

**SAE RECOMMENDED
PRACTICE J1130**

APPROVED AS ANSI/SAE J1130 MAY83-1984
BY AMERICAN NATIONAL
STANDARDS INSTITUTE

**Determination of Emissions
from Gas Turbine Powered
Light Duty Surface Vehicles –
SAE J1130 MAY83**

SPONSORED BY:
SAE, INC.

PUBLISHED BY:
SAE, Inc., 400 Commonwealth Drive, Warrendale, PA 15096

Copyright 1984 Society of Automotive Engineers, Inc.

DETERMINATION OF EMISSIONS FROM GAS TURBINE POWERED LIGHT DUTY SURFACE VEHICLES—SAE J1130 MAY83

SAE Recommended Practice

Report of the Automotive Emissions Committee, approved April 1976, revised May 1983.

Purpose—This is an SAE recommended procedure for determining the hydrocarbon, carbon monoxide, and oxides of nitrogen emissions of a gas turbine powered light duty surface vehicle operated over the EPA Urban Dynamometer Driving Schedule specified for Federal certification of vehicle exhaust emissions of light duty vehicles. This procedure, which is performed on a chassis dynamometer, is designed to yield accurate values of grams per mile (g/km) for the three pollutants.

Introduction—The Environmental Protection Agency has defined the test procedures for vehicle exhaust emissions of gasoline fueled and diesel powered light duty vehicles in the Federal Register (1-4). These procedures must be rigidly adhered to when new motor vehicles are certified to have emissions below the established standards prior to the sale of these vehicles to the public. Since these procedures are not applicable to gas turbine powered light duty vehicles, a procedure which is applicable for engine and vehicle development purposes has been defined and is presented.

The recommended procedure is defined as a "fuel based continuous technique." In this procedure, the undiluted exhaust pollutant species and the engine fuel flow are measured continuously throughout the test driving schedule. By using the carbon balance technique, the instantaneous pollutant concentrations can be expressed as an instantaneous "grams of pollutant per kilogram of fuel burned" (commonly referred to as Emission-Index). Multiplying this value by the measured instantaneous fuel flow and summing these values for the entire test will give the total grams of pollutants. Dividing by the total mileage of the test will give the desired grams per mile (g/km) value. In addition to grams per mile (g/km) values, this procedure provides instantaneous emission information which can be used for diagnostic and developmental purposes.

Background—Since gas turbine powered cars are not currently offered for sale to the public, there is no requirement for EPA to certify the emissions of a gas turbine powered light duty vehicle. For this reason, no test procedure for gas turbine powered light duty vehicles has been issued by EPA.

The EPA procedures referred to earlier are unable to accommodate a gas turbine since these procedures specify the processing and handling of the total dilute exhaust flow of the test vehicle. In all cases covered by these procedures, the total exhaust flow is significantly below the 350 ft³/min (0.165 m³/s) capacity of the equipment in use. Since turbine exhaust flows can be 10 times this value, the existing equipment for processing the total exhaust flow is inadequate. Although a scaled-up version of the equipment specified by the EPA procedure could be recommended, the committee decided that this recommendation could not be justified at this time because of technical uncertainty, very low dilute concentrations, cost, size, and lack of incentives for implementation of such a procedure. The committee, therefore, decided to recommend a procedure which would provide for an accurate determination of the three pollutant emissions for making engineering comparisons. However, the procedure was required to be reasonably simple and inexpensive as well as being suitable as a development technique.

This recommended procedure can provide data that can be used for development and comparison purposes. An attractive feature of this procedure is that it is applicable to any type of engine regardless of the exhaust flow rate, provided its instantaneous fuel flow can be measured. Therefore, this procedure is equally applicable not only to gas turbines,

but also to other engines, such as spark ignition engines, diesel engines, steam engines, and Stirling engines.

This universal applicability permits a determination of the accuracy of the procedure. The fuel based continuous procedure can be used for measuring piston engine emissions in parallel with the conventional Federally specified procedure. Results of such tests by the committee as well as those reported in the literature (5,6) establish the good correlation between the fuel based continuous procedure and the Federally specified procedure for piston engines. Although a similar parallel test is not available for a gas turbine, it is reasonable to assume that the turbine results from the fuel based procedure should be as accurate as those from the piston engine.

CONTENTS

Purpose and Introduction

1. Definitions

1.1 Terms

1.2 Abbreviations and Symbols

2. Instrumentation

2.1 Exhaust Gas Analytical System

2.2 Exhaust Gas Sampling System

2.3 Fuel Flow Instrumentation

2.4 Data Recording

2.5 Chassis Dynamometer

3. Instrumentation Routines

3.1 Exhaust Gas Analytical Procedures

3.2 Fuel Flow Instrumentation

4. Test Procedure

4.1 Test Layout

4.2 Test Conditions

4.3 Test Procedure

5. Information to be Recorded

5.1 Sample Data Sheet

5.2 Continuous Data

6. Calculation of Results

6.1 Continuous (Scan) Data

6.2 Equations for Calculation of Modal Mass Emissions from Continuous Data

6.3 Optional Combustion Performance Parameters

6.4 Computation of Composite Results

6.5 Sample Emission Calculation

7. Presentation of Results

References

1. Definitions of Terms and Abbreviations

1.1 Terms

1.1.1 EXHAUST EMISSION—Any substance (but normally limited to pollutants) emitted to the atmosphere from any opening downstream from the exhaust part of the combustion chamber of an engine.

1.1.2 GAS TURBINE ENGINE—Any engine using the basic gas turbine or Brayton cycle consisting of adiabatic compression, constant pressure heating, and adiabatic expansion.

1.1.3 CALIBRATING GAS—Gas of known concentration used to establish instrument response.

1.1.4 SPAN GAS—A single calibrating gas blend routinely used for cali-

The ϕ symbol is for the convenience of the user in locating areas where technical revisions have been made to the previous issue of the report. If the symbol is next to the report title, it indicates a complete revision of the report.

bration of an instrument such as those used for detecting hydrocarbons, carbon monoxide, and nitric oxide.

1.1.5 ZERO GAS—A calibrating gas used routinely to check instrument zero.

1.1.6 CONCENTRATION—The volume fraction of the component of interest in the gas mixture—expressed as volume percentage or as parts per million (ppm).

1.1.7 TOTAL HYDROCARBONS—The total of hydrocarbon compounds of all classes and molecular weights.

φ 1.1.8 FLAME IONIZATION DETECTOR (FID)—An analytical instrument used for determining the carbon concentration of hydrocarbons in a gas sample.

1.1.9 NON-DISPERSIVE INFRARED ANALYZER—An instrument that, by absorption of infrared energy, selectively measures specific components.

φ 1.1.10 CHEMILUMINESCENT ANALYZER—An instrument in which the intensity of light produced by the chemiluminescence of the reaction is proportional to the concentration of the component analyzed, as with the reaction of nitric oxide and ozone.

1.1.11 INTERFERENCE—Instrument response due to the presence of components other than the gas that is to be measured.

1.2 Abbreviations and Symbols

(CO) = concentration of carbon monoxide

(CO₂) = concentration of carbon dioxide

(HC) = concentration of unburned hydrocarbon as equivalent carbon (for example, ppm C)

(H₂) = concentration of hydrogen

(NO) = concentration of nitric oxide

(NO₂) = concentration of nitrogen dioxide

(NO_x) = sum of (NO) + (NO₂)

(TC) = total carbon in exhaust, (HC) + (CO) + (CO₂)

(BG) = concentration of background pollutant

() = molar percent except as noted

y = atomic hydrogen/carbon ratio of fuel

COEI = CO emission index—g CO/kg fuel

HCEI = HC emission index—g HC/kg fuel

BGEI = BG emission index—g BG/kg fuel

NOXEI = NO_x emission index—g NO_x/kg fuel

EFF = combustion efficiency

FV = fuel volume associated with combustion during a time increment

FM = fuel mass associated with combustion during a time increment

FVT = total fuel volume during driving mode

FMT = total g fuel consumed during driving mode

SG = specific gravity of fuel

M = molecular weight

CT = cold transient modes

CS = cold stabilized modes

HT = hot transient modes

BG = background

B = beginning of period

E = end of period

N = total number of time increments during driving mode

T = temperature—F (C)

2. Instrumentation

2.1 Exhaust Gas Analytical System—Fig. 1 is a schematic drawing of a typical exhaust gas sampling and analytical system for the continuous measurement of exhaust gas products emitted from the exhaust pipe of a gas turbine engine. Additional components such as instruments, valves, solenoids, pumps, and switches may be added to provide additional information and facilitate the operation of the component systems.

2.1.1 ARRANGEMENT OF ANALYTICAL SYSTEM—The following components are recommended for use in the exhaust sampling system.

(a) Water Removal Devices—No dessicants, dryers, water traps or related equipment should be used to treat the exhaust sample flowing to the HC and NO_x analysis instrumentation. Use of such devices is optional for the CO and CO₂ analyzers.

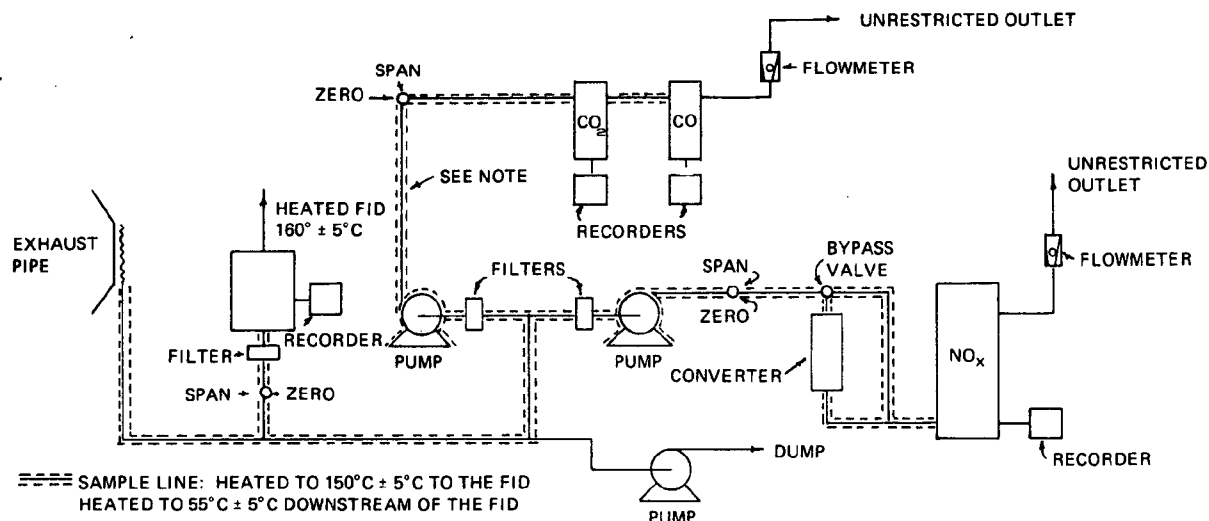
(b) Particulate Filter—Borosilicate glass fiber filters approximately 7 cm in diameter with appropriate holding fixture of low internal volume should be used (one in each leg of the sample system) to remove any particulate matter which may be present. Contaminated filters can result in excessive hang-up and should be changed frequently (as often as each test).

(c) Pumps—A positive displacement pump (typically 20 L/min with pump inlet and outlet at atmospheric pressure) should be used in each leg of the analysis system to pull the sample from the probe to the pump and then to push the sample through the analyzer. It is recommended that a diaphragm type pump with a Teflon diaphragm and stainless steel chamber be used to minimize hang-up. Carbon vane or piston pumps which may introduce a hydrocarbon lubricant into the sample gas are to be avoided. The pump should supply a non-varying flow rate. The pump and its motor should be mounted in such a manner as to minimize the transmission of mechanical vibration to the system as such vibration may affect the output of the analyzers.

(d) Flow Control and Measurement—Sample flow or pressure in each of the analyzers must be held constant and may be regulated either with an automatic flow regulator or manually by adjustable needle valves, and should then be monitored by a rotameter with an inert material float. The range of the rotameter should be consistent with the required analyzer flow.

(e) Auxiliary Heating—All specified sample lines, filters, pumps, and control valves should be heated to such a temperature that no water vapor in the exhaust sample will condense. A temperature of 55 ± 5°C should meet this requirement.

2.1.2 HYDROCARBON ANALYZERS—Hydrocarbon measurements should be made with a heated flame ionization detector (HFID) type analyzer. This analyzer should be fitted within a constant-temperature chamber housing the detector and sample handling components. This chamber



NOTE: HEATED LINE DOWNSTREAM OF PUMP OPTIONAL. IF NOT USED ADDITION OF COLD TRAP, DESICANT COLUMN, AND ASCARITE COLUMN MAY BE REQUIRED TO ELIMINATE CONDENSATION AND INTERFERENCES

FIG. 1—EXHAUST GAS ANALYSIS SYSTEM

should maintain a temperature within the range of 155–165°C. The analyzer should be capable of meeting the following specifications:

- (a) Response Time (Electrical)—90% of full scale in 0.5 s or less.
- (b) Noise— $\pm 1\%$ of full scale on most sensitive range.
- (c) Repeatability— $\pm 1\%$ of full scale on all ranges.
- (d) Zero Drift—Less than $\pm 1\%$ of full scale in 2 h on all ranges.
- (e) Span Drift—Less than $\pm 1\%$ of full scale in 2 h on all ranges.
- (f) Linearity—Response with propane in air should be $\pm 2\%$ over the range of 0–2000 ppm C.
- (g) Oxygen Effect—The response to propane in air shall not differ by more than 3% from the response to propane in a 10% O₂/90% N₂ mixture, nor differ by more than 5% from the response to propane in nitrogen.

(h) Range and Accuracy

0–10 ppm C	$\pm 5\%$ of full scale
0–100 ppm C	$\pm 2\%$ of full scale
All higher ranges	$\pm 1\%$ of full scale

(i) Flame ionization type hydrocarbon analyzers are affected by the oxygen content of the sample gas. This is normally not a problem with turbine exhaust, since the oxygen content of the exhaust does not vary greatly from that of air (which is the recommended diluent for the calibration gases). Should oxygen synergism become a problem, it should be determined and corrected for as described in Ref. 7.

2.1.3 (NDIR) ANALYZERS—Non-dispersive infrared analyzers should be used for the monitoring of carbon monoxide and carbon dioxide. These instruments may be installed either in series or in parallel. They should meet the following specifications:

- (a) Response Time (Electrical)—90% full scale in 0.5 s or less.
- (b) Zero Drift—Less than $\pm 1\%$ of full scale in 2 h on most sensitive range.
- (c) Span Drift—Less than $\pm 1\%$ of full scale in 2 h.
- (d) Repeatability— $\pm 1\%$ of full scale.
- (e) Noise—Less than 1% of full scale on the most sensitive range.
- (f) Range and Accuracy (excluding interferences)

Carbon Monoxide	
0–100 ppm	$\pm 2\%$ of full scale
All higher ranges	$\pm 1\%$ of full scale
Carbon Dioxide	
0–2%	$\pm 1\%$ of full scale
All higher ranges	$\pm 1\%$ of full scale

(g) All NDIR instruments should be equipped with cells of suitable length to measure exhaust concentrations within the ranges necessary to the above accuracies. Range changes may be accomplished either by use of stacked cells or changes in electronic circuitry.

(h) Interferences—The NDIR instruments used to measure CO and CO₂ may be heated or unheated. In either configuration they must be free from significant interferences from other gases found in the exhaust stream. The extent of water vapor and carbon dioxide interference on the carbon monoxide analyzer shall be determined by passing a range of anticipated concentrations of carbon dioxide and water vapor through the instrument and observing the response. If the effect is greater than 2% of measured CO levels, all subsequent measurements shall be corrected for these interferences. The extent of water vapor interference on the carbon dioxide analyzer shall be determined by passing a range of anticipated concentrations of water vapor through the instrument and observing the response. If the effect is greater than 2% of measured CO₂ levels, all subsequent measurements shall be corrected for this interference.

2.1.4 NO_x ANALYZERS—Oxides of nitrogen measurements should be made with a chemiluminescent type instrument. Since this type of instrument is sensitive to only nitric oxide (NO), it is necessary that the instrument be equipped with a high efficiency thermal converter which will convert any nitrogen dioxide (NO₂) to nitric oxide prior to analysis. This instrument should be capable of meeting the following specifications:

- (a) Response Time (Electrical)—90% of full scale in 0.5 s or less.
- (b) Noise—Less than 1% of full scale.
- (c) Repeatability— $\pm 1\%$ of full scale.
- (d) Zero Drift—Less than $\pm 1\%$ of full scale in 2 h.
- (e) Span Drift—Less than $\pm 1\%$ of full scale in 2 h.
- (f) Linearity—Linear to $\pm 2\%$ of full scale on all ranges.
- (g) Range and Accuracy

0–10 ppm	$\pm 1\%$ of full scale
All higher ranges	$\pm 1\%$ of full scale

- (h) Converter Efficiency—Should be greater than 90%.

NOTE: There may be problems in achieving the specified noise and response specifications simultaneously. If these problems are encountered and a specification must be relaxed, it is most important that the response times of all analyzers be balanced.

2.2 Exhaust Gas Sampling System

2.2.1 SAMPLING PROBE—The exhaust gas sampling probe/or probes shall be designed to provide a continuous representative sample of the engine exhaust gas. To minimize any change in the chemical composition of the exhaust gas sample, the probe shall be made of stainless steel, or other inert material. It should be ascertained that no catalytic action occurs in the probe. Prior to testing under this procedure, it shall be determined that the sampling probe provides an adequate representative sample of the exhaust gas. In general, a mixing probe of the following design has been shown to provide a representative sample. The probe may be fabricated from a $\frac{3}{8}$ in (9.5 mm) stainless steel tube which is sealed at one end. Sampling holes of equal diameter ($\frac{1}{16}$ in [1.6 mm] is commonly used) shall be spaced at 1 in (25.4 mm) intervals along the portion of the tube which is inserted inside the exhaust duct. The sampling holes shall be sized so that the major pressure drop through the probe assembly shall be taken at the holes or orifices. When the probe is inserted in the exhaust duct, the sampling holes shall face upstream (analogous to a total pressure probe).

Generally, one sampling probe per exhaust duct is adequate. When the vehicle has two exhaust ducts, connection of the two sampling probes with a minimum restriction "Tee" will usually provide a single representative sample for the emission analyzers. The exhaust sampling probes shall be located a minimum of 2 exhaust duct diameters downstream from the engine exhaust flange.

The emissions from an oil sump breather system must be included in this procedure. Therefore, it must be ascertained that the breather emissions are either directly or indirectly (through an internal venting system analogous to a PCV valve system in a piston engine) included in the exhaust gas sample provided by the sampling probe.

2.2.2 SAMPLE TRANSFER—The continuous exhaust sample shall be transferred from the sampling probe to the analytical instruments through a sample line of either stainless steel or other inert material. Total sample flow rate should be adjusted so that a fresh charge of sample gas will be transported from the sampling probe entrance to the inlet of each analyzer within 6 s. Sample line length should be as short as possible and sample bypass flow should be maintained as required.

2.3 Fuel Flow Instrumentation—The measurement of fuel flow shall be made using either an integrating, volumetric, positive-displacement meter or a flow rate meter of the rotor or turbine type. Other meter types may also be employed provided their performance conforms to the general specifications outlined herein.

Performance specifications for the integral, volumetric fuel meter are as follows:

Flow Rate Range:	0.5 gal/h (1.89 L/h) to 125% of highest flow rate expected during test.
Resolution:	0.0003 gal (1.14 mL) or less.
Accuracy:	$\pm 0.5\%$ of reading ¹ or ± 0.0003 gal (1.14 mL) whichever is greater for 2–20 gal/h (7.57–75.7 L/h).
	$\pm 1.0\%$ of reading ¹ or ± 0.0003 gal (1.14 mL) whichever is greater for 0.5–2.0 gal/h (1.89–7.57 L/h) and 20 gal/h (75.7 L/h) to max. flow.
Repeatability:	$\pm 0.3\%$ of reading or ± 0.0003 gal (1.14 mL) whichever is greater.
Temperature range:	60°F (15.5°C)–150°F (65.6°C) ambient.

Performance specifications for the fuel flow rate meter are as follows:

Flow Range:	0.5 gal/h (1.89 L/h) to 125% of highest flow rate expected during test.
Resolution:	0.5% of full scale.
Accuracy:	$\pm 0.5\%$ of full scale.
Zero Drift:	Less than 0.5% of full scale in 2 h.
Span Drift:	Less than 0.5% of full scale in 2 h.
Repeatability:	$\pm 1.0\%$ of reading.
Temperature Range:	60°F (15.5°C)–150°F (65.6°C) ambient.
Response:	90% of final reading for 0 to maximum fuel flow in less than 0.5 s.

¹ The readout of an integral, volumetric fuel meter normally displays the cumulative fuel volume measured (for example, in gal [L]) from reset of the readout to zero. It does not display a fuel flow rate (for example, in gal/h [L/h]). The use of the expression "% of reading" for the integral, volumetric fuel meter, therefore, refers to a percentage of the total fuel volume measured and displayed and not to a percentage of some fuel flow rate.