SAE International

SURFACE VEHICLE STANDARD

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Measurement of Passenger Compartment Refrigerant Concentrations Under System Refrigerant Leakage Conditions

RATIONALE

This standard was developed to provide a standard method for measuring refrigerant concentration in a motor vehicle. This is needed to provide consistent inputs to any risk assessment that is done on new refrigerants being developed for mobile air conditioning.

1. SCOPE

This Standard is restricted to refrigeration circuits that provide air-conditioning for the passenger compartments of passenger and commercial vehicles.

This Standard includes analytical and physical test procedures to evaluate concentration inside the passenger compartment. In the early phases of vehicle evaluation, usage of the analytical approach may be sufficient without performing physical tests.

The physical test procedure involves releasing refrigerant from an external source to a location adjacent to the evaporator core (inside the HVAC-Module). An apparatus is used to provide a repeatable, calibrated leak rate. If the system has multiple evaporators, leakage could be simulated at any of the evaporator locations.

This standard gives detail information on the techniques for measuring R-744 [CO2] and R-1234yf [HFO-1234yf], but the general techniques described here can be used for other refrigerants as well.

1.1 Purpose

The purpose of this SAE Standard is to provide a uniform test procedure to evaluate the refrigerant concentration level inside of a vehicle passenger compartment resulting from leakage of refrigerant from a Mobile Air Conditioning system (MAC). This Standard does not establish concentration limits.

Refrigerant can leak from the evaporator, hoses, lines, and connectors that are directly exposed to the passenger compartment or the cabin air distribution system. Refrigerant concentration is influenced by leak size, refrigerant charge, HVAC operation mode, body sealing, and vehicle operation mode.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

2.1.1.1 System Design Guidelines

SAE J639 Safety Standards for Motor Vehicle Refrigerant Vapor Compression Systems

SAE J2773 R-1234yf and R744 Refrigerant Standard for Safety and Risk Analysis for use in Mobile Air Conditioning Systems

SAE J2842 R-1234yf and R-744 Design Criteria and Certification for OEM Mobile Air Conditioning Evaporator and Service Replacements

2.1.2 Other Publications

Refrigerant Material Safety Data Sheet

Safe Use and Handling Guidelines available from refrigerant suppliers

3. VEHICLE SYSTEM DESCRIPTION

3.1 Vehicle Interior Volume

The vehicle interior volume is the space available to the occupants. It can change depending on vehicle interior variants. It includes volumes such as HVAC housing and duct internal volumes. For the determination of an interior volume, the net free space of the interior of the vehicle as built is to be considered. Net free space is defined as the volume of the interior of the cabin minus all components inside the vehicle, (seats, trim, instrument panel components and structure, steering wheel, etc.). CAE models may be used to determine the vehicle interior volume. Table 1 shows typical vehicle volumes.

3.2 Passenger Volume Considerations

To determine the refrigerant concentration of the vehicle interior, the volume displaced by passengers shall be considered. Therefore, the effective vehicle interior volume is reduced by 75 L/passenger. For the measurement of the interior concentration, mannequins shall be placed on the seats according to the rated seating capacity of the vehicle. Physical mannequins and the displacement volumes used in testing shall be constructed of impermeable materials (metal, hard plastic) or shall be taped with aluminum foil backed tape or encased in an impermeable plastic material to avoid the possible diffusion of the refrigerant into the mannequins.

TABLE 1 - TYPICAL VEHICLE INTERIOR VOLUMES

Vehicle Type	Interior Size [m^3]	Number of Seats	Adjusted Interior Volume [m^3]
Compact Sports Vehicle	1.6	2	1.4
Sub-Compact Vehicle	1.7	4	1.4
Compact Vehicle	2.4	4	2.1
Full Size Car	2.8	5	2.4
Large size vehicle	3.1	6	2.6
SUV	4.0	6	3.5
Mini Van	6.0	9	5.2

3.3 Air Exchange Rate Considerations

Vehicle cabins are not hermetically sealed in relation to their environment. An additional air exchange with the environment around the vehicle takes place via openings in the vehicle body. These openings include: Pressure Release Valves (PRV), body structure gaps, leaking sealing elements, etc. This air exchange is affected by the driving speed and other operating and ambient conditions. The air exchange rate [AER] expresses the frequency in which the interior air of a vehicle cabin is replaced. Air exchange is also referred to as "body leakage." Table 2 shows typical air exchange rates.

TABLE 2 - TYPICAL AIR EXCHANGE RATES

Vehicle operation condition	HVAC Status	AER [h^{-1}]
Stand still	Off	0.5-1.0
IDLE	Low Blower, 100% RECIRC	2.0-3.0
Driving	Low Blower, RECIRC	4.0-6.0

REF: "Air change rates of motor vehicles and in-vehicle pollutant concentrations from second hand smoke", WAYNE OTT, NEIL KLEPEIS AND PAUL SWITZER, Journal of Exposure Science and Environmental Epidemiology (2007), 1–14

Table 2 is for reference only. The vehicle OEM can consider the AER to use for physical test and analysis evaluations. In the analysis situation, the locations for the air exchange shall be specified in the analytical model.

4. REFRIGERANT RELEASED DURING A LEAK

4.1 Nominal Charge

The vehicle manufacturer specifies the nominal amount of charge in the refrigerant circuit. The determination of that charge is in context of the development process. It can be determined under high climatic load.

The durable nameplate or tag mounted in the engine compartment, as described in SAE J639, contains information about the lubricant type and the amount of refrigerant charge. This may be the starting point for determining the refrigerant charge to use during the test. This amount can be reduced due to oil absorption, as described below.

4.2 Oil Absorption

When the system is charged, part of the refrigerant dissolves into the compressor lubricating oil. This will reduce the amount of refrigerant released during a leak.

4.3 Factors to Consider Regarding Leaks

When a refrigerant leak occurs, only the available refrigerant will be released out of the refrigerant circuit. The refrigerant dissolved in the lubricant remains in the circuit and will be released over a longer period. The OEM shall consider how much refrigerant may be dissolved in the oil and not released. In a rapid leak [e.g., mechanical breakage, collision scenarios] more refrigerant will be retained in the system compared to a corrosion leak of refrigerant into the passenger compartment. The amount of oil retained in the system will also be variable and this should be considered when evaluating retained refrigerant. The refrigerant amount used in test shall be adjusted based on this analysis. Additional factors to be considered may include other component failures releasing refrigerant outside the passenger compartment, collision activated devices that limit the amount of refrigerant that can be released into the cabin, and/or other HVAC module design features.

4.4 Calculation of Charge Amount Released into Passenger Compartment

The following is an example calculation:

TABLE 3 - EXAMPLE OF CALCULATION FOR RELEASED REFRIGERANT

Charge Consideration	Charge amount, [g]
SAE J639 charge label [or an estimate if not yet determined]	600
Amount of refrigerant estimated to be retained in the system in a rapid discharge of refrigerant (zero (0) grams for corrosion leaks)	-40
Amount not released due to other design feature of the AC system (i.e., system internal volume or component layout and design)	-50
Amount released by breakage in another component failure	-150
Amount discharged into passenger compartment for test:	360

4.5 Passenger Generated CO_2 Due To Respiration

In the case of R-744, a saturated background CO_2 concentration shall be taken into account, due to passenger respiration. The respiration rate of 20 L of CO_2 per hour per passenger should be considered for determining the background concentration. The saturation value shall be recorded in the test summary.

5. TEST CONDITIONS

The refrigerant concentration will vary based on the wind speed over the body, temperature, atmospheric pressure, leak rate and number of occupants in the vehicle. The selected HVAC settings and controls (such as items shown in Table 4 below) also influence the concentration of refrigerant in the vehicle. The OEM shall consider these vehicle design characteristics in determining the expected case for maximum concentration in the vehicle.

Table 4 shows an example test plan for evaluating a new vehicle design.

Other test parameters should be considered, such as:

1. Unique settings that may be required by individual OEM

2. Unique settings that may be required due to hardware/software limitations or features

TABLE 4 - EXAMPLE TEST PLAN CONDITIONS

Exterior Wind Velocity	HVAC mode	Blower	RECIRC/Outside Air	Temp control
2-3 m/s	Foot	OFF	OSA	Full Hot
~0 m/s	Face/Panel	LOW	RECIRC	Full Cold
2-3 m/s	Face/Panel	LOW	RECIRC	Full Cold
2-3 m/s	Face/Panel	HIGH	RECIRC	Full Cold
2-3 m/s	DEF	HIGH	OSA	Full Hot
~0 m/s	BI-LEVEL	OFF	RECIRC	50%
2-3 m/s	BI-LEVEL	OFF	RECIRC	50%

NOTE: When in face mode, the outlets should be directed to the face of the mannequins in the vehicle.

5.1 Refrigerant Leakage Rates

The rate of refrigerant leakage is a significant parameter influencing the local refrigerant concentration inside a passenger vehicle. The following leakage rates and leak diameters have been determined from field returned evaporator failures. Two alternate refrigerants currently being considered are shown in Table 5.

For corrosion leak testing, refrigerant shall flow through an orifice of the diameter shown in Table 5. The pressure across the orifice shall be equal to that of a thermally soaked system at a temperature of 40 °C

For severed line testing, the instantaneous rate of leakage shall be maintained to within ±20% of the value shown in Table 5.

Deviation from the prescribed table shall be identified with causal reason in the test report.

TABLE 5 - REFRIGERANT FLOW RATES FOR DIFFERENT EVAPORATOR FAILURE MODES.

Leak Type	Leak diameter [mm]	Vapor flow rate [g/sec]	
		R-744	R-1234yf
Corrosion	0.1	0.10 (average)	0.03
Severed Line – Collision	6.35	50	12

5.2 Refrigerant Quality

Refrigerant released into the passenger compartment shall be in the vapor phase.

5.3 Operating and Ambient Test Conditions

Refrigerant concentration shall be determined for the different HVAC and vehicle operating conditions in the test plan. The vehicle shall be evaluated with mannequins that represent the prescribed test scenario occupant level and operated at room temperature (22 °C ± 10K). The vehicle OEM is responsible to determine the vehicle conditions to evaluate for refrigerant concentration in the passenger compartment and may run at additional ambients but shall evaluate at the ambient above.

6. IN-CABIN REFRIGERANT MEASUREMENT EQUIPMENT AND PREPARATION

There are several methods of capturing the concentration measurement in the vehicle passenger compartment that are suitable. For all methods, the time interval between readings can be chosen based on the leak rate and the measurement method used. Two physical methods are described below. Also, details to construct an analytical model are shown.

Several apparatus for releasing refrigerant are described. Investigators are not limited to the examples given.

6.1 Safety Considerations

Cylinders used for holding refrigerant shall meet high pressure cylinder requirements and be checked periodically to assure they are safe to use.

Refrigerant charge should not fill the cylinder past 80% liquid volume at room temperature.

Cylinders should be equipped with pressure relief devices.

Refrigerant concentration testing shall be conducted in a facility with sufficient air exchange rate to assure that the concentration of the refrigerant shall not exceed a toxic or flammable level.

If local regulation prohibits the release of refrigerants into the atmosphere, substitute gases with similar properties may be used for testing. At present, suitable substitute gases have not been identified.

6.2 Real-Time Electronic Sensor

For detecting the refrigerant concentration inside a vehicle compartment, commercially available sensors with sufficient long-term stability can be used. The output of the sensors shall report the refrigerant concentration in volume percent. The measuring range of the sensor for the refrigerant shall be from 0% by volume up to 20% by volume. The sensor shall maintain accuracy between 10 °C and 50 °C. The sensor shall have an accuracy of at least ±0.2% by volume at 5% volume level. All sensors shall be calibrated against a suitable standard before installing in the test vehicle. Suitable calibration standards are: gas chromatography well mixed calibrated volume with a precise refrigerant mass, and calibrated laminar flow meter controllers. Other calibration standards are allowed if it is traceable to one or more of the stated calibration standards. Sensors should be calibrated periodically as deemed necessary by the equipment manufacturer.

Electronic sensors and sensor configurations have an associated time constant response to changes in refrigerant concentration. The time constant can have a significant effect on the data if the concentration increases rapidly. Sensor response is analogous to that of an RC circuit. Time constant effects shall be accounted for in the final measurement report.

6.2.1 Electronic Sensor Installation

A refrigerant sensor may be located in the trunk or outside the vehicle with connecting tubing routed to the desired sampling location. A suitably sized air pump may be used to draw an air sample for the desired test location, across the sensor surface, and return the air-refrigerant mixture back to the sampling point location. The connecting tubing and fittings shall be leak tight. The air pump should have a nominal flow capacity of approx. 80 to 120 l/h. It shall be connected with small diameter tubing fastened to the appropriate positions in the interior, while the sensors are located on the respective other end. From the 'dead volume' of the hoses a shift of the measured values shall not exceed 10 s. All hoses shall have equal lengths for all measuring points. If the hoses are thin-walled, kinking of the tubing must be prevented.

6.3 Sampling Bags

Gas sampling bags may be used in conjunction with gas chromatography. This method consists of an air pump to inflate impermeable gas sample bags. Six or more bags can be used. The bags are inflated sequentially with time intervals chosen based on the refrigerant discharge rate. The gas sample is analyzed with a calibrated gas chromatography unit to measure the concentration of the refrigerant. The concentration shall be reported as a volume fraction [% by volume] refrigerant at the specific location and leak time. The internal volume of the connecting lines, manifolds and vapor pumps shall be leak tight and either be kept as small as possible to negate effects of air left in these spaces, or preferably, a recirculation method with the inlet and exit of the tubing at the same location shall be utilized with remotely activated solenoid valves to negate the line volume effect. The sampling equipment may be placed in the interior of the vehicle to simplify the procedure and not introduce added volume to the interior of the vehicle. While this method is a primary measurement method, continuous concentration data is not possible due to specific time and location direct sampling.

6.4 Analytical Case

Refrigerant properties and airflow shall be considered when doing this evaluation analytically.

6.4.1 Refrigerant Properties

Refrigerant Properties 25 °C and 80 °C:

TABLE 6 - TYPICAL REFRIGERANT PROPERTIES FOR R-744 AND R-1234yf

Properties	R-1234yf	R-744
Boiling Point, Tb	-29 °C	-78.5 °C (sublimates)
Critical Point, T_c	95 °C	31 °C
Pvap, MPa (25 °C)	0.68	6.4
Pvap, MPa (80 °C)	2.4	11.0 [with a charge of 260 g/dm^3]
Liquid Density, kg/m^3 (25 °C)	1094	711
Vapor Density, kg/m^3 (25 °C)	37.6	243

6.4.2 Airflow

Attributes of body leakage and blower motor flow rates for each blower speed shall be documented in the evaluation report. Examples include:

- Total body leakage flow rate
- Allocation of leak rate to vehicle components
  - Front and Rear Doors
  - Trunk Opening or Lift Gate
  - Sun/Moon roof glass
  - Other leakage paths (dash panel, body systems, etc.)

6.5 Location of the Vehicle Interior Measuring Points

For determination of the refrigerant concentration in the interior of the vehicle, a sample bag, internally vented sensor, or the probe-taking opening (end of hose) shall be located at fixed locations in the vehicle. The position of the sensors or the intake openings may be fixed with a wire frame or other appropriate designs. The investigator may choose the sampling locations based on the refrigerant and its characteristics.

In the analytical evaluation, the concentration detection locations may be a spherical volume instead of a single point.

Possible sensor locations include the breath location, between the knees, and on the floor. See Figure 1.

- The breath point is located 20 cm to the front of the headrest position at the average height of an adult occupant's face.
- The knee point is located approximately 10 cm forward of the seat between the knees of the mannequin.
- The floor location is located at the center of the foot area and 4.0 cm off the floor surface.
- The sensor locations shall be documented with respect to interior fixed points.

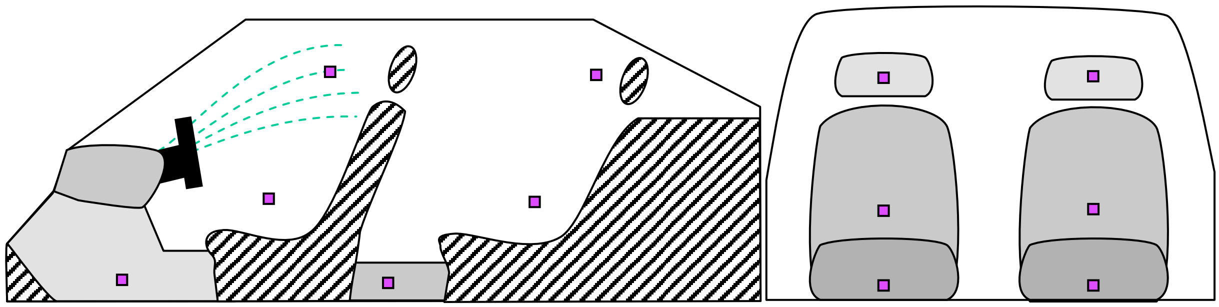

FIGURE 1 - POSSIBLE LOCATIONS OF THE INTERIOR MEASURING POINTS

6.6 Refrigerant Leak Position

The simulated evaporator leakage outlet shall be positioned in the center, upper third of the evaporator at the outlet side (cold face) or inlet side (hot face) of the evaporator. The OEM shall determine whether to measure at the outlet side or inlet side based on the location of the evaporator piping, module design, most probable leak location, etc. The location shall be included in the test report. The refrigerant leakage mass flow is fed by a feeder line carried out as pipe/hose into the HVAC module. The flow direction of the leaking refrigerant is transverse to the evaporator airflow (Figure 2). The inlet tube is positioned inside the HVAC housing. The last 25 mm of the tube shall be horizontal as shown in Figure 2. The HVAC housing has to be cut to introduce the inlet pipe and the inlet tube shall then be sealed to the housing. Systems with multi-zone temperature controls should when possible locate the injection zone so that refrigerant will flow to all zones. (e.g., dual zone, (balanced flow to the left and right side of the vehicle), Tri zone (balanced flow to left, right and rear; quad zone balanced flow left, right and front and rear). The temperature setting should be the same in all zones.

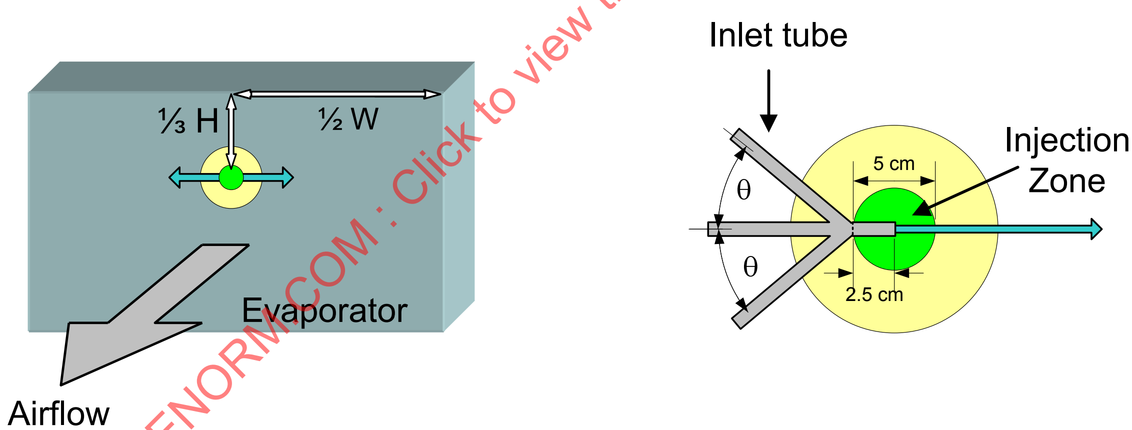

FIGURE 2 - SCHEMATIC POSITIONING OF LEAKAGE SOURCE AT THE EVAPORATOR

For multiple evaporator systems, investigator shall consider the impact of leakage from each evaporator and run tests as needed.

6.7 Vehicle Preparation

The vehicle shall be loaded with the appropriate passenger volumes. (75 L for each seat) The vehicle doors, hood, trunk lid, windows, sliding/lifting roofs shall be closed. All openings made for test equipment (tubing, wiring, etc.) to pass out of the vehicle shall be sealed. The refrigerant sensors shall be installed in appropriate positions. The HVAC mode, blower, RECIRC settings shall be set as desired for the condition under investigation.