SAE The Engineering Society For Advancing Mobility Land Sea Air and Space® INTERNATIONAL
400 Commonwealth Drive, Warrendale, PA 15096-0001

SURFACE VEHICLE RECOMMENDED PRACTICE

Submitted for recognition as an American National Standard

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(R) INSTRUMENTATION AND TECHNIQUES FOR VEHICLE REFUELING EMISSIONS MEASUREMENT

1. ***Scope***—This SAE Recommended Practice describes a procedure for measuring the hydrocarbon emissions occurring during the refueling of passenger cars and light trucks. It can be used as a method for investigating the effects of temperatures, fuel characteristics, etc., on refueling emissions in the laboratory. It also can be used to determine the effectiveness of evaporative emissions control systems to control refueling emissions. For this latter use, standard temperatures, fuel volatility, and fuel quantities are specified.

2. ***References***

2.1 **Applicable Documents**—The following publications form a part of this specification to the extent specified herein. The latest issue of SAE publications shall apply.

2.1.1 SAE PUBLICATION—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J171—Measurement of Fuel Evaporative Emissions from Gasoline Powered Passenger Cars and Light Trucks Using the Enclosure Technique

2.1.2 ASTM PUBLICATIONS—Available from ASTM, 1916 Race Street, Philadelphia, PA 19103-1187.

ASTM D 86—Method for Distillation of Petroleum Products
ASTM D 323—Test Method for Vapor Pressure of Petroleum Products (Reid Method)
ASTM D 3343—Method for Estimation of Hydrogen Content of Aviation Fuels

3. ***General Discussion***—Refueling losses are made up of the following individual losses:

a. Displaced fuel tank vapor
b. Entrained fuel droplets in the displaced vapor
c. Liquid spillage
d. Nozzle drip during insertion and removal from the filler neck

Experience has shown that displaced vapor normally is 90% or more of the total loss. The amount of displaced vapor is known to be affected by a number of factors, particularly dispensed fuel temperature, Reid vapor pressure, and the degree to which dispensed fuel and displaced vapor come into contact.

The measurement facility described in this document includes a sealed enclosure. The enclosure is identical to that described in SAE J171, except for the minimum length specified and that a refueling hose and nozzle has been added. The hydrocarbon measuring instrument is identical to that of SAE J171. This technique is used to measure the total loss for the four sources listed previously.

The document includes the following sections:

4. Test Fuel
5. Test Facilities and Equipment
6. Measurement Method
7. Information and Data to be Recorded

4. Test Fuel

4.1 Standard Conditions—The test fuel should have a Reid Vapor Pressure (RVP) of 62 kPa ± 2 kPa (9.0 psi ± 0.3 psi). To describe the fuel being used adequately, it should be inspected for the properties in Table 1:

TABLE 1—PROPERTIES

Property	ASTM Test Method
Distillation	D 86
IBP	—
5%	—
10%	—
15%	—
20%	—
30%	—
40%	—
50%	—
90%	—
FBP	—
Reid vapor pressure, Pa (psi)	D 323
Hydrogen-Carbon ratio[1]	D 3343

[1] The hydrogen-carbon (H/C) ratio is required for the calculation of losses using the enclosure method. The H/C ratio will be different for vapor losses as compared to liquid losses. Therefore, the H/C ratio should be measured for both condensed vapor and for the test fuel. Judgment should be used in interpolating between the two values for individual tests.

The fuel should not be reused for subsequent refueling emission tests.

4.2 Nonstandard Fuel—A nonstandard test fuel may be used if the purpose of the test is to examine the effect of the fuel properties on refueling emissions. If a nonstandard test fuel is used, the RVP shall be stated along with the test results.

4.3 Fuel Sampling—A sample of test fuel for laboratory inspection should be taken from the source at the start of the test. A 1.0 L (1 qt) container, prechilled to 40 °C (4 °F) should be used. It should be bottom filled to overflow and then poured out to 80% capacity. The container should be tightly sealed immediately after filling and stored at 40 °C (4 °F) or less until fuel inspection tests are made. Alternative sampling procedures may be substituted, but care must be exercised with any sampling procedure to prevent the loss of volatile constituents from the fuel during either sampling or storage.

5. Test Facilities and Equipment—Provisions must be made for controlling the ambient conditions in the enclosure, draining the fuel tank, heating the residual fuel, and performing the refueling operation.

5.1 Ambient—The ambient temperature within the enclosure must be maintained within the range of 20 to 30 °C (68 to 86 °F).

5.2 Fuel Tank Preparation—Facilities and safeguards must be provided for draining vehicle fuel tanks. The work area must be well ventilated. Drain connectors and containers must be grounded to the vehicle tank. Drain the tank through installed fuel tank drains or other suitable method. The intent is to remove all usable fuel and leave the unusable fuel, thus providing a standard repeatable empty-tank condition. For standard conditions, an amount of fuel equal to 10% of the tank capacity should then be placed in the tank. Affix fuel cap to filler pipe and tighten prior to placing the vehicle in the enclosure.

5.3 Fuel System Preparation—The entire fuel system should be inspected visually for liquid leakage or seepage. A pressure test of fuel tank assembly, filler pipe, fuel lines, vapor lines, and other components should be made to insure the integrity of the fuel system.

5.4 Thermocouples—Thermocouples should be provided for:

a. Residual fuel in tank
b. Vapor space in tank
c. Fuel in conditioner
d. Dispensed fuel (thermocouple in nozzle)
e. Displaced vapor (located either on nozzle or on filler neck)
f,g. Enclosure (see 6.1)

The thermocouples, particularly those used for vapor, should have fast response. A multichannel potentiometer-type recorder or data logger with 0.5 °C (1 °F) accuracy and a time resolution of 1 s should be used.

5.5 Tank Fuel Heating—An electric heating pad may be needed to heat the fuel tank prior to the refueling operation. This pad should cover 50% or more of the area wetted by the test fuel. A 2000 W heating pad with a variable voltage transformer to regulate heat output should be adequate in most vehicles. Alternative heating methods may be used on vehicles of unusual configuration or, if necessary, to comply with local laboratory safety practices. Storage of the vehicle at elevated ambient temperatures, instead of using a heating pad, is a possibility. All methods should avoid hot spots on the tank wetted surface which could cause local overheating of the fuel. Care must be exercised to not apply heat to the vapor in the tank above the liquid fuel. With proper heating of the tank, vapor temperature will not exceed liquid temperature by more than 3 °C (6 °F). The standard temperature for residual fuel in the tank is 31 °C ± 1 °C (87 °F ± 2 °F).

5.6 Refueling Facility—The refueling facility consists of a fuel tank with temperature control equipment, service station type dispensing pump, meter, hose, and nozzle. Only the hose and nozzle are inside the enclosure. The hose shall intersect the enclosure wall below the level of the vehicle fuel tank filler; the seal at the intersection of the base and the wall shall be gas-tight. Sealed arm holes with gloves shall extend inside the SHED and permit the operator to perform fueling operations from outside the SHED. The amount of fuel trapped in the hose and other piping outside of the temperature control unit should be minimized. Figure 1 shows a typical fuel conditioning unit.

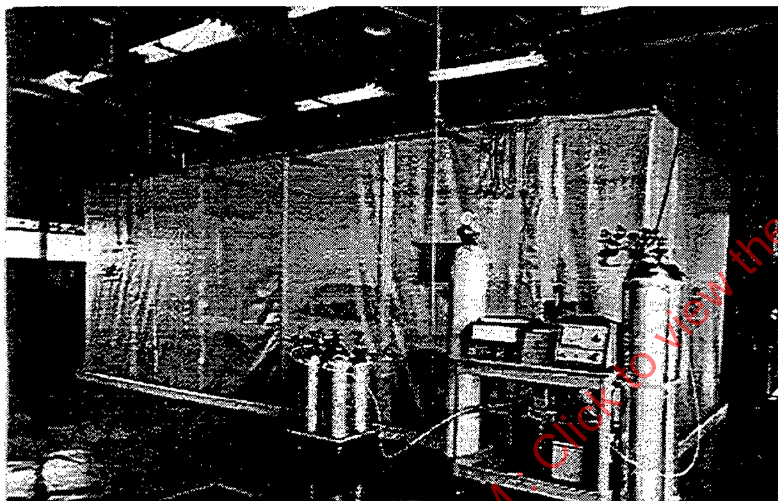
FIGURE 1—FUEL CONDITIONING UNIT

The system must be capable of delivering the fuel at the desired test temperature and flow rate. The standard temperature for fuel stored in the unit is 28 °C ± 0.5 °C (82 °F ± 1 °F). The standard flow rate is 36 L/min ± 2 L/min (9.5 gal/min ± 0.5 gal/min).

6. ***Measurement Method***—The car enclosure method provides for sealing the vehicle in an enclosure during the test. Emissions are determined from the changes in the hydrocarbon concentrations in the enclosure. This method produces a single measurement of refueling losses from all sources.

6.1 Equipment Requirements—An enclosure with internal dimensions of 3.1 x 6.7 x 2.6 m high (10 x 22 x 8.5 ft high) has been found convenient for testing most United States passenger cars. The foregoing dimensions may be adjusted to accommodate different sized vehicles without significantly affecting the test results. The enclosure door must allow entry of the maximum sized vehicle. Door sealing may be accomplished by a resilient gasket, an inflatable seal, or a pressure sealing zipper if a flexible door is used. Interior surfaces must be impermeable to hydrocarbons. Permeable materials may be covered with a polyvinyl fluoride[1] sheet of approximately 0.15 mm (0.006 in) thickness. One wall, or door or ceiling, should be of flexible material such as 0.15 mm (0.006 in) polyvinyl fluoride sheet to provide a safety "blow-out" panel, and to allow for minor temperature changes of the contained gas without excessive "breathing." The enclosure should have a window located so that the instrument operator can observe the refueling operation. Electrical ground connections must be provided between any metal parts of the enclosure and the dispensing nozzle. A ground lead and a clip must be provided for grounding any part of the vehicle coming in contact with the fuel or fuel nozzle (rear bumper, fuel filler tube, and fuel tank).

Figure 2 shows two different enclosure designs.



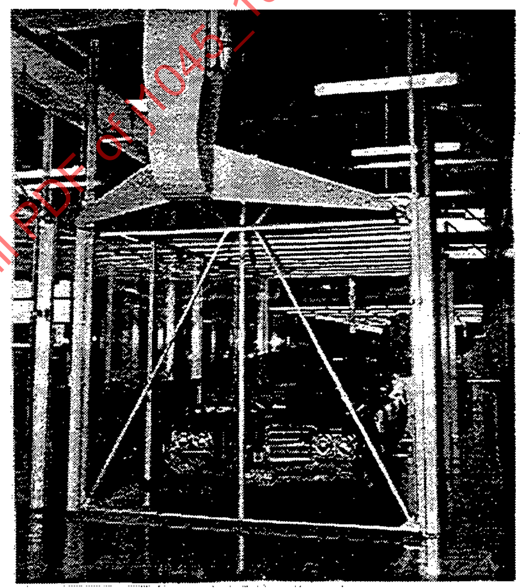


FIGURE 2—DIFFERENT ENCLOSURE DESIGNS

The enclosure must be equipped with a flame ionization detector (FID) hydrocarbon analyzer capable of measuring hydrocarbon concentrations reliably in the range of 10 to 5000 ppm carbon. Support gases recommended by the manufacturer of the FID and calibrating gases are required as follows:

a. Support Gases

Ultrapure grade zero air
40% Hydrogen in Helium

[1] "Tedlar" or equivalent.

90-1202B EG

b. Calibration Gases

50 ppm propane in air (nominal)
100 ppm propane in air (nominal)
300 ppm propane in air (nominal)
1000 ppm propane in air (nominal)

A typical sample train for the analyzer is shown in Figure 3. The sample should be withdrawn from the enclosure through a tube of 6 mm (1/4 in) OD, terminating 50 mm (2 in) inside the wall and located on the geometric center of the wall opposite the door or on one of the sides or below the center of the ceiling. The tubing connecting this tube to the analyzer should be of 6 mm (1/4 in) OD stainless steel or similarly inert material and should be as short as possible.

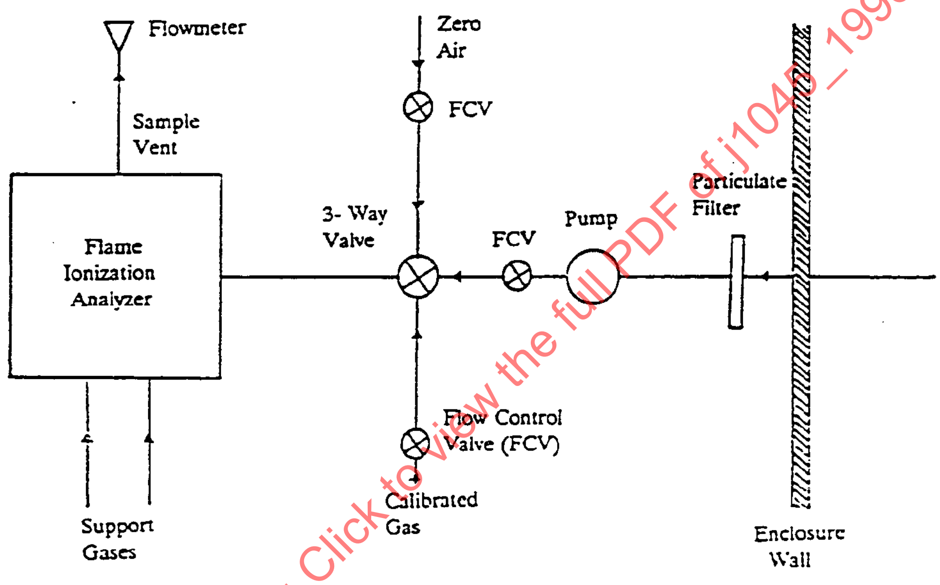


FIGURE 3—FID SAMPLE TRAIN

The FID output should be recorded on a strip chart instrument with a chart speed of about 100 mm/min (4 in/min) or a data logger with a 1 s time resolution.

A blower (portable or fixed) of 42 to 158 m^3/min (1500 to 5600 ft^3/min) is required for purging the enclosure between tests, and an explosion-proof blower of 3 to 30 m^3/min (100 to 1000 ft^3/min) capacity is required for mixing the enclosure atmosphere during tests. This blower should be directed toward the most likely area that could encounter any spilled fuel.

Two thermocouples for monitoring the enclosure temperature should be installed 760 mm (30 in) above the floor and 100 mm (4 in) in from either side, both midway along the length of the enclosure.

6.1.1 SYSTEM CHECKOUT—The complete enclosure measurement system should be checked initially and periodically for calibration, hydrocarbon retention (leakage) and self-emission. Appendix A gives details.

6.1.2 BACKGROUND EMISSIONS—Particularly in new cars, solvents, plasticizers, etc., are emitted and must be accounted for. Therefore, a measurement of background emissions is included in 6.2.

6.1.3 SAFETY AND HEALTH CONSIDERATIONS—Any test should be aborted and the enclosure immediately ventilated if hydrocarbon concentration exceeds 5000 ppm propane. This concentration provides a 4:1 safety factor against the lean flammability limit.

No person should enter the enclosure until it has been purged with ambient air to a safe hydrocarbon concentration level.

Displaced vapor as well as spillage will cause combustible mixtures to be present in localized areas. Therefore, always use the nozzle and vehicle ground leads and avoid any other source of a spark.

Suitable fire extinguishers should be provided for use in the immediate area.

6.2 Operating Sequence

6.2.1 Zero and calibrate the gas analyzer.

6.2.2 With the door open, discharge the purge blower into the enclosure for several minutes immediately prior to test.

6.2.3 Push the vehicle into the enclosure and make the thermocouple connections. Attach the vehicle ground leads. The engine should be at or near room temperature to minimize emissions from that area. Open all windows and luggage compartments. Bring the fuel tank temperature to test temperature (see 5.5) and maintain it up to step 6.2.9.

6.2.4 Start mixing blower and orient it to discharge toward the area where spillage could occur.

6.2.5 Close and seal the door. Make initial reading of FID analyzer. Determine enclosure internal air temperature and barometric pressure.

6.2.6 Watch the enclosure hydrocarbon concentration and temperature traces until the conditions are stabilized and the vehicle is ready for the refueling test. The hydrocarbon trace may not stabilize but continue to rise at a low, constant rate. This is caused by background emissions from the car.

6.2.7 Allow the FID trace to stabilize. Continue the trace long enough to determine the background emissions in terms of ppm/min. Once stabilized, read temperatures, barometric pressures, and time—these are the initial readings.

6.2.8 Perform the refueling operation. Remove fuel cap. (See 5.6 for fuel temperature.) The refueling operation ends at the time automatic nozzle shutoff occurs. The amount of fuel added should at least equal 80% of the fuel tank's nominal capacity (vehicle entered refueling operation with 10%, see 5.2). If a premature nozzle shutoff occurs, dispensing shall be resumed within 10 s.

6.2.9 Observe the FID trace until the readings are stabilized. Record the elapsed time in minutes between the initial and final FID readings including all temperature and barometric pressures.

Abort any test if the health and safety conditions of 6.1.3 are exceeded.

6.2.10 Subtract the initial from the final reading to determine the net concentration of hydrocarbons. Subtract the background correction, if any.

6.3 Calculation of Emissions—The net hydrocarbon mass change M_{HC} in the enclosure is calculated from the net hydrocarbon concentration of the enclosure in ppm carbon, enclosure volume, temperature and pressure, using the following equation:

$$M_{HC} = \frac{kC_{HC}VP \cdot 10^{-4}}{T} \quad \text{(Eq.1)}$$

where:

M_{HC} = Hydrocarbon mass in grams
C_{HC} = Net hydrocarbon concentration as ppm carbon
V = Enclosure volume, m^3 (ft^3) (subtract vehicle volume for vehicle tests, approximately 1.42 m^3 (50 ft^3) with windows and trunk open)
P = Barometric pressure, kPa (in Hg), measured when door is closed and sealed
T = Enclosure ambient temperature K (°R), measured when door is closed and sealed
H/C = Atomic hydrogen-to-carbon ratio of fuel vapor assumed to be 2.33
k = 1.20 (12+H/C) = 17.2 (in English units, k = 0.208 (12+H/C) = 2.98)

Note that hydrocarbon concentration is stated in ppm carbon, that is, ppm propane x3. Derivation of this equation is shown in Appendix B.

Report refueling emissions as grams per liter of fuel dispensed (g/L) or grams per gallon (g/gal).

7. Information and Data to be Recorded

7.1 Information

a. Test identification
b. Vehicle description
c. Nozzle description
d. Test fuel identification
e. Desired test temperatures
f. Desired fueling rate

7.2 Data to be Collected

a. Barometric pressure
b. Enclosure temperature a
c. Enclosure temperature b
d. Fuel tank initial temperature
e. Fuel tank final temperature
f. Fuel tank initial vapor temperature
g. Fuel temperature in conditioner
h. Dispensed fuel temperature
i. Displaced vapor temperature
j. Did prefill nozzle drip occur?
k. Did spillage occur?
l. Were entrained droplets visible?
m. Did post fill nozzle drip occur?
n. Gallons dispensed
o. Dispensing time, min
p. Dispensing rate, L/min (gal/min)

q. Initial FID reading, ppm carbon
r. Final FID reading, ppm carbon
s. Background correction, ppm carbon
t. Net increase, ppm carbon
u. Calculated emissions, g
v. Calculated emissions, g/L or g/gal dispensed

8. Notes

8.1 Marginal Indicia—The (R) 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.

PREPARED BY THE SAE EXHAUST EMISSIONS MEASUREMENT STANDARDS COMMITTEE

APPENDIX A
CAR ENCLOSURE SYSTEM CHECKOUT

*A.1 **Calibration***—Zero and calibrate gas analyzer. After discharging the purge blower into the enclosure for several minutes, seal the door and read the enclosure background hydrocarbons (HC) concentration.

Using gravimetric or critical flow injection techniques, inject approximately 4.0 g of propane into the SHED. After allowing sufficient time for complete mixing, read the final hydrocarbon concentration. Determine the mass of emissions using the equation in 6.3. The discrepancy between the enclosure indicated hydrocarbon mass and the mass of injected propane should be less than ±2% for satisfactory calibration.

*A.2 **Hydrocarbon Retention (Leak Check)***—Inject approximately 4 g of light hydrocarbon (Propane) into the enclosure. Record the enclosure HC concentration.

Allow the enclosure to remain sealed for 4 h without sampling the interior gases. The mixing blower should continue to operate throughout this period.

Read final HC concentration. The difference between the initial and final concentrations should indicate less than 4.0% mass leakage.

*A.3 **Emission Check***—It should be demonstrated that a new enclosure structure does not contain materials which will themselves emit hydrocarbons.

Seal the enclosure after thoroughly purging. Read HC concentration at the beginning and end of a 4 h period without sampling during the interim. Change in the HC concentration should be negligible, but in any case should be less than 0.1 g/h (mass equivalent) to be considered acceptable.

APPENDIX B
DERIVATION OF EQUATION FOR ENCLOSURE GIVING M_{HC} AS A FUNCTION OF C_{HC}

Assume that the enclosure is gas-tight and sealed at or before the time of initial reading. Also assume one enclosure surface is of flexible impermeable material to assure that the internal enclosure pressure is substantially the same as the ambient pressure. Also assume that the enclosure internal volume (V) has been measured and is the internal volume of the enclosure at the time of the initial reading.

The hydrocarbon mass change during the test (M_{HC}) is given by:

$$M_{HC} = W(n_f - n_i) \quad \text{(Eq.B1)}$$

where:

W is the molecular weight of the hydrocarbon and n is the number of moles of gases hydrocarbon in the enclosure. If we assume that both air and the hydrocarbon (at its low partial pressure) behave as ideal gases,

$$n_i = \frac{P_{Bi}V_i}{RT_i} \quad \text{(Eq.B2)}$$

and

$$C_{HCi} = \frac{V_i N(10^6)}{V} \quad \text{(Eq.B3)}$$

or

$$V_i = \frac{C_{HCi}V(10^{-6})}{N} \quad \text{(Eq.B4)}$$

where:

V_i is the initial partial volume of the hydrocarbon
N is the number of atoms of carbon in the hydrocarbon molecule
V is the net enclosure volume
R is the gas constant
P_B is the barometric pressure
T is the enclosure gas temperature
M_{HC} is the hydrocarbon mass
C_{HC} is the hydrocarbon concentration as ppm carbon
subscripts f and i represent final and initial readings

Substituting Equation B4 into Equation B2:

$$n_i = \frac{VC_{HCi}P_{Bi}(10^{-6})}{RNT_i} \quad \text{(Eq.B5)}$$

Similarly

$$n_f = \frac{P_{Bf} V_f}{RT_f} \quad \text{(Eq.B6)}$$

$$C_{HCf} = \frac{V_f N(10^6)}{V_F} \quad \text{(Eq.B7)}$$

$$V_f = \frac{C_{HCf} V_F (10^{-6})}{N} \quad \text{(Eq.B8)}$$

where:

V_F is the enclosure volume at the time of final reading

V_F may be different from V because of movement of the flexible enclosure surface in response to pressure changes caused by barometric changes, temperature changes, or an increased concentration of gaseous hydrocarbon.

$$V_F = V \frac{T_f P_{Bi}}{T_i P_{Bf}} \left[1 + \frac{(C_{HCf} - C_{HCi})(10^{-6})}{N} \right] \quad \text{(Eq.B9)}$$

The second term in the bracket is usually negligible compared to 1 and will be neglected (an increase of 3000 ppm carbon will cause a 0.1% error).

Substituting Equation B9 into Equation B8:

$$V_f = \frac{C_{HCf} V T_f P_{Bi} (10^{-6})}{N T_i P_{Bf}} \quad \text{(Eq.B10)}$$

Substituting Equation B10 into Equation B6:

$$n_f = \frac{V C_{HCf} P_{Bi} (10^{-6})}{RNT_i} \quad \text{(Eq.B11)}$$

Substituting Equations B11 and B5 into Equation B1:

$$M_{HC} = \frac{WV(10^{-6})}{RN} \left[\frac{C_{HCf} P_{Bi}}{T_i} - \frac{C_{HCi} P_{Bi}}{T_i} \right] \quad \text{(Eq.B12)}$$

Simplifying:

$$M_{HC} = \frac{0.01WV(10^{-4})}{RN} \frac{P_{Bi}(C_{HCf} - C_{HCi})}{T_i} \quad \text{(Eq.B13)}$$