support Branch
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I. Introduction

It is doubtful that anyone would disagree with the statement that automobiles (and trucks) are part of the air pollution problem in the country. In the past, Congress has specified, through the Clean Air Act and various amendments to the Act that new cars must meet certain emission performance standards prior to introduction of those vehicles into commerce. These performance standards have always been checked under closely controlled laboratory conditions with sophisticated equipment. The required accuracy and performance of this equipment has always been specified within the context of the laboratory situation.

Recently, there has been more emphasis on checking the performance of in-use vehicles. This is occurring through the implementation of state inspection and maintenance programs as well as the forthcoming emission repair warranty regulations (207(b)) authorized by the Clean Air Act. Further, the new 1984 Heavy-Duty (HD) Truck Federal Regulations specify an idle standard as well as a driving cycle standard. Both the 207(b) warranty emissions test for hydrocarbons (HC) and carbon monoxide (CO), and the Heavy-Duty idle emission test for CO are expected to be conducted on in-use vehicles with data generated mostly by state-run I/M programs.

The economic implications about the accuracy of the data from these I/M programs is of concern. The 207(b) emission repair warranty provisions and the Heavy-Duty idle test data may be used to determine who pays for emission repair maintenance on failed vehicles - the individual consumer, or the vehicle manufacturer. Additionally, the Heavy-Duty idle data may serve as a basis for recall action since failure of the HD idle test is the same as failure of any other Federal emission standard. For those failed vehicles not covered by 207(b) or HD standards, it is possible that the amount of repair maintenance performed will have some relationship to the degree of failure - (i.e. only those repairs that are needed to bring the vehicle into compliance will be performed). If this minimal maintenance scenario comes to pass, then the accuracy and variability of the measurements system will play an important role in the dollar amount of the maintenance sold.

Because the I/M emission check (as well as 207(b) and HD idle) is less sophisticated than the Federal driving cycle compliance checks, it might be expected that the requirements necessary to achieve acceptable accuracy and variability with I/M analysis systems would be less sophisticated than those used in the laboratory. To some extent this statement is true, but it is not totally true. Consider for instance, the laboratory analyzers are operated by trained and skilled technicians. These personnel can spot problems in analysis sometimes even before they happen. Complete engineering departments are constantly checking the laboratory emission values against past values and design goals. Under these conditions, errors in measurement can be detected and eliminated. In a sense, the human mind is adding considerable sophistication to the equipment. While not saying that I/M analyzer operators do not have the mental capacity to comprehend the variety of emission analysis problems, it can be said that the typical I/M

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analyzer operator generally has not had the training or experience that the laboratory technicians and engineers have had. This training problem is compounded even further in decentralized I/M programs. Mechanics in a repair shop just cannot be required to understand the gamut of measurement problems. Even though mechanics must by necessity become familiar with the I/M equipment, there is an economic incentive to direct their technical skill toward repairing vehicles.

Another significant difference between the laboratory analyzer, and the I/M type analyzer is the environmental operating conditions. Laboratory analyzers are never operated in hostile environments. They are generally operated in heated and air conditioned buildings with humidity control. I/M programs, on the other hand, expect analyzers to operate from California to Maine, from Texas to Minnesota, and from summer to winter in a variety of enclosures ranging from rain and wind shelters to permanent structures. This variety of hostile environmental conditions places a much greater burden on an I/M analyzer than a laboratory analyzer ever encounters.

The lack of measurement savvy by the I/M analyzer operator, and the significant variation in environmental operating conditions are just two among many reasons that would suggest an I/M analyzer should be more sophisticated than a laboratory instrument. However, the goals of the I/M program, and the cost of the I/M analyzer to the user must be kept in mind.

With these ideals in mind, the important parameters in the emission measurement process were evaluated. A balance among capability, cost, complexity, and operator skill has hopefully been achieved in the recommended I/M analyzer specifications presented in this document.

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II. Discussion of Specifications

A. Methodology

To those familiar with I/M analyzer specifications publicized by other organizations (State of California Bureau of Auto Repair, Equipment and Tool Institute, etc.), the specifications included in this document will appear somewhat different even though they parallel the 1980 California specifications in some areas. To the user not fully acclimated to the emission measurement process, the publication of yet another specification that is different from previous publications could cause confusion about which document should be used. To avoid confusion about the source of the specifications in this document, a brief description of the procedure used to generate the specifications is presented, followed by a description of the significant differences between this document and other specifications.

Prior to assigning any values to any measurement parameters (accuracy, drift, etc), a review of all of the parameters affecting the I/M measurement process was made. A model of error propagation was then formed to show the interaction of the various parameters. Approximate ranges of errors were assigned to each parameter based on test data, experience, and/or engineering judgment. Previously published specifications also provided many initial values. Using classical statistical approaches, this model could then evaluate the impact of each specification on the accuracy of the final emission value.

The important aspect of the model is that it focuses on the real issue involved in I/M measurements. That issue is: What is the acceptable accuracy of the I/M measurement process? After the answer to this question is known, the parameter specifications can be adjusted to insure the desired result.

There is a wide variety of opinion about what is accurate enough. A preliminary evaluation of I/M analyzers with the model indicate the error in current I/M systems could be on the order of + 25 percent (50 percent range) or worse. EPA laboratory tests have already shown a 25-30 percent variation between analyzers, even though the analyzers were set up and operated by highly skilled technicians under favorable environmental conditions.

The staff at the EPA laboratory in Ann Arbor feels that the real variability in the field among I/M analysis systems is unknown at the current time. The staff also feels that the preliminary data of 25 to 50 percent variability is too large to meet I/M, 207(b), and HD goals while maintaining consumer acceptance of the impartiality and fairness of the I/M program.

B. Comparison to Other Specifications

As stated earlier, this specification roughly parallels the technical portions of the 1980 State of California specifications. No attempt is made to recommend accrediting procedures for analyzers (other than a brief discussion in Chapter III Section A). However, there are differences in content as well as differences in techniques for specifying the same or similar parameters between this document and the 1980 California specifications.

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These differences are the result of applying the methodology in addition to the conceptualization of the actual step by step procedures that could be used to verify compliance to the recommended specifications. Some specifications in other documents, although historically specified, almost defy any type of verification measurements. Foremost, it was considered that any specification that was recommended should be capable of convenient measurements (although possibly repetitious and dull) by any emissions laboratory with typical test equipment (i.e. digital voltmeters, chart recorders, analytical gases, etc.).

The concept of parameter verification lead to the inclusion of step by step procedures that can be used for verification by anyone. No other specification document provides such procedures. While some may claim that such procedures are not necessary or that they reduce flexibility, experience in emission analysis has shown that there are many ways to interpret even what appears to be straight forward specifications with strikingly divergent results. The recommended verification procedures, therefore, provide a framework for interpreting the specifications in a consistent manner.

Another area of conceptual differences in the verification process is the use of statistical techniques on the verification data. The use of the statistical techniques are necessary to insure that the verification data actually represents the true performance of the analyzer under test. The use and extent of statistics is not overly done, and the tendency is to use them in the more important areas (e.g. accuracy) to reduce the measurement burden.

A final area of conceptual difference between this specification and others is the inclusion of specific quality control features into the basic analysis system specifications. Generally, these features are classified under the category of "fail-safe" sub-systems. In addition, many of the other analysis system requirements contained in this document are specified in a manner that reinforces the fail-safe concept. The degree of sophistication of the built-in quality control features is determined by the end use of the system. Analyzers intended for use in decentralized systems generally require more sophisticated features (than centralized systems), due to the more hostile environment and less sophisticated operators.

The highly desirable aspect of these built-in features is that they tend to improve the overall credibility of the I/M program. The improved credibility is obtained because the analysis system requires the operator to comply with good measurement practices as well as preventing the operator from committing improper practices. Both of these actions improve the overall accuracy of the I/M results.

A hidden advantage that makes these fail-safe features even more desirable is that the forced improvement of operator practices relieves some of the burden on state audit teams. Because of these features, it may be possible to perform less frequent audits, and still obtain better quality I/M results than with more frequent audits of systems without the built-in checks.

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Traversing from conceptual differences to more specific differences, the following items represent the more significant areas of difference.

1. Analyzer Calibration Curve: The analyzer calibration curve requirements are more statistically sound than other published specifications. Since the calibration curve sets the basic accuracy of the analyzer, it is important to measure the true performance when attempting to verify compliance to the specifications. Additionally these recommendations require better accuracy than other specifications at the projected 207(b) emission warranty levels of 220 ppmh HC and 1.2% CO, and the Heavy-Duty idle standard of 0.47% CO.
2. Analyzer Fail-Safe Systems: These recommended specifications include requirements for certain lock-out features in order to prevent improper operation of the analyzer. These fail-safe systems are segregated into systems applicable to all analyzers, and those systems addressing the unique problems associated with decentralized programs. The decentralized fail-safe systems will most likely require an on-board microprocessor.
3. Analytical Gases: All analytical gases must be traceable to National Bureau of Standards, Standard Reference Materials (SRMs), or an EPA Office of Mobile Source's approved standard. A procedure is referenced for determining traceability.
4. Analyzer Measurements: A policy decision was made that all I/M measurements would be considered on a "dry-basis". This decision is consistent with the 1984 Federal H.D. Truck idle standard, the projected 207(b) requirements, and the effective policy of many state I/M programs (due to the act of using a refrigeration water trap). The effect of this decision would be to consider all current and future data as dry-basis data. However, the recommendation to implement a recommended specification for dry measurement hardware should be delayed until January 1986. For analyzer manufacturers who wish to implement dry measurement systems sooner, they may do so by either of the two techniques permitted - electronic compensation or physical water removal. The effect of implementing a dry-basis measurement is to remove a potential 7-10% variability in measurement.
5. Analyzer Spanning Concepts: The recommended specifications require all analyzers to be gas spanned at least once a week and electrical spanned at least once an hour. More frequent gas span checks are recommended every 4 hours. Two alternatives to the 4 hour gas span check are possible which would reduce the use of analytical gas. One allows the use of sample cell pressure and temperature compensation. The other allows analyzers with a basic accuracy significantly better than that required in these specifications to demonstrate that even considering the degradation of accuracy (due to external effects of pressure and temperature), the analyzer would still be within the recommended accuracy specifications.

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The weekly gas and hourly electrical spanning concept is consistent with projected requirements for 207(b) and the H.D. idle standard. The frequency of gas spanning is less than emissions testing experience and engineering judgment would dictate, but more frequent than other specifications which generally call for a 30 day gas span check.

6. HC Measurements: Most I/M specifications require reporting of HC as ppm hexane. Since the span gas is propane, and the analyzer responds differently to propane than hexane, a propane to hexane factor is required. Additional verification of the relation of this factor to the composition of exhaust hydrocarbons is generally required by comparing the I/M analyzer performance to the performance of a laboratory NDIR HC analyzer.

These general requirements are included in this document but with more definitive procedures for developing the factor and conducting the comparison. But, there is a more fundamental question involved in determining HC measurement criteria. The point is that the Non-dispersive Infrared (NDIR) HC analyzer is limited in its ability to measure all of the hydrocarbons in the exhaust. Current NDIR analyzers tend to measure only straight chain paraffinic hydrocarbons, although they do have some response to aromatics and aldehydes. The lack of response to these non-paraffinic compounds is the primary reason why the Federal Test procedure changed from NDIR HC measurement to FID (flame ionization detector) HC measurement 8 years ago (1972).

Even though catalyst vehicles tend to produce more paraffinic hydrocarbons than non-catalyst vehicles, chromatographic analysis of gasoline-fueled engine exhaust indicates significant quantities of the non-paraffinic hydrocarbons even in catalyst vehicles. The very same compounds that current NDIR HC analyzers have difficulty in measuring.

Two questions arise from this discussion - "Why measure HC at all if the only measurement technique is NDIR?", and "Why can't the FID be used in I/M work?". First, although the NDIR does not respond well to all hydrocarbons, a reduction in hydrocarbons that it can measure still tends to reduce the overall HC output from a vehicle. Further, in many cases reduction of paraffinic HC can also reduce other classes of hydrocarbons.

The answer to the second question is that an FID is a complex piece of laboratory equipment that requires a mixture of hydrogen and helium for fuel, and purified air for an oxidizer. At this point, the staff is somewhat skeptical about the comparability of an FID in an I/M test environment.

The response characteristics of current NDIR analyzers could, however, be improved, and new less complex techniques could be developed. In order to provide an incentive for this advancement in technology, beginning in January 1986, it is recommended that all I/M analyzers correlate to an FID HC analyzer by the procedures provided. To assist

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in the degree of correlation that is technically feasible, it is recommended during the verification of current analyzer performance that an additional test be performed that compares the I/M HC analyzer to an FID. Review of the NDIR/FID correlation data generated by the accreditation procedures is recommended prior to the implementation of the 1986 specifications.

7. System Leak Checks: Leaks in the sample system are probably the source of the largest and most frequent errors that occur in practically all emission measurement systems. This is because a leak is transformed directly into an error (i.e. a 15% leak is a 15% error). Most laboratories have rigid procedures for leak checking of analysis systems, and the process of searching for a leak can be very time consuming.

I/M analysis systems have special problems that the laboratory systems do not. First, laboratory systems are generally not moved around; I/M systems in decentralized systems are. Two, laboratories have special equipment to identify leaks, the expertise to use the equipment, and the knowledge to repair leaks inside the systems; the I/M operator generally does not have this knowledge available. Three, the laboratories generally have a strong commitment to prevent and repair leaks, and subsequently provide resources of time and money for this commitment; the independent decentralized system operator may not have this commitment, and may not be able to apply the resources to it. Four, the flow rates used in I/M systems are so small that even a 10% leak is difficult to measure without laboratory equipment, let alone a 2 or 3% leak.

Most other specifications do not provide for a routine leak check, and if they do provide for equipment, the equipment is usually a tapered tube flow meter. A tapered tube flow meter is not practical for field use. They are a high maintenance item if built into the system, and tend to stick from a combination of hydrocarbons and water. This is true even in a laboratory situation with overkill on filter changing frequency. If the flow meter is used to monitor system response time as well, the capacity of the flow meter is too large to read leaks without a 15-20% error in the reading. Primarily for these reasons a flowing span gas leak check (through the sample line) is recommended on a weekly basis.

C. Costs

In all likelihood, the additional features and specifications will increase the retail cost of the I/M analysis system. Developing incremental costs for each change in specification or additional feature may not be possible (at least not without extensive analysis) due to the degree of interaction between the features. Another aspect of cost, however, is the overall cost to the economy. More precise and fail-safe analyzers may well decrease the cost of performance checks on the analyzers conducted by state audit teams. Furthermore, more accurate and less variable systems will tend to improve

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allocation of the repair costs and the need for maintenance to those vehicles that really need it. To the consumer with the marginally passing vehicle, that could get by with less maintenance because of the better discrimination, it would also be a cost savings. Further the more accurate fail-safe analyzer makes it considerably more difficult for an unscrupulous operator to defraud a consumer, or for a well meaning operator to make an error in analysis. The prevention of fraud or accidental errors may also lead to cost savings.

When costs are considered not only the incremental cost of the analyzer to the user should be considered, but the total cost and impact on society must be considered as well. The more accurate system has the potential for a net savings to the national economy plus having positive environmental benefit.

Even though the benefits to society do exist, the cost of the better system to the system user must be reasonable. The EPA staff estimates that approximately 50,000 pass/fail I/M units will be sold to support the I/M programs. Assuming 10 analyzer manufacturers 1/ actively market this type of analyzer, and assuming equal market share, each manufacturer would be able to spread the development costs across approximately 5000 analyzers.

Development and modification costs could be as high as \$100,000 2/ on some systems. Spread across 5000 analyzers this would be \$20 per analyzer. Using a 3 to 1 mark-up which is standard industry practice 2/, would cause the retail price to increase \$60 per analyzer due solely to development costs. Since current analyzers are in the \$2500-\$3500 price range, it is apparent that development costs are not an overwhelming burden.

A list of assumed system changes is provided in Table 1 along with estimated retail cost increase. These costs represent an average estimate, some systems may require more improvement, while others may be less costly to improve. The basic group of improvements (\$690) are designed for well-trained, competent analyzer operators. These improvements are expected to reduce current measurement errors of 25 to 50 percent down to the 10 to 15 percent range. The cost for these improvements are estimated at \$17 to \$69 for each percent of improvement in measurement accuracy and variability.

For decentralized programs, accuracy and repeatability of emission measurements by less sophisticated analyzer operators can be compensated for by adding a microprocessor to the analysis system. The microprocessor allows simpler external system controls and automatic operation. The simpler operation does increase the cost of the system. However, considering the cost to the consumer, and the great potential to inhibit improper system operation and fraud, the increase in cost is reasonable and well worth it.

1/ Eight(8) Manufacturers participated in the December 20, 1979 Equipment and Tool Institute development of performance test specifications for garage type analyzers.

2/ Based on informal conversations with industry representatives.

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Table 1

<u>Item</u>	<u>Retail Cost Increase</u>
1. Basic Improvements	
a) Development	\$ 60
b) Gas Spanning System	\$150
c) Improved Detector	\$210
d) Improved Signal Conditioning	\$ 80
e) Leak Check System	\$120
f) Sample Cell Heater	\$ 70
	<u>\$690</u>
2. Decentralized System Safe Guards	
a) Microprocessor Based System	<u>700</u>
	<u>\$1390</u>
3. Options	
a) Anti-dilution	\$600
b) Printer	\$250
c) Data Collection and Storage	\$300

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III. How to Use the Specifications

A. Overview

As they are stated, the analyzer specifications listed in Chapter IV have meaning only when properly defined. The test procedures presented in Chapter V provide this context. These test procedures are intended to provide a consistent technique to verify analyzer performance. As such, these tests should only be conducted by a laboratory with sufficient facilities, and personnel experienced in emission measurement.

The test procedures should be performed in the following order.

1. Follow manufacturer's initial start-up and pre-test procedure as listed in the manufacturer's manual(s).
2. Durability Tests
 - 1st - Vibration and Shock Test
 - 2nd - Sample Line Crush Test
 - 3rd - Temperature Effect
 - 4th - Filter Check
3. Inspect Design Requirements
4. Analyzer Performance
5. Sample System Performance
6. Operating Environment Test
7. Fail-Safe Features
8. Correlation Tests

After the analyzer passes these tests, the user can be fairly confident of the in-use emission test results. However, the confidence applies only to the analyzer tested.

As stated before, this document is not an accreditation procedure. This document presents specifications and procedures for determining the performance of an individual analyzer, not a product line.

In order to develop confidence in the manufacturer's product line as a whole, additional analyzers must be tested. The number of additional analyzers tested determine the confidence level of the product line. For instance, every single laboratory analyzer used at the EPA Laboratory in Ann Arbor, and at most auto manufacturers' facilities are thoroughly checked out before they are put into service. In many instances, the analyzer is required to meet performance checks even before it is paid for. This measure is probably impractical for the large volume of I/M instruments.

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One practical solution would be to perform a selective enforcement audit (SEA) as part of the analyzer manufacturer's QA/QC procedures. EPA uses this SEA principle to evaluate emission compliance of automotive manufacturers' product lines. The SEA sample plan is a sequential sample plan, and relies on separate criteria (number of failed units) to determine a pass decision versus a fail decision. Such a sample plan can determine with a reasonable level of confidence compliance of a product from test data on less than 1 percent of the product line.

Sample selection, procedures, and test plans can be found in 40CFR 86 Subpart K and Appendix X (both in the Federal Register, January 21, 1980). An inspection plan incorporating an audit quality level (AQL) of 10% would insure with 95 percent confidence level that no more than 10 percent of the production would fail to comply with the specifications.

A sampling plan for determining product line compliance (over 400 units of production) is presented in Table 2. If the market share is 5000 I/M units per analyzer manufacturer, as suggested by the cost section, the upper limit of 50 units to be tested represents only 1 percent of production. In automotive SEA testing, the determination of pass/fail is usually determined with much less testing - normally around 12 to 17 units. Twelve I/M analysis systems tested would represent only 0.24 percent of production which should not be a burden to the manufacturer.

There are other types of production quality checks that could be used. However, the advantages of the SEA type check of a small sample size as well as a sequential nature may outweigh the possible improvements of other checks. In fact, if tighter quality is required, the SEA sampling plan could be adjusted for yearly production rates (see 40CFR 86, Appendix X, Federal Register, January 21, 1980).

Once the analysis systems are delivered, periodic performance checks of certain variables can insure proper operation. However, these periodic checks are useless if the analyzer owner cannot obtain effective repair service and parts. Further, performance checks after maintenance are necessary to insure that the analyzer was repaired properly.

The previously mentioned items are beyond the scope of this report, but it was felt that they should be mentioned in order to make the reader aware of some of the additional factors involved in obtaining reasonable measurement results.

B. Definitions and Abbreviations

The following definitions are somewhat general but are provided for reference. For many definitions, the specific test procedures used for verification of the specifications provide the final interpretation.

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Table 2

SEA Sample Plan
10% AOL Over 400 Units Produced

<u>No. of Units Tested</u>	<u>No. of Failed Units For Pass Decision</u>	<u>No. of Failed Units For Fail Decision</u>	<u>No. of Units Tested</u>	<u>No. of Failed Units For Pass Decision</u>	<u>No. of Failed Units For Fail Decision</u>
1	(1)	(2)	31	4	9
2	(1)	(2)	32	5	9
3	(1)	3	33	5	9
4	(1)	3	34	5	9
5	(1)	3	35	5	9
6	(1)	4	36	6	10
7	0	4	37	6	10
8	0	4	38	6	10
9	0	4	39	6	10
10	0	4	40	6	11
11	0	5	41	7	11
12	1	5	42	7	11
13	1	5	43	7	11
14	1	5	44	7	11
15	1	5	45	7	12
16	1	6	46	8	12
17	2	6	47	8	12
18	2	6	48	8	12
19	2	6	49	8	12
20	2	6	50	8	13
21	2	7	51	9	13
22	3	7	52	9	13
23	3	7	53	9	13
24	3	7	54	9	13
25	3	7	55	9	13
26	3	8	46	10	13
27	4	8	47	10	13
28	4	8	48	10	13
29	4	8	49	10	13
30	4	8	50	12	13

(1) Test sample passing not permitted at this stage.

(2) Test sample failure not permitted at this stage.

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1. Accreditation: Certification that an analysis system has been tested by the required procedures, and it has been verified that the analysis system complies with those specifications. Further, accreditation implies that the analyzer manufacturer follows proper procedures to insure that subsequent production systems are also in compliance.
2. Accuracy: The combination of bias and precision errors that quantify the difference between the analyzer reading and the true value (see equivalency).
3. Analytical Gases: Gases of known concentration used in the analytical process as a reference. The three basic categories are:
 - a) Calibration Gas
 - b) Span Gas
 - c) Zero Gas
4. Analysis System: A system that incorporates an analyzer(s) and sampling components for the purpose of exhaust gas analysis.
5. Analyzer: A device that has the capability to identify unknown concentrations of particular constituents in automobile or truck exhaust gases by comparison to analytical gases. Commonly used interchangeably with "instrument".
6. Calibration Gases: Analytical gases that are used to determine the accuracy of an analyzer calibration curve.
7. CO: carbon monoxide
8. CO₂: carbon dioxide
9. Detector: The portion of the analyzer that detects the constituent of interest, and provides the original signal proportional to the concentration of the constituent.
10. Drift: The amount of change with time of analyzer reading. Two components of drift are:
 - a) Zero drift - change in zero reading
 - b) Span drift - change in the difference between zero and span readings
11. Dry-Basis Concentration: The resultant concentration after the water has been removed from the sample either physically or by electronic simulation techniques.
12. Equivalency: A statistical comparison of a candidate analysis system performance versus the reference analysis system performance on exhaust gas in order to determine the acceptability of the candidate system.

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13. FID: Flame ionization detector. Most common laboratory analyzer used for determination of hydrocarbon (HC) concentrations in exhaust samples.

14. fs: Full scale of the analyzer.

15. Hang-up: Hang-up refers to the process of hydrocarbon molecules being absorbed, adsorbed, condensed, or by any other method removed from the sample flow prior to reaching the analyzer detector. It also refers to any subsequent desorption of the molecules into the sample flow when they are assumed to be absent.

16. HC: hydrocarbons

17. Instrument: see analyzer

18. Interference (electronic): Analyzer read-out errors caused by instrument response to electromagnetic sources and power supply variations. Common forms of electromagnetic sources are:

a) Radio Frequency Interference (RFI)

b) Very High Frequency Interference (VHF)

19. Interference (gases): Analyzer read-out errors caused by instrument response to non-interest gases typically occurring in vehicle exhaust.

20. L.S.: Low scale or range of the analyzer.

21. NDIR: Non-dispersive Infrared Analyzers

22. Optical Bench: The portion of the analyzer that consists of the main sample processing and detecting assembly. Generally included are the detector, optical filters, sample tubes, infra red source, and chopper systems.

23. Precision: Statistical quantification of random measurement errors.

24. ppm: parts per million by volume

25. ppm C: ppm by Carbon atom

26. ppm C3 or ppmp: ppm propane ($C_3 H_8$)

27. ppm C6 or ppmh: ppm n-hexane

28. Propane to Hexane Conversion Factor: A factor that accounts for the difference in analyzer response (relative response) between propane and n-hexane. Sometimes referred to as a "C" factor, or a propane equivalence factor (P.E.F.).

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29. Response: Analyzer indication to a gas.
30. Response Time: The reaction time between a change in concentration at the inlet to the sample system and the time the analyzer indicates a given percentage of that change.
31. Sample System: The portion of the analysis system that is responsible for delivering an unaltered sample to the analyzer.
32. Span Gases: Analytical gases that are used to adjust or return the analyzer response characteristics to those determined by the calibration gases.
33. Zero Gas: An analytical gas that is used to set the analyzer response at zero.

C. Analyzer Technology

These specifications were determined based on current I/M practice of using non-dispersive infrared (NDIR) analyzers for HC and CO measurements. Nothing in these specifications should be construed as prohibiting other analysis techniques. Potential improvements in technology should be considered on a case by case basis. To that extent, many of the concepts expressed by these specifications can be applied.

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IV. I/M Analysis System Specifications

A. Gases

1. Accuracy

- a) Calibration gases: $\begin{array}{l} + 2\% \text{ of True Value} \\ \pm 1\% \text{ of NBS Standard Reference} \\ \text{Material (SRM)} \end{array}$
- b) Span gases: $\begin{array}{l} + 3\% \text{ of True Value} \\ \pm 2\% \text{ of NBS Standard Reference Material} \end{array}$
- c) Zero gases: $\begin{array}{l} \text{less than 10 ppm C hydrocarbon} \\ \text{less than 50 ppm CO} \\ \text{less than 1000 ppm CO}_2 \end{array}$

2. Composition

- a) CO and HC (propane) with N_2 or air diluent
- b) CO_2 with N_2 or air diluent
- c) Zero gas may be bottled gas or chemically purified room air such as with an activated charcoal trap on the analysis system.
- d) Hexane to propane conversion factor checking gases shall consist of n-hexane in nitrogen, gravimetrically blended to the accuracy of SRM's. The gravimetric analysis is only valid for 1 year from the date of analysis unless historical data and correlation checks can verify stability of the gas concentration. The gravimetric analysis is void if the gas cylinder temperature drops below 20°C (68°F) for any reason including shipping and storage. The required concentrations are:

- i) 200 ppmh (± 15 ppmh)
- ii) 1800 ppmh (± 150 ppmh)

3. Recommended number of gases

- a) for new instrument check out
 - i) 7 equally spaced concentration values of calibration gases per range
 - ii) bottled zero gas
 - iii) 2 concentrations of hexane/propane conversion factor checking gas

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b) for in-use systems

i) one span gas concentration between 70-95% of fs on low range for each HC and CO analyzer

ii) room air zero gas

c) for periodic check (i.e. state inspection) of in-use systems

i) a minimum of 3 concentrations per range for each analyzer, or

ii) one concentration for each cutpoint with a concentration value within 10 percent of the cutpoint (need not exceed 5 concentration levels), and

iii) bottled zero gas

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B. Gas cylinder specifications

1. Span gases

- a) Gas cylinder should be of a 1A size.
- b) All cylinders shall meet DOT specifications for 1A cylinders.

2. Concentration Label

A semi-permanent label shall be affixed or attached by the Certifying Laboratory to each gas cylinder with the following information.

- a) Name of the Gas Blender
- b) Name of the Laboratory Analyzing the Gas Blend
- c) Cylinder I.D. number
- d) Date of Analysis
- e) Traceability to NBS or to other certified EPA Mobile Source Standard
- f) Statement of Impurities
- g) Gas Concentration

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C. Durability Criteria

1. Vibration and Shock Test : a) zero shift: 2% fs LS
(See Test Procedure) b) span shift: 2% fs LS
c) All analyzer and system performance checks must be met.

2. Sample Line (see Test Procedure)
 - a) Line crush : i) No visible failure or deterioration
ii) Meet leak check specifications
iii) Meet response time specifications

3. Sample Handling System Temperature : a) No visible failure or deterioration.
Effect (20 minutes @ 600°F sample inlet, see Test Procedure) b) Meet leak check specification.
c) Meet response time specification.
d) Meet HC hang-up specification.

4. Filter Check (see Test Procedure)
 - a) 2 hr sample time : i) Low Flow Not Activated
ii) Meet Leak Check specifications
iii) Meet Response Time Check
iv) Meet HC hang-up check

 - b) Sample until "low flow" indication : i) Time until "low flow" system activates
ii) Until the low flow system activates the system response time must be met.

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D. Design Requirements

1. The analysis system shall be designed for a minimum of a 5 year useful life. Useful life has terminated when the analysis system can no longer be repaired to meet the specifications in this document at a cost of less than 60 percent of the replacement cost at the time of repair.

2. NAME PLATE Permanently Located and Readable.

a) Analyzer System Manufacturer

- i) Name
- ii) Address
- iii) Phone number (customer service)

b) Analyzer Detector or Optical Bench Manufacturer

i) If the same manufacturer as the analyzer manufacturer item b) may be deleted.

ii) Name

iii) Addresss

iv) Phone number (customer service)

c) Analyzer Model Number and Serial Number

d) Detector Model Number and Serial Number

e) Date of Analyzer System Assembly

3. Sample System

a) Sample system components should be designed for intermittent sampling (20 minutes out of 10 hr.) of 600°F inlet (to probe) exhaust temperature. Such systems shall be designated "Unloaded" analysis systems. Systems designed for continuous duty with a minimum of 1000°F inlet (to probe) exhaust temperature, and proper sample handling equipment (i.e. water removal and/or heated lines) may be called "Loaded" analysis systems.

b) The type of system (Loaded or Unloaded) shall be permanently attached and prominently displayed in large letters.

c) The materials used in the sample handling system shall not alter the exhaust sample. Some examples of non-reactive materials are teflon, viton, stainless steel, silicone rubber (red), and in some areas nylon. Some examples of reactive materials are, brass, copper, and tygon.

d) Water Trap:

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i) A water trap shall be included in the sample system. The trap shall be self draining, visible to the operator, and shall prevent condensable water from occurring in the sample system downstream of the water trap.

ii) Alternative 1: Electronic correction to a "dry-basis" reading is permitted if the temperature of the sample after the water trap is measured and the sample is assumed to be saturated at the measured temperature. The water correction system must be deactivated for leak checks.

iii) Alternative 2: A dry-basis measurement is permitted if the absolute moisture content entering the analyzer is less than the saturation moisture content at a sample gas temperature of 7°C (45°F). Ice traps or refrigerators are permitted.

e) **Particulate Filter**

i) A particulate filter shall be included in the sample system.

ii) The filter shall be located in a manner that allows convenient filter element replacement.

iii) The proper direction of flow for the filter body(s) and element(s) (if applicable) shall be indicated in a manner that is easily discernible.

iv) The filter body shall be designed to provide leak free operation with normal filter element changing frequency for the lifetime of the analyzer, or a parts list of specific replaceable parts shall be listed in the maintenance manual as parts that may contribute to sample system leaks.

v) All manuals and filter element replacement instructions shall indicate that the system should be leak checked every time a filter element is changed. A similar message should be located on or near the filter body(s).

vi) The filter element and filter system shall be designed to prevent particulates larger in size than 5 microns from entering the analyzer. Verification of filter particulate size removal is permitted to be determined by the filter manufacturer using standardized ASTM or Filter Industry procedures.

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4. **Sample Pump**

The sample pump shall be designed for at least a 2000 hour life of continuous duty.

5. Sample Probe

- a) The probe must sample at least 16 inches from the end of the tailpipe or dilution adaptor.
- b) The probe shall have a flexible portion that will allow the probe to be inserted in a 1½ inch O.D. tailpipe. Assume the tailpipe has a 3 inch radius 90° bend beginning 4 inches from the end of the tailpipe.
- c) The probe shall be designed for easy servicing and/ or replacement.
- d) A universal leak proof dilution adapter (tailpipe extender) shall be provided.
- e) The tailpipe extender shall be able to be attached to the vehicle within 60 seconds.
- f) The tailpipe extender shall be designed to allow the attachment of standard service center building exhaust evacuation systems.
- g) The tailpipe extender shall not alter the sample and the material shall conform to D.3.c.) of this chapter.
- h) The probe and tailpipe extender shall have sufficient hardware (insulated handles, etc.) that will allow the user to insert, attach, or remove the probe or the dilution adapter safely and conveniently.
- i) The probe or tailpipe extender shall be designed in a manner that will prevent the probe or extender from being removed from the vehicle unintentionally.

6. Sample Line

- a) The sample line shall be flexible at the temperatures to be encountered during vehicle testing (See Section G)).
- b) The sample line shall not be longer than 35 feet nor shorter than 10 feet (excluding the probe).
- c) The portion of the sample line in contact with the exhaust gases shall not alter the exhaust sample, and shall minimize HC hangup, due to absorption, adsorption, desorption, outgassing, etc.
- d) The manufacturer must state the estimated useful life of the sample line in the owners manual or on the name plate.

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7. Analyzer Spanning System

a) Overview and Frequency: All analyzers shall follow the following spanning frequencies:

- i) Weekly - gas span
- ii) Daily

- 1) Recommended Basic System - gas span every 4 hours,
electric span every hour

- 2) Alternative 1 - electric span every hour
(pressure and
temperature
compensation)

- 3) Alternative 2 - electric span every hour
(extra basic
analyzer accuracy)

b) The analyzer shall be designed for routine gas spanning every 180 hours (once per week).

c) The gas spanning operation must automatically correct for changes between the gas span point gain and the electrical span point gain. In all cases the electric span point gain is the parameter that must be changed such that the new electric span point gain setting will cause the analyzer to read the span gas properly.

d) Unless the other spanning alternatives are exercised the basic analyzer shall be designed for routine gas spanning after:

- i) every "power on" and warm-up sequence, and
- ii) every 4 hours of "power on" condition.

e) Alternative Spanning System 1: The analysis system may provide temperature and pressure compensation to the analyzer output and spanning system. The compensation shall be based on sample cell pressure and inlet temperature. If such a system is used, and verified by subsequent checkout, an electrical span check may be substituted for the "power on" and 4 hour gas span checks, but not for the weekly gas span checks. During analyzer checkout, only one gas span check is allowed as part of the initial analyzer set-up prior to the initiation of the entire check out procedure. An electric span shall be substituted for all gas spanning operations in Chapter V (unless otherwise noted). Additional tests will be required in order to verify the accuracy and linearity of the compensation network at the various atmospheric pressures and temperatures required by the performance specifications (Chapter IV, Section E).

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f) Alternate Spanning System 2: The basic accuracy and precision of the analysis system may be significantly better than the specifications put forth in this document. In such a case, the analysis system may be capable of meeting the specifications of this document without any pressure and/or temperature compensation of the analyzer output and spanning system. If such a claim is made, and verified by subsequent checkout, an electrical span check may be substituted for the "power on" and 4 hour gas span checks, but not for the weekly gas span checks. During analyzer check out, only one gas span check is allowed as part of the initial analyzer set-up prior to the initiation of the entire checkout procedure. An electric span shall be substituted for all gas spanning operations in Chapter V (unless otherwise noted). Additional tests will be required in order to verify the accuracy of the analysis system at the various atmospheric pressures and temperatures required by the performance specifications (Chapter IV, Section E).

g) All analyzers shall be electrically spanned every hour after "power on" or 4 hour gas span checks.

h) The analysis system shall include suitable timers to insure that the spanning frequencies are met. The timing systems shall also prevent use of the analysis system by driving the readout devices to full scale and prevent any printer that may be used from printing. Performing the appropriate spanning operation shall automatically reset the timer for that specific type of operation regardless of the time elapsed since that operation was last performed.

i) The analyzer shall be spanned with flowing zero and span gases.

j) The analyzer system shall calculate and make available to the operator the span gas set point as ppmh (hexane) based on the span gas cylinder concentration in propane, and the analyzer's propane/hexane conversion factor.

k) The span point for all analyzers shall be between 70 and 100 percent of full scale on the lowest range.

l) Appropriate valves, switches, and electrical controls shall be provided that will allow the operator to conveniently select zero, span, or sample gases, and zero and span the analyzer.

m) The analysis system shall include a structure for safely securing two 1A size cylinders.

8. Analyzer Ranges

- | | | |
|--------------|---|------------------|
| a) Low-Range | : | 1) 0-400 ppmh HC |
| | | ii) 0-2% CO |

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- i) alert the operator of the problem which would require a new gas span and/or repair of the component causing the restriction, or
 - ii) use automatic compensation of the analyzer readout device for the change in restriction.
- b) A change in restriction that will cause a 3 percent of point change in the analyzer response shall activate the alert system.

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E. Analyzer Performance Specifications

1. Calibration Curve Uncertainty including Bias errors, Precision errors, and Hysteresis (Per test procedure):

- a) 5% of point
- b) Below 60 ppmh HC or 0.30% CO the uncertainty specification need not apply.
- c) If the analyzer prevents the operator from reading below 10 percent of full scale on the high scale, then the uncertainty specification need not apply to that portion of the high scale.

2. Resolution:

- a) analog meters - 2.5% fs on each range
- b) digital meters
 - i) xxxx ppmh
 - ii) xx.xx% CO

3. Compensation:

a) Altitude compensation: The analyzer shall have sufficient zero and span adjustment to allow the spanning of the analyzer at any altitude between 0 and 7000 feet. The external span adjustment may be limited in range as long as a clearly marked internal adjustment will make up the difference.

b) Compensated Systems: (Pressure and temperature compensation of analyzer read-out and span system)

i) The temperature compensation network shall provide accurate results over the ambient temperature range specified in Section G of this chapter as well as exhaust gas temperatures up to 55°C (131°F).

ii) The pressure compensation network shall provide accurate and linear results (analyzer read-out) over a pressure range of + 2 inches HgG from the local barometric pressure. The system shall operate between 24 and 31 inches HgA. Test points about which the pressure shall be varied in order to ascertain the accuracy and linearity of the compensation network are 24.5, 28.5, and 30.0 inches HgA.

c) Non-compensated Systems: For those analysis systems that claim pressure and temperature compensation is not necessary, the analysis system shall be tested to specification outlined in step b) for pressure and temperature compensated systems.

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4. Zero Drift: $\pm 2\%$ fs L.S. for 1 hour
5. Span Drift: $\pm 2\%$ fs L.S. for 1 hour
6. Noise (clean environment): 0.50% fs L.S.
7. Minimum Sample Cell Temperature: 55°C (131°F)
8. Interferences

a) Gases

	Analyzer	
	HC	CO
i) 14% CO ₂	: 1% fs L.S. (RR = 37500)*	0.5% fs L.S. (RR = 1500)
ii) Saturated Water @ 40°C (101°F)	: 1% fs L.S. (RR = 20,000)	0.5% fs L.S. (RR = 800)
iii) 100 ppm NO ₂	: .5% fs L.S. (RR = 50)	0.5% fs L.S. (RR = 100)

b) Electronic

i) RFI	: 0.50% fs L.S.
ii) VHF	: 0.50% fs L.S.
iii) Induction	: 0.50% fs L.S.
iv) Line Interference	: 0.50% fs L.S.
v) Line Voltage and Frequency Variation 90-130 v A.C. 55-65 hz	: 0.50% fs L.S.
vi) Static Electricity (Analog meters only)	: 1 meter division or 2½% fs L.S. whichever is greater.

* RR = Rejection Ratio

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9. Propane to Hexane conversion factor: The mean propane to hexane conversion factor for each analyzer sold as a pass/fail inspection analyzer shall be between 0.48 and 0.56 for each test point. The mean value shall be known at the 90% confidence level to two significant figures. The confidence interval shall not exceed a 0.01 increment in the correction factor. Due to the exceptional hang-up characteristics of hexane, all components that come in contact with the hexane gas used for determination of the factor shall be either clean stainless steel or teflon (viton valve seats are permitted).

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F. Sample System Performance Specifications

1. Maximum Sample cell pressure variation
between gas spanning and sampling : 4" H₂O
2. Maximum sample cell
Pressure variation during sampling : 6" H₂O
3. Maximum sample cell
Pressure variation between normal
flow and low flow indication : 4" H₂O
4. Response Time : 12 sec
Inlet of probe to 95% fs L.S. (@ low flow indication)
(See Test Procedure)
5. System Leakage Rate : a) sample side 3% of
(See Test Procedure) point on L.S.
b) span gas side, None
6. HC Hangup (see Test Procedure) : 5% fs L.S. in 20 sec.

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G. Operating Environment

1. The analysis system shall meet the analyzer performance and the sample system performance specifications under the following conditions (see Test Procedure):

- a) Ambient Temperature: Between 35°F to 110°F
- b) Relative Humidity: Between 10% to 99%

2. The analysis system shall be able to be stored at any temperature between -20°F to 130°F with no adverse effects on subsequent analysis system performance.

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H. Fail-Safe Features

1. Required Features For All Pass/Fail Systems

a) Warm-Up

i) The analyzer must have a warm-up lock-out feature with indicators.

ii) The lock-out feature shall prevent operation of the printer (if used) and read-out meter until the system is warmed up.

iii) The lock-out feature shall be activated when:

1) the sample cell is less than the temperature specified in Chapter IV section E, and

2) When system power is first turned on. The lock-out shall stay on until the zero drift is stabilized. Stabilization is determined by observing the zero drift over a 5 minute period after the lock-out feature deactivates. The zero drift during this 5 minute period may not exceed one-half of the zero drift specifications in Chapter IV Section E.

b) Low-Flow

i) The analyzer must have a low sample flow indicator. If the indicator is activated, the analyzer read-out shall be driven to 100% of full scale and the printer (if used) shall be prevented from printing.

ii) The low flow indicator shall be activated when the sample flow rate is decreased to a point that would not allow the analysis system to meet the response time specifications.

iii) The low flow indicator shall be prominently displayed, and shall be observable from at least 15 feet away.

c) Leak-Check

i) The sampling system shall have an automatic leak checking system for the sample side of the system.

ii) The analyzer shall have a timer that will allow the analyzer to operate for 180 hours (once per week) between leak checks. If after 180 hours the system is not leak checked, or the system fails a leak check, the analyzer readout shall be electronically driven to 100 percent of full scale, and the printer (if used) shall be prevented from printing.

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iii) The leak check shall compare the analyzer's response to span gas with the analyzer's response to that same span gas introduced through the probe and sample line. The span gas flow to the probe shall be restricted such that the pressure in the sample line during leak checking is approximately equal to or slightly below the pressure occurring during sampling.

iv) The system shall automatically compare the two analyzer responses, and make a determination of pass or fail.

v) A leak check pass or fail indicator shall be prominently displayed.

vi) The analysis system shall provide a leak tight receptacle for the probe on the system structure for the purpose of leak checking the system.

2. Required Features for All Decentralized Pass/Fail Systems

The following fail-safe features are specified in order to prevent improper operation of analysis systems used for decentralized systems. However, they could be useful in centralized systems as well. In general these features may require an on-board microprocessor.

a) Automatic zero/span check

i) The analyzer shall not have any adjustments available to the operator for adjusting zero or span point for either the gas spanning operation or the electrical spanning operation. These adjustments shall be available in the tamper-proof box described in Section H.2.d) of this chapter.

ii) The analyzer shall have a selector switch or button (with indicator light) labeled "gas span". Activation of the switch shall cause the analyzer to automatically perform the gas spanning sequence with flowing zero and span gas consistent with the requirements for the manual analyzer spanning system specified in Section D.7. of this chapter.

iii) The analyzer shall have a selector switch or button with indicator light labeled "electrical span". Activation of the switch will cause the analyzer to automatically perform an electrical zero and span operation consistent with the requirements for the analyzer manual spanning system specified in Section D.7. of this chapter.

iv) The automatic gas spanning operation shall not require more than 90 seconds to complete once the "gas spanning" switch is activated.

v) The gas span values shall be entered via switches or other convenient means to the following resolution:

HC = XXXX ppm propane
CO = XX.XX% CO

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The switches shall be in a tamper proof box as described in Section H.2.d) of this chapter.

vi) If the adjusted span voltage changes by more than 20 percent of the previous span voltage, the analyzer read-out shall be electronically driven to 100% of full scale, the printer if used shall be prevented from printing, and an indication of analyzer malfunction shall be prominently displayed.

vii) The automatic checking feature shall compute the equivalent hexane (HC) span set point based on the input propane value, and the analyzer propane/hexane conversion factor.

b) Automatic Read System

i) The analyzer shall have a selector switch or button (with indicator light) labeled "Sample" or "Test".

ii) Activation of the "sample" switch shall cause the analyzer system to begin integrating or averaging the analyzer response 15 seconds after the switch is activated, and continue integrating the analyzer response to a flowing sample for the next 15 seconds.

iii) The analyzer read-out device shall display the integrated value, and hold the display until reset. An indicator light shall signal the operator when the integrated value is displayed.

iv) The analyzer shall be prevented from printing the integrated value until the "sample" switch is activated and the "sample" cycle is completed.

c) Printer

i) The analysis system shall have a printer that provides the consumer a receipt with the following information:

1) Applicable cutpoints or standards for HC and CO.

2) Integrated vehicle test values for HC and CO.

3) A pass or fail indication.

ii) The print system shall have appropriate means (switches, etc.) to enter the cutpoints.

iii) The system shall determine items i)2) and i)3).

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d) Vehicle Diagnosis

i) For the purpose of vehicle diagnosis and/or repairs, the analyzer shall have a selector switch or button (with indicator light) labeled "Vehicle Diagnosis" or "Vehicle Repair".

ii) Activation of the "Vehicle Diagnosis" switch shall allow the analyzer to continuously monitor the vehicle exhaust.

iii) The printer, or any automatic data collection system, shall be prevented from operating anytime the analysis system is in a "Vehicle Diagnosis" status.

e) Anti Tampering

i) The anti-tampering feature shall be designed to prevent intentional tampering with the analysis system.

ii) All switches or entry access for automatic zero/span check adjustments, anti-dilution limits, etc. shall be contained in a tamper-proof box or other tamper-proof mechanism with provisions for an inspector's seal.

iii) The tamper-proof system must allow convenient access by an inspector.

3. Anti Dilution (Optional for all systems)

The anti-dilution feature can perform three useful functions: 1) most important, it can serve as an indicator of vehicle exhaust system leaks that would cause the measured emission values to be lower; 2) it can be used to identify dilution of the sample due to either probe placement or tailpipe extender leaks; and 3) it could potentially be used to insure decentralized operators actually insert the sample probe (or attach the extender), and actually measure vehicle exhaust samples.

i) The anti-dilution feature shall identify vehicle exhaust system leaks and sample dilution.

ii) The preferred technique for identifying leaks is monitoring the CO₂ levels in the exhaust.

iii) At least three lower limit CO₂ values shall be capable of being used.

- 1) no air pump
- 2) air pump
- 3) spare channel

iv) The resolution of the CO₂ span gas values entered shall be, XX.X% CO₂.

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v) The CO₂ values shall be entered by switches or other convenient means.

vi) The CO₂ analyzer shall meet all applicable analyzer design and performance specifications (Chapter IV) between CO₂ values of 8% and 14%.

vii) If the CO₂ is less than the lower limit, the analyzer output shall be electronically driven to 100% of full scale, the printer (if used) shall be prevented from printing, and an indication of exhaust system dilution shall be prominently displayed.

viii) The analyzer operator shall be able to select one of the three lower limits.

ix) The analyzer shall be prevented from reading auto exhaust until one of the three limits is selected.

x) If a printer is used, the CO₂ limit for the test shall be printed.

4. Printer (Optional features for decentralized systems, Print system optional for centralized systems)

i) The printer shall print the following for each vehicle tested

1) Date

2) Vehicle license plate number

3) Vehicle model year

4) Applicable cutpoints or standards for HC and CO (standard feature for decentralized systems)

5) Integrated vehicle test values for HC and CO (standard feature for decentralized systems)

6) A pass or fail indication (standard feature for decentralized systems)

ii) Items 1) to 3) in 4. i) may be deleted if each vehicle tested is assigned a sequential number by the printing system that can be transferred to the inspector's invoice or testing form.

iii) Appropriate means (switches etc.) shall be provided to enter the data required in 4.i) 1) through 4).

iv) The system shall determine items 4.i) 5) and 6).

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5. Automatic Data Collection (optional for all systems)

i) The automatic data collection feature shall store all of the pertinent data on a magnetic cassette tape.

ii) The tape shall contain data on at least 150 vehicles.

iii) The tape shall be available only to an appropriate inspector, and shall be protected by a seal.

iv) A keyboard shall be available to allow the following types of data to be entered. As indicated, the system may automatically enter certain data:

1) Date (Auto)

2) Vehicle license plate number

3) VIN

4) Vehicle make

5) Vehicle model

6) Vehicle Model Year

7) Emission Family Number (from emission label)

8) Odometer

9) Test Facility I.D. (Auto)

10) Facility Test Number (Auto)

11) Applicable cutpoints for HC and CO (cutpoints may be automatically determined and entered based on Vehicle Model Year selection)

12) Anti-dilution decision criteria (ie. air pump, no air pump, etc.)

v) The processor shall then enter the following data on the tape.

1) Integrated vehicle test values for HC and CO.

2) A pass or fail indication for HC and CO.

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6. System Diagnostic Testing

- a) Switches or other devices for rendering any fail-safe or automatic feature inoperative for the purpose of diagnostic or performance checking of the analyzer are permitted.
- b) These switches (or devices) must be contained in a tamper proof box(es) or other tamper-proof mechanism with provisions for a seal.
- c) All analyzer systems must be shipped with all fail-safe and automatic features operating, and the defeat systems sealed.

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I. System Correlation (on Raw Exhaust) to Laboratory Analyzers

1. All analyzers (comparison to NDIR Analyzer per Test Procedure)

- a) Precision Test: $\Delta p \leq 5\%$
- b) Slope Test: $0.95 \leq m \leq 1.05$
- c) Ratio of Modal Ave: $0.90 \leq R \leq 1.10$

2. HC analyzer (comparison to FID per Test Procedure)

a) Analyzers produced through December 1985:

i) During analyzer check out determine the following parameters between the candidate instrument and an FID (See Test Procedure)

- 1) Precision
- 2) Slope comparison
- 3) Ratio of Modal Averages

ii) Each analyzer manufacturer shall use the data to develop a historical comparison to FID analyzers that can be used to evaluate, prior to implementation, the correlation parameters specified for analyzers produced after January 1, 1986.

b) Analyzers produced after January 1, 1986 (see Test Procedure):

- i) Precision Test: $\Delta p \leq 5\%$
- ii) Slope Test: $0.317 \leq m \leq 0.350$
- iv) Ratio of Modal Ave: $1.80 \leq R \leq 2.20$

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J. Manuals

1. Each analyzer shall be delivered with one each of the following manuals.

- a) Operating Instructions
- b) Maintenance Instructions
- c) Initial Start-up Instructions

2. The manuals shall be constructed of durable materials, and shall not deteriorate as a result of normal use over a five year period.

3. The operating instructions must contain :

- a) The analyzer model and serial number
- b) The propane/hexane conversion factor
- c) A step by step sequence of pre-test procedures (span, leak check, probe insertion, etc.)
- d) Sampling procedures
- e) A step by step sequence of post-test procedures (hang-up etc.)

4. The maintenance manual must contain:

- a) Name, address, and phone number of the manufacturer's customer service and maintenance center at the home office and nearest field office.
- b) Name, address, and phone number of the nearest service center authorized to make warranty adjustments.
- c) A technical description of the system.
- d) A separate section that clearly outlines the required or anticipated maintenance schedule. The schedule shall be broken down into maintenance intervals such as weekly, monthly, etc.
- e) A separate section that provides a step by step sequence for each maintenance requirement.
- f) A list of replaceable items such as filters, probes, etc. with part numbers, and the estimated service life of each component.
- g) A list of recommended spare parts that the user should maintain.
- h) Functional mechanical and electrical schematics.
- i) The manufacturer's warranty provisions.

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- i. Each manual shall be attached to the analyzer in a manner that will:
- a) allow convenient storage,
 - b) allow easy use, and
 - c) prevent accidental loss or destruction.

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V. Test Procedures

The test procedures in this chapter are presented to provide a consistent interpretation of the specifications. Although the procedures do provide a step by step sequence, and it is expected that the evaluator follow that sequence, they are not a substitute for common sense or good engineering judgment. Some analysis system designs may simply not be amenable to certain portions of certain test procedures. Further, there may be ways to simplify or combine certain test procedures. In those cases, the evaluator should review the procedure as written, determine the important conceptual aspects and parameters of the procedure, and then use engineering judgment in testing the analyzer.

The basic test procedure should be performed in a laboratory that has experience in automotive emission testing. The general testing should be conducted at an ambient temperature between 68°F and 86°F. Section G requires certain test procedures to be conducted at other ambient temperatures.

If either of the non-gas spanning alternatives are used (See Chapter IV, Section D.7.), only one gas span operation is permitted for the entire Chapter V procedure, unless otherwise noted. This single gas spanning operation shall take place during the initial start-up procedure. Electrical span will be substituted for all other gas spanning operations. Analytical gases, of course, will be required for check out of the system.

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A. Traceability of Analytical Gases

The traceability of analytical gases may or may not be part of the analyzer manufacturer's responsibility. The choice belongs to the state. However, we would recommend that the analyzer manufacturers not be held responsible. We suggest that gas manufacturers meeting certain performance standards be accredited as acceptable vendors, or that the state provide distribution service.

The traceability of all gases used in the I/M program is of course important. Traceability implies not only blending, but analyzing the gases properly. Although operating the analysis equipment properly seems like a trivial task, some very prominent laboratories have sometimes been embarrassed by subsequent review of their procedures and analysis of their blended gases.

In order to provide the automobile manufacturers with what EPA/OMSAPC considers proper traceability procedures, the Emission Control Technology Division (ECTD) of EPA is publishing a Recommended Practice for Assuring Gas Traceability to NBS. This procedure, which is a compilation of internal EPA procedures, is applicable to I/M analytical gases.

The entire traceability procedure may involve more equipment than a state may wish to become initially involved with. A minimum recommendation for I/M programs is that each gas blender or certifying laboratory that is allowed to supply gases for pass/fail I/M systems should follow the ECTD procedure. The next step would be a continuing quality-audit of each supplier by the state using the correlation portion of the traceability procedure.

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B. Gas Cylinder Specifications

No test procedures required.

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C. Durability Test Procedures

1. Vibration and Shock Test Procedure

The vibration and shock test procedure is designed to evaluate the ability of the analyzer to tolerate moderate use in a service facility. Although a simple span test is performed, the real test of the analyzer is the ability of the analyzer to meet the remaining performance checks to follow this test.

a) Equipment Required

i) Candidate instrument.

ii) One span gas between 70 and 90 percent of full scale on the low range, and bottled zero gas.

iii) A special test floor 6 feet by 10 feet. The top of the floor shall be elevated 2 inches off the test facility floor. The floor shall consist of an expanded metal grating with diamond shape openings measuring 1 x 3.7 inches or equivalent. The length of the floor in the direction of the "short way of the diamond" shall be 10 feet.

b) Test Sequence

i) Warm up the analyzer.

ii) Span the analyzer on the low range with the span gas per the manufacturer's recommendations (on the test floor).

iii) Record the zero response and the span response.

iv) Roll the instrument the entire length of the test floor in the direction of the "short way of the diamond", and off the end of the test floor onto the facility floor.

v) Pull the analyzer back onto the test floor.

vi) Repeat steps iv) and v) a total of six times.

vii) Check the zero response and span response (do not adjust the analyzer).

viii) Record the zero response and the span response.

c) Calculations

i) Subtract the zero response from the span response in step b) iii)---(span before).

ii) Subtract the zero response from the span response in step b) viii)---(span after).

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iii) Subtract the zero response in step b viii) from the zero response in b) iii)---(zero shift).

iv) Subtract the value calculated in step c) ii) from the value calculated in step c) i)---(span shift).

d) Acceptance Criteria

i) If the values calculated in step c iii) and c iv) are less than or equal to the vibration and shock zero and span shift specifications, then the vibration and shock performance is acceptable.

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2. Sample Line Crush Test Procedure

The sample line crush test is to be repeated under the "operating environment" testing. If space is a problem in the environmental chamber, after stabilization, the sample line can be removed from the chamber to perform the crush test. If the line is removed from the chamber, the crush test must be performed and the line returned to the chamber within 3 minutes.

a) Equipment Required

- i) Candidate instrument.
- ii) One span gas between 70 and 90 percent of full scale on the low range, and bottled zero gas.
- iii) One vehicle with at least 4000 pound curb weight.

b) Test Sequence

- i) Stabilize the sample line at the prevailing ambient temperature.
- ii) Warm up the analyzer. Do not turn on the sample pump.
- iii) Span the analyzer with the analytical gases.
- iv) Leak-check the system.
- v) Stretch out the sample line across a solid (concrete etc.) floor.
- vi) Drive across the sample line so that at least one front and one rear vehicle wheel passes over the sample line.
- vii) Back over the sample line so that at least one front and one rear vehicle wheel passes over the sample line.
- viii) Repeat steps vi) and vii) twice.
- ix) Leak-check the system.
- x) Check for "low flow" indication.
- xi) Check for visible failures, kinks, deterioration, etc.

c) Calculations (none)

d) Acceptance Criteria

- i) If the system passes the leak check (step ix), does not indicate a "low flow" condition (step x), and shows no sign of damage (step xi), then the crushability performance of the sample line is acceptable.

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3. Sample Handling Temperature Effect

a) Equipment Required

- i) Candidate instrument.
- ii) Catalyst equipped vehicle.
- iii) Thermocouple read-out device.
- iv) Type "J" or type "T" thermocouple (1/16 inch diameter MgO shielded and grounded).
- v) One HC span gas between 70 and 90 percent of full scale on the low range, and bottled zero gas.
- vi) Associated fittings.

b) Test Sequence

- i) Locate a point approximately 1 inch upstream from the end of the probe, and weld a thermocouple boss on the extender (top side when installed on vehicle).
- ii) Install the thermocouple into the extender to a distance approximately half-way between the extender wall and the sample probe.
- iii) Warm up the analyzer.
- iv) Span the analyzer with the analytical gases.
- v) Leak check the system.
- vi) With the vehicle running, locate a position away from the vehicle to avoid vehicle contamination, and measure the background HC levels with the sample system. Record the background HC levels.
- vii) Install the extender on the vehicle.
- viii) Adjust the vehicle to elevate the exhaust gas temperature (as measured by the thermocouple) to at least 300°C (572°F) and not more than 360°C (680°F).
- ix) As soon as the exhaust gas has stabilized between 300°C and 360°C, start a timer and begin sampling.
- x) After twenty (20) minutes at the temperature in step viii), remove the probe or extender, and simultaneously start another timer.

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xi) Immediately move the probe or extender to the location previously used to measure background HC, while continuing to sample room air.

xii) Twenty (20) seconds after the probe or extender is removed from the tailpipe, record the analyzer's response.

xiii) Introduce zero gas into the analyzer through the gas spanning system. Record the response.

xiv) Introduce span gas into the analyzer through the gas spanning system. Record the response.

xv) Leak check the system.

xvi) Check for "low flow" indication.

xvii) Check for visible failure, melted or deformed parts, deterioration etc.

xviii) When the testing is completed, remove the thermocouple and cap the boss with a leak proof cap.

c) Calculations

i) Compute the difference in zero response between step b) xiii) and b) xiv) --- (hang-up HC plus background HC and zero drift).

ii) Compute the difference in zero response between step b) xiii) and b) vi) --- (hang-up HC minus background).

iii) Compute the difference in span response between step b) xv) and b) iv) --- (span drift).

d) Acceptance Criteria

i) The value computed in c) i) must be less than the hang-up specifications plus the zero drift specifications.

ii) The value computed in c) ii) must be less than the hang-up specifications.

iii) The value computed in c) iii) must be less than the span shift specifications.

iv) The system must pass the leak check.

v) A low flow condition shall not be indicated.

vi) No portion of the system shall show signs of heat damage.

vii) If the above criteria are met, then the high temperature performance of the system is acceptable.

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4. Filter Check and Hang-up Test Procedure

The filter check procedure consists of two phases - a 2 hour check, and a check to determine the useful life of the filter. It is intended that all subsequent system check procedures are to be conducted with a filter and sample system that have experienced at least 2 hours of exhaust sample as defined in this procedure. Therefore, the second part of the filter test may be performed after the other tests are complete if a log of sampling time during the other tests is maintained. If during subsequent testing, a low flow indication occurs due to filter loading, the filter may be changed, the filter life recorded, and testing may continue with a new filter.

a) Equipment Required

- i) Candidate instrument.
- ii) Test vehicle that can create a hydrocarbon sample of at least 1500 ppmh with a spark plug wire removed or the choke partially closed.
- iii) Clean sample filter.
- iv) One span gas between 70 and 90 percent of full scale on the low range, and bottled zero gas.

b) Test Sequence

- i) Install a clean sample filter.
- ii) Warm up the analyzer.
- iii) Span the analyzer with the analytical gases, and leak check the system.
- iv) With the vehicle running, locate a position away from the vehicle to avoid vehicle contamination, and measure the background HC levels with the sample system. Record the background levels.
- v) Attach the tailpipe extender to the vehicle.
- vi) Insert the probe into the extender and begin sampling.
- vii) Begin the vehicle malfunction.
- viii) As soon as the emissions exceed 1500 ppmh, begin a timer.
- ix) Maintain the HC level above 1500 ppmh, and sample the vehicle for two (2) hours.

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- x) During the two hours monitor the "low flow" indication.
- xi) After two hours, remove the probe or extender, and simultaneously start another timer.
- xii) Immediately move the probe or extender to the location previously used to measure background HC, while continuing to sample room air.
- xiii) Twenty (20) seconds after the probe or extender is removed from the tailpipe, record the analyzer's response.
- xiv) Introduce zero gas into the analyzer through the gas spanning system. Record the response.
- xv) Introduce span gas into the analyzer through the gas spanning system. Record the response.
- xvi) Leak check the system.
- xvii) Alternatives: 1) at this point the filter testing may be suspended in order to complete the other tests. A log book of sampling time must be kept for the other tests, or 2) reinsert the probe into the extender, and continue testing until the "low flow" system activates, or 3) repeat the 2 hour filter check at the end of the performance testing of the analyzer, then continue testing until the "low flow" system activates.
- xviii) Record the elapsed time to "low flow" indication.

c) Calculations

- i) Compute the difference in zero response between step b) xiii) and b) xiv) --- (hang-up HC plus background HC and zero drift).
- ii) Compute the difference in zero response between step b) xiii) and b) vi) --- (hang-up HC minus background).
- iii) Compute the difference in span response between step b) xv) and b) iv) --- (span drift).

d) Acceptance Criteria

- i) The value computed in c) i) must be less than the hang-up specifications plus the zero drift specifications.
- ii) The value computed in c) ii) must be less than the hang-up specifications.
- iii) The value computed in c) iii) must be less than the span shift specifications.

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iv) A low flow condition shall not occur during the 2 hour check.

v) If the above criteria are met, then the performance of the filter is acceptable.

vi) If the total elapsed time to "low flow" activation is not less than 70 percent of the analyzer manufacturer's estimate of sample life-time of the filter, the manufacturer's estimate is acceptable. If the elapsed time is less than 70 percent of the estimate, the manufacturer's estimate shall be revised downward.

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D. Design Requirement Inspection and Test Procedures

1. Useful Life: No test procedure.
2. Name Plate: Visual observation.
3. Sample System:
 - a) Visual observation.
 - b) Visual observation.
 - c) Visual observation.
 - d) See "Analyzer Gaseous Interference and Noise Test Procedure," Chapter V, Section E.8.
 - e)
 - i) Statement by analyzer manufacturer on particulate size and element lifetime.
 - ii) See "Filter Check and Hang-Up Test Procedure."
4. Sample Pump: No test procedure.
5. Sample Probe: Test procedures self-explanatory or features can be determined by visual observation.
6. Sample Line:
 - a) Flexibility Test Procedure: Perform the normal motions required to use the sample line for testing vehicles. Perform this test for all environmental conditions used for check out under Chapter V procedures. Make a determination about whether the sample line can be used without a great deal of difficulty at the conditions tested. If it is determined that the sample line is not sufficiently flexible, then the manufacturer may suggest more objective test procedures and/or more data to demonstrate compliance.
 - b) Self-explanatory Test Procedure.
 - c) Visual observation.
 - d) Statement by analyzer manufacturer.

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7. Analyzer Spanning System Test Procedure

a) The performance and acceptance of the spanning system will generally be determined by the system's performance on the other test procedures conducted during the evaluation procedures, and visual observation of the equipment features. In other cases (such as event timers), the test procedures are self-explanatory, and are not listed. Guidance for the one exception, gas span versus electrical span gain adjustments is provided by the following procedure.

b) Equipment Required

- i) Candidate instrument.
- ii) One span gas 70 to 90 percent of full scale on the low range, and zero gas.

c) Test Sequence

- i) Warm up the analyzer.
- ii) Span the analyzer with the analytical gases. Record the span value.
- iii) Perform an electrical span check. Do not adjust the analyzer. Record the electrical span point.
- iv) Reintroduce the span gas. Do not adjust the analyzer. Note the span response.
- v) While the span gas is flowing through the analyzer, arbitrarily increase the analyzer response (gain setting) to a value approximately 10% to 15% greater than the span value.
- vi) Perform an electrical span check. Do not adjust the analyzer. Record the electrical span point.
- vii) Reintroduce the span gas. Arbitrarily reduce the analyzer response (gain setting) to a value approximately 10% to 15% less than the span value.
- viii) Perform an electrical span check. Do not adjust the analyzer. Record the electrical span point.
- ix) Repeat steps ii) through viii) a total of three times. The increased and decreased span adjustments are to be random settings.

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d) Calculations

i) Compute the standard deviation(s) and mean(\bar{x}) of the electrical responses recorded in steps c) iii), vi), and viii).

ii) Multiply the standard deviation(s) by a K factor of 2.6.

iii) Determine the following:

$$\begin{aligned}y_1 &= \bar{x} + Ks \\y_2 &= \bar{x} - Ks\end{aligned}$$

iv) Compute the uncertainty (U) of the electrical spanning system by:

$$U = \frac{\text{Electrical Span Point} - y_i}{\text{Electrical Span Point}} \times 100$$

where, $i = 1, 2$

e) Acceptance Criteria

i) If the uncertainty is less than or equal to the calibration curve uncertainty (Chapter IV, Section E), the electrical span system is acceptable.

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8. Analyzer Ranges: Visual observation.
9. System Grounding: See Test Procedure E.9. (Analyzer Electrical Interferences).
10. System Vents: If restrictions downstream of the analyzer exit are apparent, a test procedure shall be devised that evaluates the analyzer performance under restricted conditions. Test Procedures E.3.a) (Altitude Compensation) and F.1. (Sample Cell Pressure Variation, Low Flow, and Response Time) shall be used for guidance.

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E. Analyzer Performance Test Procedures

1. Calibration Curve Test Procedure

a) Equipment Required

i) Candidate instrument

ii) Seven or more calibration gases for each range of each analyzer roughly equally spaced over each range.

iii) Zero gas

iv) Associated valves and fittings

b) Test Sequence

i) If necessary, follow the manufacturer's instructions for initial start-up and basic operating adjustments.

ii) Warm up the analyzer

iii) Zero the analyzer with the zero gas

iv) Span the analyzer with one of the calibration gases. The span point should be approximately 80 to 90 percent of full scale of the low range

v) Recheck the zero. If the zero has shifted, repeat steps iii), iv), and v) a maximum of one more time.

vi) Do not adjust the zero or span controls on the analyzer for the remainder of the test.

vii) Introduce the calibration gases in ascending order of concentrations beginning with the zero gas. Record the analyzer response to each concentration value.

viii) After the highest concentration has been introduced and recorded, introduce the same calibration gases to the analyzer in a descending order. Include the zero gas. Record the response of the analyzer to each gas. Record negative zero responses (if any) as they occur as negative values.

ix) Repeat steps vii), and viii) a total of five times.

c) Calculations

i) For hydrocarbon analyzers, compute the hexane equivalent (ppmh) of each calibration gas by multiplying the concentration value in ppm propane (ppmp) by the propane/hexane conversion factor listed on the analyzer.

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ii) Compute the standard deviation(s) and mean(\bar{x}) of the analyzers response for each concentration of calibration gases. Include both upscale responses and downscale responses to the same calibration gas. Zero may be a special case and not amenable to the calculations.

iii) For all concentration values except the highest value, multiply the standard deviation(s) by a factor (K) of 2.5.

iv) Multiply the standard deviation(s) of the analyzers response to the highest concentration by a K factor of 3.5.

v) Compute the following for each concentration

$$1) y_1 = \bar{x} + Ks$$

$$2) y_2 = \bar{x} - Ks$$

vi) Compute the uncertainty(U) of the calibration curve for each concentration by:

$$U = \frac{\text{concentration value} - y_i}{\text{concentration value}} \times 100$$

where $i = 1, 2$

d) Acceptance Criteria

i) Identify the maximum uncertainty for each range.

ii) If the maximum uncertainty is less than or equal to the uncertainty specification (Chapter IV, Section E), (plus or minus), the calibration curve is acceptable. If the uncertainty is greater than specification, the calibration curve is not acceptable.

iii) If the calibration curve is not acceptable, then the instrument manufacturer should undertake an engineering study to identify the cause of the problem prior to continued testing or introduction of the analyzer to the commercial market.

iv) After the cause of the problem is identified and the analyzer is repaired or adjusted this test should be repeated.

e) Repeat steps b), c), and d) for each range of the analyzer.

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2. Analyzer Resolution

a) Analog Meters: The resolution is determined by the interval of the smallest graduation of the meter face for each analyzer range.

b) Digital Meters: The resolution is determined by the increment of the least significant digit of the meter readout for each range.

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3. Compensation Test Procedures

a) Altitude Compensation Test Procedure (not required for analyzers with Spanning Alternative, 1 or 2)

i) Equipment

- 1) Candidate instrument.
- 2) One pressure gauge or manometer that reads in absolute pressure (e.g. 20 to 32 in. HgA) with 1% accuracy.
- 3) One differential pressure gauge (0 to 15 inches of water).
- 4) One flowmeter (0-20 cubic feet per hour (CFH)).
- 5) Two needle valves.
- 6) One vacuum pump (greater than 20 CFH@ 24 in. HgA).
- 7) One span gas 70 to 90 percent of full scale on the low range.
- 8) One Tedlar sample bag.
- 9) Associated lines and fittings (non-reactive).

ii) Test Sequence

This procedure is written around parallel HC and CO analyzers, and should be performed on each analyzer. If the analyzers are in a series configuration, then an additional pressure gauge(s) will be required, but the test can be performed on both analyzers at the same time.

If the analyzer manufacturer states in writing that the structural integrity of the sample cell will not withstand the pressure differential associated with this test procedure at 24 inches of HgA, the altitude check must be made in an altitude chamber. In an altitude chamber only steps 8), 9), 10), 14), 15), 16) and 20) need be performed at the pressures specified in step 13) and 18).

- 1) Identify the sample line entering the sample cell of each analyzer.
- 2) Install a tee fitting in the sample line immediately upstream of the sample cell (as close as practical). Install the tee with branch pointing up.
- 3) Immediately upstream of the tee install one of the needle valves.

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- 4) Identify the exhaust line from the sample cell and install two tees or a 4-way cross fitting in the line with the branches pointing up.
- 5) Downstream of the tees or cross fitting install the flow meter.
- 6) Attach a differential pressure gauge to the tee upstream of the sample cell and one of the exhaust tees. Attach one gauge across each analyzer in a series system.
- 7) Attach the absolute pressure gauge to the second exhaust tee.
- 8) Warm up the analyzer.
- 9) Check for leaks.
- 10) Sample room air through the sample line with the needle valve wide open.
- 11) Record the sample cell exhaust flow rate, the differential pressure across each analyzer, and the absolute pressure.
- 12) Attach the second needle valve after the flowmeter.
- 13) Adjust both the needle valves to obtain an absolute pressure of 31 inches of HgA, the sample differential pressure recorded in step 11), and a flow-rate of not less than 2 cfh.
- 14) Fill the sample bag with the span gas, and introduce the span gas from the bag into the sample line.
- 15) Use the analytical gases to set the zero and span of the analyzer. Note if internal adjustments were required to span the analyzer.
- 16) Return to sampling room air.
- 17) Attach the vacuum pump to the exhaust line after the second needle valve with an appropriate length of line, and open both needle valves.
- 18) Turn the vacuum pump on, and adjust both needle valves to obtain an absolute pressure of 24 inches of HgA, the same differential pressure recorded in step 11), and a flow rate approximately the same as recorded in step 11).

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19) Refill the sample bag if necessary, and introduce the span gas into the sample line from the bag.

20) Use the analytical gases to set the zero and span of the analyzer. Note if internal adjustments were required to span the analyzer.

iii) Calculations (none)

iv) Acceptance Criteria

1) If the analyzer can be spanned properly in steps ii) 15), and ii) 20, and the technique required to span the analyzer under these conditions is identified in the owner's manual, then the altitude compensation network is acceptable.

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b) Pressure and Temperature Compensated Analyzer Test Procedure

i) Testing concepts: This test procedure is to be performed in order to identify the performance of any pressure or temperature compensation systems under the various environmental conditions that may be encountered during vehicle inspection testing. In general, temperature compensation will be evaluated during the basic check-out (68°F to 86°F) and during the more hostile environmental temperature tests specified in Section G. No other special testing would normally be necessary.

In order to evaluate pressure compensation systems, additional testing is necessary. If the analyzer manufacturer can make a case that testing the pressure compensation system in a manner similar to the procedure specified in Chapter V Section E.3.a) (altitude compensation) will represent actual analysis system operating conditions in the field, then that procedure (E.3.a) may be used for check-out. If a sufficient case cannot be made, and a suitable alternative test procedure cannot be determined, then performance evaluations of the pressure compensation system must be carried out in an altitude chamber. The pressure compensation test shall be conducted at each environmental temperature condition specified in Chapter V. The tests shall be performed on each range of each analyzer.

ii) Test conditions: The test conditions shall consist of three basic barometric pressures about which excursions in pressure shall be made. The values are:

<u>Basic Test</u> <u>Point (inches HgA)</u>	<u>Excursion</u> <u>Points (inches HgA)</u>
24.5	24.0, 26.5
28.5	26.5, 29.5
30.0	28.5, 31

iii) Test Sequence

1) Identify the concentration value that provides the greatest uncertainty in measurement as determined by Test Procedure E.1). Obtain a calibration gas at that level (same bottle if possible).

2) Set up the test equipment for one of the three test points.

3) Warm up the analyzer.

4) Gas span the analyzer with a different calibration gas between 80 and 90 percent of full scale on the low range and bottled zero gas.

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5) Leak check the system.

6) Alternately introduce zero gas and the calibration gas identified in step 1) through the sample probe until a total of three readings are obtained and recorded for each test step.

7) The test steps for the 24.5 in HgA test point are:

<u>Test Step</u>	<u>Action</u>
24.5	gas span
24.0	3 readings
24.5	3 readings
26.5	3 readings
24.0	3 readings
26.5	3 readings
24.5	3 readings
24.0	3 readings
24.5	3 readings
26.5	3 readings

8) Repeat steps 4) through 6) at the 28.5 inch HgA test point. The test steps for this test point are:

<u>Test Step</u>	<u>Action</u>
28.5	gas span
26.5	3 readings
28.5	3 readings
29.5	3 readings
26.5	3 readings
29.5	3 readings
28.5	3 readings
26.5	3 readings
28.5	3 readings
29.5	3 readings

9) Repeat steps 4) through 6) at the 30.0 in. HgA test point. The test steps for this test point are:

<u>Test Step</u>	<u>Action</u>
30.0	gas span
28.5	3 readings
30.0	3 readings
31.0	3 readings
28.5	3 readings
31.0	3 readings
30.0	3 readings
28.5	3 readings
30.0	3 readings
31.0	3 readings

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iv) Calculations

1) For each test point, compute the standard deviation(s) and mean (\bar{x}) for the 9 readings obtained at each pressure level.

2) Multiply each standard deviation by a K factor of 2.6.

3) For each pressure level at each test point, compute the following:

$$y_1 = \bar{x} + Ks$$

$$y_2 = \bar{x} - Ks$$

4) For each pressure level at each test point, compute the uncertainty (U) of the measurements based on the calibration gas used in step iii) 6) from:

$$U = \frac{\text{concentration value} - y_i}{\text{concentration value}} \times 100$$

where $i = 1, 2$

v) Acceptance Criteria

1) Identify the maximum uncertainty

2) If the maximum uncertainty is less than or equal to the uncertainty specification (Chapter IV, Section E), (plus or minus), for the basic analyzer calibration curve, the pressure compensation is acceptable. If the uncertainty is greater than specification, the pressure compensation is not acceptable.

3) If the pressure compensation is not acceptable, then the instrument manufacturer should undertake an engineering study to identify the cause of the problem prior to continued testing or introduction of the analyzer to the commercial market.

4) After the cause of the problem is identified and the analyzer is repaired or adjusted this test should be repeated.

vi) Repeat steps iii), iv), and v) for each range of the analyzer.

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c) Test Procedure for Analyzers with Improved Accuracy

i) If an analyzer manufacturer claims that the measurement uncertainty specifications (Chapter IV, Section E.) can be met without pressure and/or temperature compensation, this claim can be verified by the test procedure in Section E. 3-6) of this Chapter.

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4. Analyzer Zero and Span Drift Test Procedure

(See Test Procedure Section H.1.a), Warm-up Lock-out Test Procedure).

a) Equipment Required

- i) Candidate instrument.
- ii) One span gas between 70 to 90 percent of full scale on the low range.
- iii) One cylinder of zero gas.
- iv) One chart recorder (one megohm impedance or greater) with approximately a 10 to 12 inch wide chart.

b) Test Sequence

- i) Begin the test sequence with an analyzer that is turned off, and has stabilized at the prevailing ambient temperature for at least 3 hours.
- ii) Remove the analyzer's protective cover.
- iii) Locate the meter readout and attach leads from the readout terminals to the chart recorder.
- iv) Reinstall the protective cover.
- v) Turn on the analyzer.
- vi) Select a voltage range on the chart recorder so that full scale of chart recorder equals full scale voltage of the analyzer meter on the range under test.
- vii) The chart recorder must indicate both negative and positive zero drift. If necessary, offset the chart recorder zero 5 units up scale.
- viii) As soon as the warm-up lock-out feature deactivates, zero and span the analyzer with the analytical gases per manufacturer's operating instructions, and start the chart recorder at a minimum chart speed of 0.5 inches per minute.
- ix) Do not adjust the analyzer or recorder controls (zero or span) for the remainder of the test.
- x) Reintroduce zero gas (if not done already) and start the test.
- xi) Mark the chart paper indicating the zero response, the span response, and the start of the test.

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- xii) Flow zero gas through the analyzer for one hour.
- xiii) Introduce the span gas to the analyzer (do not adjust the equipment).
- xiv) Reintroduce the zero gas to the analyzer (do not adjust the equipment).
- xv) Reintroduce the span gas to the analyzer (do not adjust the analyzer).
- xvi) Flow span gas through the analyzer for one hour.
- xvii) Reintroduce zero gas to the analyzer.

c) Calculations

- i) Compute the difference (as a percent of full scale chart deflection) between the analyzer zero response for the first span check (step b)viii)) and the zero response after the 1 hour span check (step b) xiv)) --- (zero drift).
- ii) Locate on the chart the maximum and minimum analyzer zero response during the first 1 hour period (step b) xii)).
- iii) Compute the difference (as a percentage of full scale chart deflection) between the analyzer zero-response for the first span check (step b) viii)), and the maximum zero response and then the minimum zero-response as identified in step c) ii) --- (zero drift).
- iv) Compute the analyzer span-response at the 1 hour span check as the difference between the chart reading of the span gas (step b) xiii) and the chart reading of the zero gas (step b) xiv)) --- (span response).
- v) Locate on the chart the maximum and minimum chart reading during the one hour span period (step b) xvi)).
- vi) Compute the difference (as a percentage of full scale chart deflection) between the analyzer zero-response immediately prior to the one hour span period (step b) xiv)), and the maximum and minimum span chart readings identified in step c) v) --- (span response).
- vii) Compute the difference (as a percentage of full scale chart deflection) between the span chart deflection at the end of the 1 hour span, and the zero-response after the 1 hour span --- (span response).

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viii) Compute the difference (as a percentage of full scale chart deflection) between the span chart deflection immediately prior to the start of the one hour zero test (step b) viii)) and the zero-response just prior to that span check --- (span response).

ix) Compute the difference (as a percent of full scale chart deflection) between the zero-response just prior to the start of the 1 hour span (step b) xiv)), and the zero-response just after the 1 hour span (step b) xvii)) --- (zero drift).

x) Compute difference (as a percentage of full scale chart deflection) between the following span responses in step c):

(vi max) to (iv)	span drift
(vi min) to (iv)	span drift
(vii) to (iv)	span drift
(viii) to (iv)	span drift

d) Acceptance Criteria

i) If each value computed in steps i), iii) max, iii) min, and ix) is less than or equal to the specifications listed for zero drift, the zero drift of the analyzer is acceptable.

ii) If each value computed in step x) is less than or equal to the specifications for span drift, the span drift of the analyzer is acceptable.

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5. Analyzer Span Drift Test Procedure

(See Analyzer Zero and Span Drift Test Procedure, E.4.)

6. Analyzer Noise Test Procedure

(See Analyzer Gaseous Interference and Noise Test Procedure, E.8.)

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7. Analyzer Sample Cell Temperature Test Procedure
(See Test Procedure Section H.1.a), Warm-up Lock-out Test Procedure).

a) Equipment Required

- i) Candidate instrument.
- ii) Thermocouple readout device.
- iii) Type J or type T thermocouple.

b) Test Considerations

- i) The sample cell test procedure may be run concurrently with the zero/span drift test or any other test that begins with an analyzer that is not warmed up.
- ii) It is recommended that the test equipment remain hooked up to the analyzer for the duration of the analyzer check out, and the temperature of the sample cell should be monitored from time to time.

c) Test Sequence

- i) Locate on the sample cell a point, based on engineering judgement, that would be the coldest point.
- ii) Attach a thermocouple to the sample cell at the location identified in step i).
- iii) Conductive, convective, and radiation losses must be considered in the selection of the location, and in the manner of thermocouple attachment.
- iv) Stabilize the analyzer at the prevailing ambient temperature for at least 3 hours.
- v) Record the sample cell temperature.
- vi) Turn on the analyzer.
- vii) As soon as the warm-up lock out feature is deactivated, record the temperature of the sample cell.
- viii) Immediately switch to sample ambient air (or analytical gas at the ambient temperature) through the sample line.
- ix) Monitor the sample cell temperature over the next 5 minutes.
- x) Record the lowest sample cell temperature during the 5 minute period.

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d) Calculations
(None)

e) Acceptance Criteria

i) If the temperature recorded in step c) v) is approximately the same as the ambient temperature, the analyzer is properly stabilized.

ii) If the temperatures recorded in step c) vii) and step c) x) are equal to or greater than the specifications for sample cell temperature, the sample cell temperature is acceptable.

iii) While monitoring the sample cell temperature during the analyzer check-out procedure, if the temperature is less than the specifications when concentration data (span or sample) is read, the acceptance in step ii) is void.

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8. Analyzer Gaseous Interference and Noise Test Procedure

a) Equipment Required

- i) Candidate instrument.
- ii) One high impedance (1 megohm or greater) digital voltmeter with at least $4\frac{1}{2}$ digit resolution. Generally, a 2 volt (1.9999 v) and a 20 volt (19.999 v) scale will be adequate. A chart recorder of similar impedance, resolution, and scaling may be used in place of a voltmeter.
- iii) One calibration gas with approximately 14% CO₂ and the balance N₂.
- iv) One steam generator.
- v) One mixing chamber with probe attachment, dilution valve, and chamber air temperature readout system.
- vi) One calibration gas with approximately 100 ppm NO₂. The NO₂ value must have been checked within 48 hours of the start of the testing sequence with a chemiluminescent analyzer meeting the specifications of 40 CFR 86 Subpart B, D, or N.
- vii) One span gas between 70 and 90 percent of full scale on the low range, and bottled zero gas.
- viii) Tedlar sample bags.
- ix) Associated lines and fittings (non-reactive).

b) Test Sequence

- i) Remove the analyzer's protective cover.
- ii) Locate the meter readout and attach the voltmeter or chart recorder leads to the meter terminals.
- iii) Reinstall the analyzer's protective cover.
- iv) Temporarily bypass the water trap.
- v) Warm up the analyzer.
- vi) Introduce the span gas to the analyzer through the span port.
- vii) Adjust the span so that the analyzer reads 100 percent of low scale.

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viii) Observe the voltmeter reading at 100 percent full scale of the analyzer and record the voltage value. Alternatively, adjust the chart recorder so that full scale is equivalent to the analyzer full scale.

ix) Zero and span the analyzer with the analytical gases to the proper values.

x) Fill a sample bag with span gas.

xi) Introduce the span gas from the sample bag to the analyzer through the probe.

xii) After the reading has stabilized, observe the voltmeter or chart recorder. Record the highest value and the lowest value over a 3 minute time span. The scale can be changed for better resolution.

xiii) Fill another sample bag with CO_2 .

xiv) Introduce the CO_2 through the sample probe.

xv) Record the average voltmeter or chart recorder reading. The scale can be changed for better resolution.

xvi) Fill a sample bag (after purging with N_2) with NO_2 .

xvii) Introduce the NO_2 through the sample probe.

xviii) Record the average voltmeter or chart recorder reading. The scale can be changed for better resolution.

xix) Start the steam generator.

xx) Attach the probe to the mixing chamber and adjust the dilution valve to obtain a 40°C (101°F) temperature in the dilution box. To prevent condensation in the analysis system this test should be performed with an ambient temperature between 30°C and 40°C . This test cannot be performed correctly when testing at the lower ambient temperature conditions specified in Section G of this chapter, and should therefore, be omitted when testing under Section G.

xxi) Sample from the dilution box.

xxii) Record the average voltmeter or chart recorder reading. The scale can be changed for better resolution.

xxiii) Reconnect the water trap.

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xxiv) Repeat steps xix) through xxii) with an ambient temperature at the same value as in step xx) and 40°C in the dilution box. When repeating this test at the operating environmental conditions specified in Section G of this chapter, perform this test with a 40°C dilution box temperature and the analysis system at the prevailing ambient temperature.

c) Calculations

i) Compute the difference between the high and low reading recorded in step b) xii), then divide that result by the full scale voltage value recorded in step b) vii). This value, expressed as a percentage and divided by 2, is defined as noise of the analyzer.

ii) Divide the value recorded in step b) xv) by the full scale voltage value recorded in step b) vii). The result, expressed as a percentage, is the CO₂ interference of the analyzer.

iii) Divide the value recorded in step b) xviii) by the full scale voltage value recorded in step b) vii). The result, expressed as a percentage, is the NO₂ interference of the analyzer.

iv) Divide the value recorded in step b) xxii) by the full scale voltage value recorded in step b) vii). The result, expressed as a percentage, is the water interference of the analyzer.

v) Divide the value recorded in step b) xxiv) by the full scale voltage value recorded in step b) vii). The result, expressed as a percentage, is the water interference of the system.

d) Acceptance Criteria

i) If the percentages calculated in paragraph c) for the analyzer are equal to or less than the specifications for noise and gaseous interferences (Chapter V, Section E.), then the noise and gaseous interferences are acceptable.

ii) Inspect the analysis system downstream for condensed water. If water is found, the effectiveness of the water trap is not acceptable.

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9. Analyzer Electrical Interference Test Procedure

a) Equipment Required

- i) Candidate instrument.
- ii) One high impedance (1megohm or greater) digital volt meter with at least $4\frac{1}{2}$ digit resolution. Generally, a 2 volt (1.9999 v) and a 20 volt (19.999 v) scale will be adequate. A chart recorder of similar impedance, resolution, and scaling may be used in place of a voltmeter.
- iii) One vehicle with high energy ignition system, and solid core ignition and coil wires.
- iv) One 3 amp or more variable speed (commutator type) hand drill with a plastic handle.
- v) One 20 foot extension cord with 3 sixteen gauge wires, and a 2 plug outlet. For systems without ground fault circuits, a 2 wire extension cord or a non-grounded adaptor will be required.
- vi) A CB transmitter at or near FCC legal maximum power with a matching antenna.
- vii) One variable voltage transformer (90v to 130vAC).
- viii) One span gas between 70 and 90 percent of full scale on the low range.
- ix) One dry flannel cloth.

b) Test Sequence

- i) Remove the analyzer's protective cover.
- ii) Locate the meter readout, and attach the voltmeter or chart recorder leads to the meter terminals.
- iii) Reinstall the analyzer's protective cover.
- iv) Plug the analyzer's power cord into a 2-outlet grounded electrical outlet box and warm up the analyzer.
- v) Use a non-grounded adapter to check any ground fault circuit.
- vi) If the system does not have a ground fault circuit, perform the remainder of the test sequence with the non-grounded adapter.

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vii) Mark the adapter and the outlet box, and perform the testing sequence with the adapter in that orientation. After completion of the sequence, reverse the adapter orientation (hot lead versus neutral lead) and repeat the sequence.

viii) Introduce the span gas through the span port, and adjust the span so that the analyzer reads 100 percent of low scale.

ix) Observe the voltmeter or chart recorder reading at 100 percent full scale of the analyzer, and record the voltage value.

x) Zero and span the analyzer with the analytical gases to the proper values. Record the values.

xi) Introduce span gas to the analyzer. Record the average span gas voltage levels over a 5 minute time span. The scale can be changed for better resolution.

xii) Either move the analyzer or the vehicle (engine compartment) to within 2 feet of each other.

xiii) Introduce the span gas to the analyzer.

xiv) Open the hood and start the vehicle.

xv) Record the average span gas voltage level during a 5 minute time span.

xvi) Stop the vehicle engine.

xvii) Plug the electric drill into the other outlet of the same receptacle that the analyzer is connected to.

xviii) Move the drill at approximately 3 to 4 feet high to within 12 inches of the analyzer. At four locations around the analyzer vary the drill speed from minimum to maximum speed. Attempt to locate the positions that provide the greatest interference.

xix) Record the average span gas voltage level at each position.

xx) Key the CB radio within 50 feet of the analyzer.

xxi) Record the average span gas voltage level when the CB radio is transmitting.

xxi) Turn the analyzer off.

xxii) Plug both the analyzer and the drill into the extension cord. For systems without a ground fault circuit use either a 2 wire extension cord, or a non-grounded adapter.

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xxiii) Plug the extension cord into the variable voltage transformer and set the transformer output to 110 volts.

xxiv) Turn the analyzer on, and warm it up.

xxv) Check the zero and span. If necessary reset to the exact voltage level recorded in step b) x).

xxvi) Repeat step b) xii) through xxi).

xxvii) Record the average span gas voltage level as indicated in steps b) xv), xix), and xxi).

xxviii) Reduce the transformer output voltage to 90 volts. Let analyzer stabilize for 2 minutes.

xxix) Repeat steps b) viii) through xxi) with the extension cord and 90 volt set-up. Non-relevant set-up steps may be omitted.

xxx) Increase the transformer output to 130 volts. Let the analyzer stabilize for 2 minutes.

xxxi) Repeat steps b) viii) through xxi) with the extension cord and 130 volt set-up. Non-relevant set-up steps may be omitted.

xxxii) If the unit has an analog meter, observe and record the meter reading with span gas.

xxxiii) Rub the meter face 10 times with the dry flannel cloth in the up-scale direction. Record the meter reading.

c) Calculations

i) Compute the difference between each set of voltage levels recorded in step b) x) and b) xv). The maximum difference expressed as a percentage of the voltage recorded in step b) ix) is defined as the RF interference (RFI).

ii) Compute the difference between each set of voltage levels recorded in step b) x) and b) xx). The maximum difference expressed as a percentage of the voltage recorded in step b) ix) is defined as the induction interference.

iii) Compute the difference between each set of voltage levels recorded in step b)x) and b)xxi). The maximum difference expressed as a percentage of the voltage recorded in step b)ix) is defined as the VHF interference.

iv) Compute the difference between the voltage levels recorded in step b) x) and step b) xxvii). The largest result expressed as a percentage of the voltage recorded in step b) ix) is defined as the line interference.

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v) Compute the difference between the voltage levels recorded in step b) x) and b) xxix). Compute the difference between the voltage levels recorded in step b) x) and b) xxxi). The largest value of the results expressed as a percentage of the voltage recorded in step b) ix) is defined as the line voltage interference.

vi) Compute the difference between the meter reading recorded in step b) xxxii) and b) xxxiii). Also compute the difference as a percentage of full scale. The difference is defined as the static electricity interference.

d) Acceptance Criterion

i) If the percentages calculated in paragraph c) are equal to or less than the electronic interference specifications (Chapter IV, Section E.), then the electrical interferences are acceptable.

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10. Propane to Hexane Conversion Factor Test Procedure

a) Testing Concepts

i) The conversion factor shall be evaluated at two hexane concentration levels.

1) 200 ppmh (\pm 15 ppmh) on the low scale, and

2) 1800 ppmh (\pm 150 ppmh) on the high scale.

ii) A minimum of three samples of the hexane gas at each concentration level shall be performed.

iii) Because of the exceptional hang-up characteristics of hexane, an auxilliary sample/spanning system that is specially constructed to be essentially hang-up free may be used. The auxilliary system should be of laboratory quality, and may bypass the candidate analysis system controls.

iv) The test should always be conducted at an ambient temperature greater than 20°C (68°F).

v) A flame ionization detector (FID) properly optimized and calibrated (see 40 CFR 86 Subpart D or N) may be used to provide additional quality control on the conversion factor determination procedure.

b) Test Sequence

i) Set up the test equipment.

ii) Warm-up the candidate analyzer.

iii) Leak check the system used.

iv) Span the analyzer on the low range with a propane calibration gas near (\pm 5%) the expected low concentration hexane response, and with bottled zero gas. Use the propane to hexane conversion factor indicated on the analyzer.

v) Alternately cycle low concentration hexane gas and the calibration gas through the analyzer a total of 3 or more times.

vi) Record each response for each gas.

vii) Span the analyzer on the high range with a propane calibration gas near (\pm 5%) the expected high concentration response, and bottled zero gas. Use the propane to hexane conversion factor indicated on the analyzer.

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viii) Alternately cycle the high concentration hexane gas and the calibration gas through the analyzer a total of three or more times.

ix) Record each response for each gas.

c) Calculations

i) For the values recorded in step b) vi), and b) ix), compute the mean (\bar{x}) and standard deviation(s) for the hexane response and the propane response.

ii) Use an α of 0.05 and the student's "t" test to determine the confidence interval of the population mean at the 90% confidence level based on the values computed in step c) i) for each range.

iii) Use the following equation to determine the mean propane to hexane conversion factor (CF) for each range:

$$CF = \frac{(.5) + (.5)(\bar{x}_{\text{hex}} - \text{Hex Cal})}{\text{Hex Cal}}$$

where:

\bar{x}_{hex} = the mean hexane response determined in step c) i).

Hex Cal = concentration of hexane calibration gas.

iv) Determine if sufficient number of cycles (steps b) v) and b) viii)) were run on each range by the following equation:

$$0.01 \leq \frac{(.5)(\bar{x}_{\text{hex}} - x_{\text{CI}}) + (.5) \text{Hex Cal}}{\text{Hex Cal}}$$

where:

\bar{x}_{hex} = the mean hexane response determined in step c) i).

x_{CI} = the confidence interval determined in step c) ii).

Hex Cal = concentration of hexane calibration gas.

v) For each range, multiply the mean propane response (\bar{x}) determined in step c) i) by the CF computed in step c) iii).

vi) Determine the difference between the CFs for each range, and determine the mean CF.

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d) Acceptance Criteria

- i) If the value computed in step c) iv) is greater than 0.01, perform additional cycles (see steps b) v) and b) viii)) until the computed value is less than 0.01.
- ii) If the difference between the CFs computed for each range (step c) vi)) is greater than .030 a sperate CF must be used for each range. If the difference is less than .030, a mean CF may be used for both ranges.
- iii) The CF value(s) determined by step d) iii) must agree exactly with the CF posted on the analyzer. ASTM round-off shall be used.
- iv) The mean propane value determined in step c) v) must agree with the propane calibration gas within 1 percent of the propan calibration gas concentration.

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F. Sample System Test Procedures

1. Sample Cell Pressure Variation, Low Flow, and Response Time

a) Test Equipment

- i) Candidate instrument system.
- ii) One span gas cylinder with a concentration between 70 and 90 percent of full scale, and bottled zero gas.
- iii) One gauge (0-30 inches of water).
- iv) One pinch clamp.
- v) One Tedlar sample bag (approximately 3 cubic foot capacity).
- vi) One 3-way ball valve, minimum orifice size is .180 inches.
- vii) One stop watch or timer.
- ix) Associated fittings and lines (non-reactive material).

b) Testing Sequence

This test procedure is written around parallel HC and CO analyzers, and should be performed on each analyzer. If the analyzers are in a series configuration then an additional pressure gauge will be required, but the test can be performed on both analyzers at the same time.

- i) Identify the sample line entering the sample cell.
- ii) Install a tee fitting in the sample line immediately upstream of the sample cell (in as close as practical). Install the tee with the branch pointing up.
- iii) Connect the gauge to the tee with the suitable length of flexible tubing.
- iv) Warm up the analyzer.
- v) Zero the analyzer.
- vi) Span the analyzer with the span gas through the spanning network. Record the pressure gauge reading, and the span response.
- vii) Recheck the zero. If the zero has shifted repeat steps v), vi), and vii).
- viii) Switch the analyzer from span gas flow to sample flow (pump on).

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ix) Record the maximum and minimum fluctuations in the gauge reading.

x) Attach the pinch clamp to the pressure gauge line. Slowly pinch the line until the gauge fluctuations are minimized.

xi) The gauge reading should be approximately halfway between the readings recorded in step ix). Record the stabilized gauge reading in step x).

xii) Attach the common port of the 3-way valve to the probe with a leak free adapter.

xiii) Attach a short length of tube to one of the remaining two ports of the three-way valve, and sample room air through the tube.

xiv) Fill the sample bag with span gas.

xv) Attach the sample bag to the remaining port of the 3-way valve.

xvi) The 3-way valve should be sampling room air.

xvii) switch the 3-way valve to the sample bag, compare the stabilized concentration reading of the bag to the reading in step vi). A difference of more than 1 percent from the concentration reading in step vi) could indicate a leak in the system. Repair any leaks, and restart the procedure at step b)i).

xviii) Recheck the zero by switching the 3 way valve back to room air.

xix) Identify the concentration value corresponding to 95% of the span gas in the bag. Record the 95% value.

xx) Switch the 3-way valve to the sample bag and simultaneously start a timer.

xxi) When the analyzer response reaches the 95% value stop the timer. Record the elapsed time.

xxii) Record the sample cell pressure after the analyzer reading has stabilized. Record the stabilized analyzer concentration reading.

xxiii) Identify the concentration value (5%) corresponding to the stabilized reading in step xxi) (100%) minus the 95% value identified in step xix).

xxiv) switch the 3-way value back to room air and simultaneously start the timer.

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xxv) When the analyzer reaches the 5% value, stop the timer. Record the elapsed time.

xxvi) Connect the needle valve between the probe and the 3-way valve.

xxvii) Adjust the needle valve until the low flow indicator is just barely activated.

xxviii) Repeat steps xvi) through xxv).

xxix) Use the same 95% and 5% values identified in step xix) and xxiii).

xxx) Record the 5% and 95% response times.

xxxi) Record the stabilized concentration reading, and sample cell pressure in the same manner used in step xxii).

c) Calculations

i) Compute the difference in pressure between step vi) and step xi), and step vi) and step xxii). The values will be the pressure difference between spanning and sampling.

ii) Compute the difference between maximum and minimum pressure readings in step b) ix). The value will be the pressure variation during sampling.

iii) Compute the difference in pressure between step xi) and step b) xxxi). The value is the difference in pressure variation between normal flow and low flow conditions.

iv) Compute the percentage change in analyzer gas response between step b) xxii) and step b) xxxi).

d) Acceptance Criteria

i) If the calculated value in steps c)i, and c)iii are less than 4 inches of water, and less than 6 inches of water for step c)ii, the pressure variations in the analyzer flow system under these test conditions are acceptable.

ii) If the change in analyzer response computed in step c)iv is less than 1.5 percent and the elapsed times recorded in step b) xxx) are less than 12 seconds, the low flow indicator system is acceptable as well as the system response time.

iii) If the elapsed time in steps b) xxi) and b) xxv) is less than 12 seconds, the system response time is acceptable under normal conditions.

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iv) It is recommended that the sample cell pressure gauge(s) remain hooked up for the duration of the analyzer check out. If the sample pressure varies by more than 4 inches of water from the most recent span pressure, then the acceptance in d)i is void.

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2. Maximum Sample Cell Pressure Variation during Sampling Test Procedure
(See Test Procedure F.1)
3. Maximum Sample Cell Pressure Variation Between Normal Flow
and Low Flow Indication Test Procedure
(See Test Procedure F.1)
4. Response Time Test Procedure
(See Test Procedure F.1)

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5. System Leakage Test Procedures

a) Equipment Required

- i) Candidate instrument.
- ii) One tee fitting.
- iii) One needle valve.
- iv) One span gas 70 to 90 percent of full scale on the low range, and bottled zero gas.
- v) Associate lines and fittings (non-reactive).

b) Test Sequence

This sequence is written assuming that the analyzer incorporates the automatic leak checking feature specified.

- i) Install the tee fitting between the probe and the sample line.
- ii) Attach the needle valve to the remaining port of the tee and close the valve.
- iii) Warm up the analyzer.
- iv) Zero and span the analyzer with the analytical gases.
- v) Record the span value.
- vi) Place the probe in the leak check receptacle.
- vii) Record the analyzer response to span gas introduced through the leak check receptacle, probe, and sample line.
- viii) If the analyzer response in step vii) differs from the response in step v) by more than 1 percent of the value recorded in step v), check the system for leaks or other problems. Restart the procedure at step iii).
- ix) Gradually open the needle valve until the leak check fail light just comes on.
- x) Record the analyzer response.
- xi) Use the bubble check method to check for leaks in the spanning system.

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c) Calculations

i) Compute the percent leakage by subtracting the response recorded in step b) x) from the response in step b) v), and then dividing result by the value recorded in step b) v). Multiply the result by 100.

d) Acceptance Criteria

i) If the value calculated in step c) i) is equal to or less than the leakage rate specification (Chapter IV, Section F.5.), the system leakage indication system is acceptable.

ii) If the spanning system shows significant leaks at fittings, attempt to repair the leaks by tightening or replacing the fittings. If leaks occur in other locations of the spanning system, or appear to be the result of system design, an engineering report must be submitted by the analyzer manufacturer describing the causes and preventive remedies for the leak prior final acceptance of the system.

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G. Operating Environmental Test Procedure

1. Test Procedure

a) Equipment required

i) Candidate instrument

ii) Environmental chamber with temperature capability between 35°F and 110°F, and humidity capability between 10 and 99 percent relative humidity.

b) Test Conditions

i) 105°F (\pm 5°F) with a relative humidity between 96 and 100 percent (non-condensing).

ii) 40°F (\pm 5°F) with a relative humidity between 75 and 80 percent with a 10 mph wind.

iii) 35°F (\pm 5°F) with a relative humidity between 15 and 25 percent.

c) Required Tests of each test condition (Test Procedure numbers are given in parentheses).

i) System Warm-up (H.1.a))

ii) System Leakage (F.5.)

iii) Sample Line Crush Test (C.2.)

iv) Analyzer Calibration Curve (E.1.)

v) Pressure and Temperature Compensation (E.3. b) and c))

vi) Analyzer Zero and Span Drift (E.4.)

vii) Sample Cell Temperature (as applicable, see E.7. and H.1.)

viii) Analyzer Water Interference (E.8.)

ix) Sample Cell Pressure Variation, Low Flow, and Response Time (F.1.)

x) HC hang-up (C.4)

xi) If used, automatic zero/span system (H.2. a))

xii) If used, automatic read system (H.2. b) i) 1))

xiii) If used, anti-dilution system

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xiv) If used, printer

xv) If used, automatic data collection system

d) Test Sequence

i) The analyzer shall be turned off and allowed to stabilize at least 3 hours at the test condition prior to beginning the performance check.

ii) The warm-up test followed by the leak check test shall be the first two tests performed at each test condition.

iii) The remaining tests may be performed in any convenient order.

iv) An additional leak check shall be performed at the completion of the required tests for each test condition.

v) The first test condition shall be the 35°F condition followed by the 40°F and the 105°F conditions.

e) Acceptance Criteria

i) If the analysis system passes all of the individual test requirements as specified by each test in c) and d), then the environmental operating characteristics of the system are acceptable.

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H. Fail-Safe System(s)

1. Test Procedures for Features Required for All Systems

a) Warm-up Lock-out Test Procedure

i) Equipment Required

- 1) Candidate analyzer.
- 2) The equipment required to perform the Analyzer Sample Cell Temperature Test Procedure (see Section E.7.).
- 3) The equipment required to Perform the Analyzer Zero and Span Drift Test Procedure (see Section E.4.).
- 4) A timer.

ii) Test Sequence

- 1) Follow the basic measurement preparations indicated in Test Procedures E.4. and E.7.
- 2) After the analyzer has stabilized at the ambient conditions as determined by Test Procedure E.7. Turn on the analyzer power and simultaneously start a timer. (A chart recorder may be used).
- 3) The chart recorder must indicate both negative and positive zero drift. If necessary, offset the chart recorder zero 5 units up scale.
- 4) As soon as the warm-up lock-out feature deactivates, record the elapsed time from power on, the sample cell temperature, and immediately zero and span the analyzer with analytical gases per manufacturer's operating instructions. Simultaneously, start the chart recorder (if already started, mark the chart) at a minimum chart speed of 0.5 inches per minute.
- 5) Immediately after spanning, begin sampling ambient air (or analytical zero gas at the ambient temperature) through the sample line.
- 6) Monitor the zero drift and the sample cell temperature for 5 minutes.
- 7) Record the lowest sample cell temperature during the 5 minute period.

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iii) Calculations

- 1) Locate on the chart the maximum and minimum analyzer zero-response during the 5 minute period.
- 2) Compute the difference (as a percentage of full scale chart deflection) between the analyzer zero-response determined by the span check in step b) 4) and the maximum zero-response, and then the minimum zero-response as identified in step iii) 1).
- 3) Determine the largest difference in step c) 2) and multiply it by 2 --- (zero drift).

iv) Acceptance Criteria

- 1) If the temperature observed in step ii) 2) is approximately the same as the ambient temperature, the analyzer is properly stabilized.
- 2) If the temperatures recorded in step ii) 4) and step ii) 7) are equal to or greater than the specifications for sample cell temperature, the sample cell temperature is acceptable.
- 3) While monitoring the sample cell temperature during the analyzer check-out procedure, if the temperature is less than the specifications when concentration data (span or sample) is read, the acceptance in step 2) is void.
- 4) If the zero drift, as calculated in step iii) 3) is less than the specifications for zero drift (Chapter IV, Section E.), then the zero drift after warm up is acceptable.
- 5) Acceptance of the above criteria constitutes acceptance of the Warm-up Lock-out system.
- 6) If the analyzer manufacturer indicates a typical lock-out elapsed time to the ultimate user, then the manufacturer must show that the elapsed time supplied to the user is truly typical if the time recorded in step ii) 4) is more than 30 percent longer than the time indicated to the user.

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b) Analyzer Low Flow Test Procedure

i) See Test Procedure F.1., Sample Cell Pressure Variation, Low Flow, and Response Time.

ii) Visual Observation of Features

c) Analyzer Leak Check Test Procedure

i) See Test Procedure F.5., System Leakage Test Procedure

ii) Visual observation of features

iii) Self explanatory test procedure for timer check-out.

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2. Test Procedures for Features Required on Decentralized Systems

a) Automatic Zero/Span Check Test Procedure

i) If the analysis system is equipped with the automatic gas span feature, the gas spanning feature must be used throughout the entire evaluation procedure unless noted otherwise (e.g. pressure and temperature compensation, Section E.3. b)).

ii) The automatic span system shall be used with calibration gas (instead of span gas) for the Calibration Curve Test Procedure (E.1.).

iii) Self-explanatory Test Procedures for the other requirements.

b) Automatic Read Feature Test Procedure

i) If the analysis system is equipped with the automatic read feature, the system shall be deactivated for all evaluation testing except:

1) The response time portion of test procedure F.1. shall be rerun with the automatic read feature operational.

2) All system correlation tests (Procedures in Section I) shall be run with the automatic read feature operational.

3) Other tests self explanatory.

c) Printer Feature Test Procedure

If the analysis system is equipped with a printer, the printer shall be checked for proper operation. The printer shall provide the official system results to be used in the correlation procedures (Section I).

d) Vehicle Diagnosis Feature Test Procedure

Check for proper operation. No other test procedures are required.

e) Anti-Tampering Feature Test Procedure

i) Visual observation

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I. System Correlation Test Procedures

The correlation procedure is designed to evaluate the performance of the I/M analyzers when sampling auto exhaust. The NDIR procedure is slightly different from the FID HC correlation procedure. However, it is expected the data collection phase of each procedure can occur simultaneously. For clarity they will be presented as separate procedures.

1. NDIR Analyzer Correlation Test Procedure

a) Equipment Required

i) Candidate instrument.

ii) A raw exhaust CO analysis system meeting the requirements of 40CFR 86, Subpart D, for gasoline-fueled engines.

iii) A laboratory grade NDIR HC analyzer substantially similar in quality to the laboratory CO analyzer, and operated according to the requirements for general NDIR analysis of gasoline-fueled engines contained in 40 CFR 86, Subpart D.

iv) A tailpipe extension that meets the probe location requirements in 40CFR 86 Section 312-79 (c) (v).

v) Two test vehicles.

vi) Calibration gases for each range used on both the candidate analyzers and the reference analyzer. In this test procedure, calibration gases will be used instead of span gases to span both analysis systems. The calibration gases should be between 70 and 90 percent of full scale on each range used. Calibration gases for the Subpart D analysis system shall meet or exceed the requirements specified in Subpart D.

vii) Option: An adjustable dilution box and mixing chamber may be used to obtain different exhaust concentration levels from the vehicle. The dilution box and mixing chamber would be installed between the tailpipe and the analysis system probes.

viii) Option: A chassis dynamometer would be useful for loading the vehicle to obtain different emission levels, but is not required.

b) Test vehicles

i) One 1975 or later non-catalyst light-duty vehicle (LDV), LDT, or HDG is acceptable.

ii) One 1978 or later oxidation catalyst equipped vehicle with air injection.

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iii) All vehicles must be in good operating condition with all emission control systems functional. A 1975 FTP type test may be performed on the vehicle to verify functional operation of the emission controls.

c) Test Procedure Overview

The correlation procedure consists of testing the candidate analyzer at several points on each range. The range scale of the candidate analyzer determines the approximate test points. The exact test points are then determined by the concentration levels observed by the reference system. The exact test points are then replicated several times (minimum of 6) based on the reference system response values. This replicate data is then analyzed to determine correlation between the candidate system and the reference system.

d) Test Sequence

i) Select a test vehicle, and warm up that vehicle with at least 30 minutes of hard load. (freeway operation, hard accelerations, etc.

ii) Prepare the analysis systems for measurement (i.e. warm-up, spanning etc.) operate the reference system according to the provisions in Subpart D where applicable.

iii) Insert the probe of the candidate instrument into the tailpipe approximately 16 inches.

iv) Operate the vehicle (or adjust the dilution box) to obtain stable concentration readings at approximately 20, 50, 70 and 90 percent of full scale concentration value on the low range of the candidate analyzer.

v) Select the lowest useable range on the Subpart D system for each test point in d)iv) (see § 86.338).

vi) Sample for approximately 1 minute at each test point.

vii) Record the average emission value of the candidate instrument and the average chart deflection from the reference system over the last 10 seconds for each test point. The two readings recorded at each test point should be recorded over the same time frame, and are defined as a "paired" data point.

viii) Select the high range of the candidate instrument.

ix) Operate the vehicle (or adjust the dilution box) to obtain stable readings at approximately 20, 50, 70, and 90 percent of full scale on the high range of the candidate

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instrument. If the higher emission values require impractical vehicle operation, cease data generation and continue with the test procedure. At least one vehicle should be able to achieve the higher values.

x) For the attainable test points in the preceding step, repeat step d)vii).

xi) The chart deflections recorded in steps d)vii) and d)x) for the Subpart D system are now defined as "reference set points" that will be used for the remainder of the correlation test. When repeating the test sequence with the same vehicle or a different vehicle, the vehicle or dilution box should be adjusted to obtain, as close as possible, the exact "reference" chart deflection. For the test points not attainable in step d)ix), the chart deflection of the reference system becomes the set point the first time a data pair is recorded for that test point.

xii) Repeat steps d) iv) through d) x) at the set points described in step d)xi). Record the emission values from the candidate system, and the chart deflections from the reference system.

xiii) Ground or short two plug wires on V8 engines (opposite sides of intake manifold), or one plug wire for 6 cylinder and 4 cylinder engines.

xiv) Perform steps d)iv) through d)x) at the set points described in step d)xi) a minimum of three times. Record the emission values from the candidate system, and the chart deflections from the reference system.

xv) Select the 2nd test vehicle, and repeat steps d)iv) through d)xiv) at the set points described in step d)xi). Record the emission values from the candidate system, and the chart deflections from the reference system.

xvi) Repeat the procedure as necessary to obtain a minimum of 6 replicate responses at each test point.

e) Calculations

i) For the candidate system compute the mean (\bar{x}) and standard deviation(s) of the emission values for each test point.

ii) For the reference system convert each chart deflection to a concentration value from the analyzer calibration curve.

iii) For the reference system compute the mean (\bar{x}) and standard deviation(s) concentration values for each test point.

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iv) Compute the normalized precision difference (ΔP) for each test point by:

$$\Delta P = ((Ks/\bar{x}) \text{ candidate}) - ((Ks/\bar{x}) \text{ reference})$$

where:

<u>Sample Size</u>	<u>K</u>	<u>Sample Size</u>	<u>K</u>
5	3.5	10	2.5
6	3.1	11	2.46
7	2.9	12	2.40
8	2.7	13	2.36
9	2.6	14	2.31

v) For each range of the candidate analyzer perform a linear regression on all of the paired data that were measured on that range. Force the regression through zero. The reference system is the independent variable. Identify the slope(m) of the regression line.

vi) For each range of the candidate analyzer compute the ratio(R) of the analyzer mean concentrations for each test point corrected for the slope(m) identified in the preceding step by:

$$R = (\bar{x} \text{ reference} / \bar{x} \text{ candidate})m$$

f) Acceptance Criteria

i) Identify the largest ΔP value. If the largest ΔP value is less than or equal to the specification for ΔP , then the in-use precision of the candidate system is acceptable.

ii) If the slope(m) for each range of the candidate analyzer is within the limits for slope, then the slope test results are acceptable.

iii) Identify the minimum and the maximum ratio(R) of slope corrected mean concentration values. If the minimum and maximum ratios are within the range specified, then the mean concentration ratio test results are acceptable.

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2. FID Analyzer Correlation Test Procedure

a) Equipment required

i) Candidate instrument.

ii) An HC analysis system meeting the requirements of 40CFR86, Subpart D for gasoline-fueled engines.

iii) A tailpipe extension that meets the probe location requirements in 40CFR86 Section 312(c)(v).

iv) Three test vehicles.

v) Calibration gases for each range used by both the candidate analyzers and the reference analyzer. In this test procedure, calibration gases will be used instead of span gases to span both analysis systems. The gases should be between 60 and 90 percent of full scale on each range used.

vi) Calibration gases for the Subpart D analysis system shall meet or exceed the requirements specified in Subpart D.

vii) Option: A dilution system that allows the auto exhaust to be diluted in a controlled manner with a suitable mixing chamber, may be used to obtain different exhaust concentration levels from the vehicle.

viii) Option: A chassis dynamometer may be used with or without the dilution system to obtain different concentration levels.

b) Test Vehicles

i) The type of test vehicle required for the FID correlation test are the same as the type required for the NDIR correlation. Generally it is preferred that the same vehicles be used for both correlations.

c) Test Procedure Overview

The correlation procedure consists of testing the candidate analyzer at several points on each range. The range scale of the candidate analyzer determines the approximate test points. The exact test points are then determined by the concentration levels observed by the reference system. The exact test points are then replicated several times (minimum of 6) based on the reference system response values. This replicate data is then analyzed to determine correlation between the candidate system and the reference system.

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d) Test Sequence

The test sequence is identical to CO correlation test required with the following exception.

- 1) Stabilized concentration readings of approximately 10, 20, 35, 50, 70, and 90 percent of full scale concentration values should be substituted for the value in step 1.d)iv) and 1.d)ix). Record the HC concentration value from the candidate analyzer as ppmh or ppmC6.

e) Calculations

- i) For the candidate system compute the mean (\bar{x}) and standard deviation(s) of the emission values for each test point.
- ii) For the reference system convert each chart deflection to a concentration value in ppm C3 (propane) from the analyzer calibration curve.
- iii) For the reference system compute the mean (\bar{x}) and standard deviation(s) concentration values for each test point.
- iv) Compute the normalized precision difference (ΔP) for each test point by:

$$\Delta P = ((Ks / \bar{x}) \text{ candidate}) - ((Ks / \bar{x}) \text{ reference FID})$$

where:

<u>Sample Size</u>	<u>K</u>	<u>Sample Size</u>	<u>K</u>
5	3.5	10	2.5
6	3.1	11	2.46
7	2.9	12	2.40
8	2.7	13	2.36
9	2.6	14	2.31

- v) For each range of the candidate analyzer perform a linear regression on all of the paired data that were measured on that range. Force the regression through zero. The reference system is the independent variable. Identify the slope(m) of the regression line.

- vi) For each range of the candidate analyzer compute the ratio(R) of the analyzer mean concentrations for each test point corrected for the slope(m) identified in the preceding step by:

$$R = (\bar{x} \text{ reference FID} / \bar{x} \text{ candidate})m$$

f) Acceptance Criteria

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i) For HC analyzers manufactured before January 1986, the following data shall be available:

- 1) Precision
- 2) Slope Comparison
- 3) Ratio of Modal Averages

ii) For HC analyzers manufactured after January 1986, the analyzer shall meet the following criteria:

- 1) Identify the largest ΔP value. If the largest ΔP value is less than or equal to the specification for ΔP , then the in-use precision of the candidate system is acceptable.
- 2) If the slope(m) for each range of the candidate analyzer is within the limits for slope, then the slope test results are acceptable.
- 3) Identify the minimum and the maximum ratio(R) of slope corrected mean concentration values. If the minimum and maximum ratios are within the range specified, then the mean concentration ratio test results are acceptable.

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