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Fuel cell road vehicles — Energy consumption measurement — Vehicles fuelled with compressed hydrogen

Véhicules routiers avec pile à combustible — Mesurage de la consommation d'énergie — Véhicules alimentés par hydrogène comprimé

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 23828 was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 21, *Electrically propelled road vehicles*.

Introduction

Fuel cell vehicles (FCV) include the following types:

— pure fuel cell vehicle (PFCV), in which the fuel cell system is the only on-board energy source for propulsion and auxiliary systems;

— fuel cell hybrid electric vehicle (FCHEV), in which the fuel cell system is integrated with an on-board rechargeable energy storage system (RESS) for electric energy supply to propulsion and auxiliary systems.

FCHEV design options include:

a) externally chargeable or non-externally chargeable;

b) rechargeable energy storage system (RESS): battery or capacitor;

c) driver-selected operating modes: if the FCHEV has no driver-selected operating mode, it has only an FCHEV mode.

Table 1 shows the classification of FCHEV.

Table 1 — Classification of FCHEV

	Chargeability	Operating mode
FCHEV	externally chargeable	FCHEV mode
		EV mode
	non-externally chargeable	**FCHEV mode**
		EV mode

This International Standard is applicable to PFCV and to non-externally chargeable FCHEV with FCHEV mode only (see shaded boxes in Table 1).

Fuel cell road vehicles — Energy consumption measurement — Vehicles fuelled with compressed hydrogen

1 Scope

This International Standard specifies the procedures for measuring the energy consumption of fuel cell passenger cars and light duty trucks which use compressed hydrogen and which are not externally chargeable.

Annexes A, B and C describe procedures specific to particular regions.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 1176, *Road vehicle — Masses — Vocabulary and codes*

ISO 3833, *Road vehicles — Types — Terms and definitions*

ISO 10521-1, *Road vehicles — Road load — Part 1: Determination under reference atmospheric conditions*

ISO 10521-2, *Road vehicles — Road load — Part 2: Reproduction on chassis dynamometer*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 3833 and ISO 1176 and the following apply.

3.1
battery state of charge
battery SOC
residual capacity of battery available to be discharged

NOTE   Battery state of charge is normally expressed as a percentage of full charge.

3.2
charge balance of battery
change of charge in battery during test period

NOTE   Charge balance of battery is normally expressed in A·h.

3.3
electric vehicle operation mode
EV operation mode
mode of a FCHEV in which only the RESS is used for the vehicle propulsion and possibly auxiliary systems

1

3.4
fuel cell hybrid electric vehicle operation mode
FCHEV operation mode
mode of a FCHEV in which both RESS and fuel cell system are used sequentially or simultaneously for vehicle propulsion

NOTE   The fuel cell system can also charge the RESS during propulsion or standstill.

3.5
fuel cell vehicle
FCV
electric vehicle using a fuel cell power system for vehicle propulsion

NOTE   A FCV can have additionally a RESS or other power sources for vehicle propulsion.

3.6
fuel cell hybrid electric vehicle
FCHEV
electric vehicle using a RESS and a fuel cell power system for vehicle propulsion

3.7
pure fuel cell vehicle
pure FCV
FCV using only a fuel cell power system for vehicle propulsion

3.8
rechargeable energy storage system
RESS
system that stores energy for delivery of electric energy and that is rechargeable

EXAMPLE   Batteries, capacitors.

4 Measurement accuracy

4.1 General

Measurement accuracy shall be in accordance with national standards.

4.2 Hydrogen measurement accuracy

Test apparatus shall assure the accuracy of measurement of $\pm 1 \%$ for the total mass of hydrogen consumption during the test cycle, unless otherwise specified in the relevant annexes.

5 Hydrogen consumption measurement

5.1 General

Various methods for the measurement of hydrogen consumption have been developed which reflect the current state of studies in the field. Hydrogen consumption shall be measured using one of the following:

— pressure method;

— gravimetric method;

— flow method.

These three methods, which are described in detail in Annexes D, E and F, have been shown to give sufficiently equivalent results. Other methods may also become applicable if they show comparable equivalence and reliability.

5.2 Pressure method

Hydrogen consumption is determined by measuring the pressure and temperature of gas in the high-pressure hydrogen tank, before and after the test. A tank with known internal volume that allows measurement of gas pressure and temperature shall be used for the test.

5.3 Gravimetric method

Hydrogen consumption is calculated by measuring the weight of the high-pressure hydrogen tank before and after the test. The tank used for the test shall be suitable for measuring weight.

5.4 Flow method

The amount of hydrogen supplied to and consumed by a vehicle is measured by a flow meter.

6 Test procedure

6.1 General condition

The test shall be conducted after preparation of the vehicle and test apparatus as described in this clause.

6.2 Vehicle condition

6.2.1 General

The vehicle shall be clean, and the windows and air entries that are not needed for the correct operation of the vehicle and the drive system shall be closed by the normal operating controls.

The lighting, signalling and auxiliary devices shall be turned off, except those required for testing and for usual day-time operation of the vehicle.

6.2.2 Vehicle stabilization

Prior to testing, the test vehicle shall be stabilized; this includes vehicle mileage accumulation in accordance with a manufacturer-determined distance, unless otherwise specified in Annex A, B or C (as appropriate).

6.2.3 Vehicle appendages

Vehicles shall be tested with normal appendages (mirrors, bumpers, etc.). Where necessary, certain items (e.g. hub caps) may be removed for safety on the dynamometer.

6.2.4 Vehicle test mass

The vehicle test mass shall be selected in accordance with Annex A, B, or C.

6.2.5 Tyres

6.2.5.1 General

Tyres recommended by the vehicle manufacturer shall be used.

6.2.5.2 Tyre pressure

When the vehicle tyres are at ambient temperature, they shall be inflated to the pressure specified by the vehicle manufacturer for the chosen test (track or chassis dynamometer).

6.2.5.3 Tyre conditioning

Tyres shall be conditioned as recommended by the vehicle manufacturer. See Annex A, B, or C for additional requirements.

6.2.6 Lubricants

The vehicle lubricants specified by the manufacturer shall be used.

6.2.7 Gear shifting

If the vehicle is fitted with a manually shifted gear box, gear shifting positions shall correspond to the test procedures described in Annexes A, B and C. However, the shift positions may be selected and determined previously in accordance with the vehicle characteristics.

6.2.8 Regenerative braking

If the vehicle has regenerative braking, the regenerative braking system shall be enabled for all dynamometer testing. If a vehicle is equipped with an antilock braking system (ABS) or a traction control system (TCS) and is tested on a single-roll dynamometer, these systems may inadvertently interpret the non-movement of the set of wheels that are off the dynamometer as a malfunctioning system. If so, modifications to these systems shall be made to achieve normal operation of the remaining vehicle systems, including the regenerative braking system.

6.2.9 RESS stabilization

The RESS shall have been stabilized with the vehicle, as defined in 6.2.2, or by equivalent conditioning.

6.3 Chassis dynamometer conditions

6.3.1 General

The vehicle generally should be tested on a single-roll chassis dynamometer. A four-wheel-drive vehicle shall be tested by modifying the drive train of the vehicle. When the vehicle is modified, the details shall be explained in the test report.

A four-wheel-drive dynamometer test may be performed when a modification for a single-roll dynamometer test is not possible for a specific four-wheel-drive vehicle.

6.3.2 Dynamometer calibration

The dynamometer shall be calibrated as specified by the vehicle manufacturer, or in accordance with the specifications indicated in the service manual provided by the dynamometer manufacturer.

6.3.3 Dynamometer warm-up

The dynamometer shall be warmed up sufficiently prior to the testing.

6.3.4 Determining the dynamometer load coefficient

The determination of vehicle road load under reference atmospheric conditions shall conform to ISO 10521-1, and the reproduction on a chassis dynamometer shall conform to ISO 10521-2 or national standards. Vehicles equipped with regenerative braking systems that are activated at least in part when the brake pedal is not depressed shall have regenerative braking disabled during the deceleration portion of coast-down testing on both the test track and dynamometer.

6.4 Fuel consumption tests

6.4.1 General

Depending on the region concerned, the appropriate procedure shall be followed from Annex A, B, or C. Details and common procedures for each test mode are described below.

6.4.2 Vehicle preconditioning

Vehicle preconditioning shall be carried out in accordance with the annex appropriate for the region. In the case of FCHEV, the RESS state of charge may be pre-adjusted by charging or discharging, to obtain a suitable energy difference in RESS between the start and the end of test.

6.4.3 Vehicle soak

The vehicle shall be soaked in accordance with the appropriate regional procedure prescribed in Annex A, B, or C.

6.5 Measurement over scheduled driving test

For the measurement of hydrogen consumption, the test vehicle shall be driven on the chassis dynamometer in accordance with the running mode prescribed for the region (see Annex A, B, or C, as appropriate). The hydrogen consumption can be measured by one of the methods described in Annex D, E, or F, or by an alternative method that provides equivalent accuracy.

The hydrogen consumption is determined by means of one of the following equations:

$$C_{\text{F1}} = \frac{b_{t0} \times 10^{-3}}{L} = \frac{w \times \dfrac{22,414}{m} \times 10^{-3}}{L} \tag{1}$$

$$C_{\text{F2}} = \frac{w \times 10^{-3}}{L} = \frac{b_{t0} \times \dfrac{m}{22,414} \times 10^{-3}}{L} \tag{2}$$

$$C_{\text{F3}} = \frac{b_{t0} \times 10^{-3} \times Q_{\text{H}}}{L} = \frac{w \times \dfrac{22,414}{m} \times 10^{-3} \times Q_{\text{H}}}{L} \tag{3}$$

where

C_{F1} is the hydrogen consumption per unit distance, in m³/km, referred to volume at normal conditions (273 K; 101,3 kPa);

C_{F2} is the hydrogen consumption per unit distance, in kg/km, referred to weight;

C_{F3} is the hydrogen consumption per unit distance, in MJ/km, referred to caloric value;

L is the distance, in km;

b_{t0} is the hydrogen consumption at normal conditions (273 K, 101,3 kPa);

w is the hydrogen consumption, in g;

m is the molecular weight of hydrogen (2,016);

Q_H is the lower calorific value of hydrogen (10,8 MJ/Nm^3).

6.6 Correction of the test results for FCHEV

6.6.1 General

After the FCHEV has been tested, the hydrogen consumption shall be corrected if the energy difference in the RESS between the start and the end of test is above the limit described in 6.6.2.

6.6.2 Allowable limit for RESS energy change for FCHEV

The allowable limit for RESS energy change is

$$| \Delta E_{RESS} | \leqslant 0,01 \times E_{CF} \tag{4}$$

where

ΔE_{RESS} is the energy change in RESS over the test cycle;

E_{CF} is the energy of consumed fuel over the test cycle.

Further details are described in Annex J.

6.6.3 Correction procedure using a correction coefficient

The hydrogen consumption at $\Delta E_{RESS} = 0$ shall be calculated by using a correction coefficient to be provided by the vehicle manufacturer. Details on the acquisition and the application of the correction coefficient are given in Annex K.

NOTE   Annex L gives recommendations on the data collecting procedure to obtain the correction coefficient.

7 Presentation of results

Test results should be recorded in accordance with Annex I. The fourth significant digit should be rounded off to provide the hydrogen consumption rate to three significant digits.

Other data should be recorded as required by the regional regulations.

Annex A
(informative)

Test procedure in Japan

A.1 General

This annex describes the typical procedures and related conditions in Japan for measuring the fuel consumption of passenger cars and light duty trucks, as defined in Japanese regulations.

A.2 Accuracy for determining vehicle road load and others

When determining road load, the accuracy shall conform to ISO 10521-1 and ISO 10521-2.

A.3 Driving procedure

A.3.1 General

The gear manipulation in each operational condition specified in Tables A.1 and A.2 shall be performed smoothly and quickly in accordance with the instructions in this clause.

A.3.2 Vehicles with manual transmission

A.3.2.1   The idling operation refers to a condition in which the accelerator pedal is not depressed, with the transmission gear in neutral.

A.3.2.2   The transmission gear shall be shifted to the low gear position (or such a gear in instances where the "low" gear position should read otherwise in Tables A.1 and A.2) 5 s before the idling operation mode is switched to the acceleration mode.

A.3.2.3   For deceleration, the clutch shall be disengaged at a speed of 10 km/h during the deceleration operation from 20 km/h to 0 km/h, and at a speed of 20 km/h during the deceleration operation from 40 km/h to 0 km/h, as specified in Tables A.1 and A.2. In the same way, the clutch shall be disengaged at a speed of 30 km/h during the deceleration operation from 70 km/h to 0 km/h, as specified in Table A.2.

A.3.2.4   On vehicles with a 6-speed transmission in which it is not possible to drive by operating the shift lever in respective gear positions as specified in Table A.2 because of the running performance of the vehicle, driving may be carried out in accordance with the example of the 5-speed transmission specified in Table A.2.

A.3.2.5   If the revolutions of the motor of the test vehicle exceed the revolution speed at which the motor delivers its maximum output during the operation of the test vehicle, the gear position that is one step higher than the original gear may be used. In this case, the vehicle speed at which the gearshift takes place shall be the vehicle speed corresponding to the revolution speed at which the motor delivers its maximum output.

A.3.3 Vehicle with automatic transmission

The selector position shall remain in drive position. No further manipulation shall be made.

A.3.4 Vehicles with other transmissions

Gear changes shall be made taking into consideration the running characteristics of the tested vehicle with transmissions other than those described in A.3.2 and A.3.3.

A.4 Vehicle test mass

The test vehicle mass shall be obtained when two persons (each of an assumed mass of 55 kg) or a mass of 110 kg are loaded on the test vehicle, under the "unloaded state" prescribed in the *Safety Regulations for Road Vehicles*, Ministry of Transportation Ordinance No. 67, 1951, Article 1, paragraph 1, item (3).

A.5 Tyre conditioning

Tyres shall be conditioned as recommended by the vehicle manufacturer, shall have accumulated a minimum of 100 km (62 miles) and shall have at least 50 % of the original usable tread depth remaining.

A.6 Dynamometer inertia setting

The equivalent inertia mass set for the chassis dynamometer shall be the standard value of equivalent inertia mass specified in the right column of Table A.3, corresponding to the vehicle test mass specified in the left column of Table A.3.

However, if the specified equivalent inertia mass is not available on the chassis dynamometer being used, the equivalent inertia mass of within +10 % of the specified standard value may be used.

Table A.1 — Operation conditions, vehicle speed, acceleration/deceleration of 10 mode

| Mode no.	Operation conditions	Vehicle speed	Duration of operation	Cumulative time	Standard gear positions				Acceleration or deceleration
		km/h	s	s	3-speed transmission	(3+OD)- speed transmission	4-speed transmission	5-speed transmission	m/s²
1	idling	—	20	20	—	—	—	—	—
2	acceleration	0-20	7	27	(0-20)ᵃ Low	(0-20)ᵃ Low	(0-15)ᵃ Low (15-20)ᵃ 2nd	(0-15)ᵃ Low (15-20)ᵃ 2nd	0,78
3	constant speed	20	15	42	2nd	2nd	2nd	2nd	—
4	deceleration	20-0	7	49	2nd	2nd	2nd	2nd	0,78
5	idling	—	16	65	—	—	—	—	—
6	acceleration	0-40	14	79	(0-20)ᵃ Low (20-40)ᵃ 2nd	(0-20)ᵃ Low (20-40)ᵃ 2nd	(0-15)ᵃ Low (15-30)ᵃ 2nd (30-40)ᵃ 3rd	(0-15)ᵃ Low (15-30)ᵃ 2nd (30-40)ᵃ 3rd	0,78
7	constant speed	40	15	94	Top	3rd	Top	4th	—
8	deceleration	40-20	10	104	Top	3rd	Top	4th	0,59
9	constant speed	20	2	106	Top-2nd	3rd-2nd	Top-3rd	4th-3rd	—
10	acceleration	20-40	12	118	2nd	2nd	3rd	3rd	0,49
11	deceleration	40-20	10	128	Top	3rd	Top	4th	0,59
		20-0	7	135	Top	3rd	Top	4th	0,78
ᵃ Figures in brackets represent vehicle speeds for respective gear positions.									
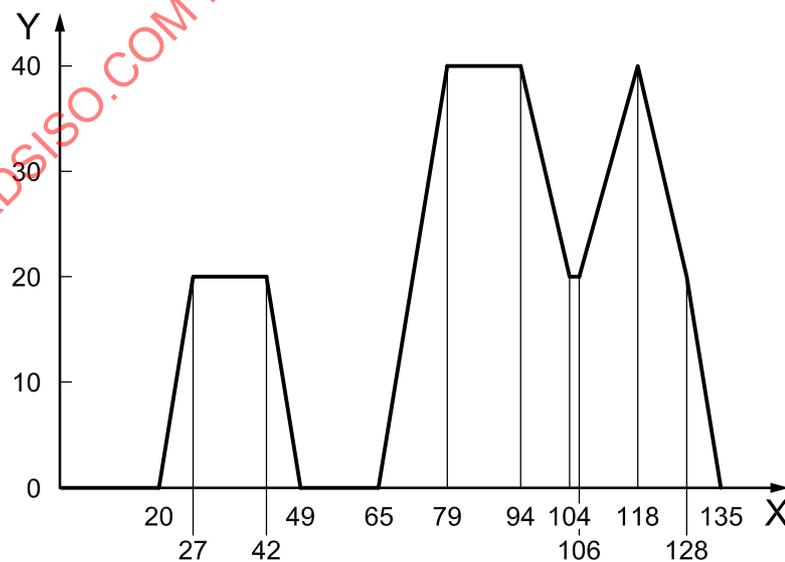
Key

Y vehicle speed (km/h)

X time (s)

Figure A.1 — 10 Mode, vehicle speed versus time

Table A.2 — Operation conditions, vehicle speed, acceleration/deceleration of 15 mode

Mode no.	Operation conditions	Vehicle speed	Duration of operation	Cumulative time	Standard gear positions					Acceleration or deceleration
		km/h	s	s	3-speed transmission	(3+OD)-speed transmission	4-speed transmission	5-speed transmission	6-speed transmission	(m/s²)
1	idling	—	65	65	—	—	—	—	—	—
2	acceleration	0-50	18	83	(0-20)[a] Low (20-40)[a] 2nd (40-50)[a] Top	(0-20)[a] Low (20-40)[a] 2nd (40-50)[a] 3rd	(0-15)[a] Low (15-35)[a] 2nd (35-50)[a] 3rd	(0-15)[a] Low (15-35)[a] 2nd (35-50)[a] 3rd	(0-15)[a] Low (15-35)[a] 2nd (35-50)[a] 3rd	0,78
3	constant speed	50	12	95	Top	3rd	Top	4th	4th	—
4	deceleration	50-40	4	99	Top	3rd	Top	4th	4th	0,69
5	constant speed	40	4	103	Top	3rd	3rd	3rd	3rd	—
6	acceleration	40-60	16	119	Top	3rd	3rd	3rd	(40-50)[a] 3rd (50-60)[a] 4th	0,39
7	constant speed	60	10	129	Top	3rd	Top	4th	5th	—
8	acceleration	60-70	11	140	Top	3rd	Top	4th	5th	0,29
9	constant speed	70	10	150	Top	OD	Top	Top	Top	—
10	deceleration	70-50	10	160	Top	OD	Top	Top	Top	0,59
11	constant speed	50	4	164	Top	3rd	Top	4th	5th	—
12	acceleration	50-70	22	186	Top	3rd	Top	4th	5th	0,29
13	constant speed	70	5	191	Top	OD	Top	Top	Top	—
14	deceleration	70-30	20	211	Top	OD	Top	Top	Top	0,59
		30-0	10	221	—	—	—	—	—	0,88
15	idling	—	10	231	—	—	—	—	—	—
[a] Figures in brackets represent vehicle speeds for respective gear positions.										

Key
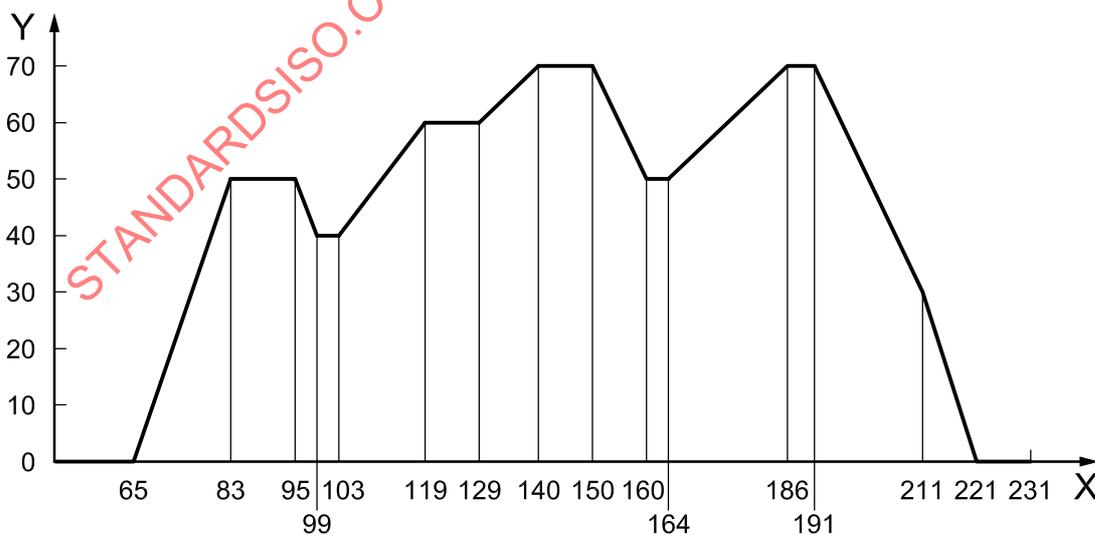
X   time, s

Y   vehicle speed, km/h

Figure A.2 — 15 Mode, vehicle speed versus time

Table A.3 — Standard value of equivalent inertia mass versus test vehicle mass

Test vehicle mass m_V kg	Standard value of equivalent inertia mass I kg
$m_V \leqslant 562$	500
$562 < m_V \leqslant 687$	625
$687 < m_V \leqslant 812$	750
$812 < m_V \leqslant 937$	875
$937 < m_V \leqslant 1\,125$	1 000
$1\,125 < m_V \leqslant 1\,375$	1 250
$1\,375 < m_V \leqslant 1\,625$	1 500
$1\,625 < m_V \leqslant 1\,875$	1 750
$1\,875 < m_V \leqslant 2\,125$	2 000
$2\,125 < m_V \leqslant 2\,375$	2 250
$2\,375 < m_V \leqslant 2\,625$	2 500
$2\,625 < m_V \leqslant 2\,875$	2 750
$2\,875 < m_V \leqslant 3\,250$	3 000
continues in increments of 500 kg	continues in increments of 500 kg

A.7 Test procedure

A.7.1 Preconditioning for vehicle

The test vehicle shall be placed on the chassis dynamometer and warmed up continuously for about 20 min at a constant speed of 60 ± 2 km/h. The vehicle shall then be further warmed up with 15 mode operation (as shown in Table A.2) performed once.

A.7.2 Operating cycle

After the preconditioning, the operating cycle shall start with the idling operation for 24 s, then 10 mode operation (as shown in Table A.1) shall be repeated 3 times consecutively, and 15 mode operation (as shown in Table A.2) shall be performed once.
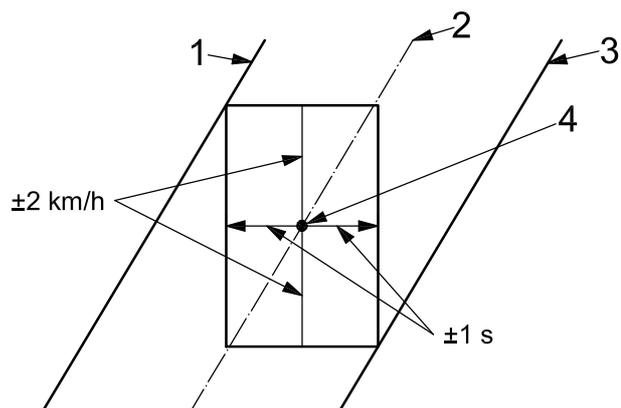
A.7.3 Tolerance of vehicle speed and time

The test vehicle shall be operated within a range of ± 2 km/h of the specified speed, and within a range of ± 1 s of the specified time, during the operations specified in Tables A.1 and A.2. The tolerable range is shown in the area marked in Figure A.3.

If the testing time deviates from the tolerance, but the deviation time is less than 1 s at the time of gear shift and transition of operation mode, the test result is acceptable.

For those vehicles that cannot reach the acceleration specified in Tables A.1 and A.2 with full stroke of the accelerator pedal, the aforesaid requirement shall not apply.

If the test vehicle cannot reach the level of acceleration specified in Tables A.1 and A.2, the acceleration obtained from fully depressing the accelerator pedal shall be used.

Key

1   upper tolerable line

2   reference mode

3   lower tolerable line

4   reference point

Figure A.3 — Tolerance of vehicle speed and time in 10-15 driving mode

Annex B
(informative)

Test procedure in Europe

B.1 General

Based on the legal requirements in Europe, this annex specifies the specific preconditioning procedures and relevant test equipment for the determination of hydrogen consumption of PFCV and FCHEV non-externally chargeable, and with FCHEV mode only of categories M1 and N1 with a maximum permissible total mass (in accordance with ISO 1176) of 3 500 kg.

NOTE   The outline given in this annex contains only those elements essential to understanding the procedure. For further details, reference is made to the relevant clauses and subclauses in the regulations UNECE R 101 and UNECE R 83.[1)]

B.2 Test equipment

B.2.1 Chassis dynamometer

Features, accuracy, load and inertia setting, calibration and other steps to prepare the chassis dynamometer to be used are prescribed in UNECE R 83, Annex 4, 4.1, 5.1 and 5.2, and in Annex 4, Appendixes 2 and 3. The adjustment of the inertia simulators to the vehicle's translatory inertias shall be in accordance with Table B.1, given in UNECE R 83, Annex 4, 5.1.

B.2.2 Chassis dynamometer

Features, accuracy, load and inertia setting, calibration and other steps to prepare the chassis dynamometer to be used are prescribed in UNECE R 83, Annex 4, 4.1, 5.1 and 5.2 and in Appendixes 2 and 3 of Annex 4. The adjustment of the inertia simulators to the vehicle's translatory inertias shall be in accordance with Table B.1 (as given in UNECE R 83, Annex 4, 5.1).

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1)   This annex is based on the following editions of the two regulations:

— UNECE R 101: Trans/WP.29/GRPE/2004/2, 30 October 2003;

— UNECE R 83: E/ECE/324 Rev.1/Add.82/Rev.2 E/ECE/Trans/505, 30 October 2001.

It does not necessarily reflect subsequent amendments to UNECE R 101 and UNECE R 83.

Table B.1 — Equivalent inertia of the dynamometer related to the reference mass of the vehicle

Reference mass of the vehicle m_V kg	Equivalent inertia I kg
$m_V \leqslant 480$	455
$480 < m_V \leqslant 540$	510
$540 < m_V \leqslant 595$	570
$595 < m_V \leqslant 650$	625
$650 < m_V \leqslant 710$	680
$710 < m_V \leqslant 765$	740
$765 < m_V \leqslant 850$	800
$850 < m_V \leqslant 965$	910
$965 < m_V \leqslant 1\,080$	1 020
$1\,080 < m_V \leqslant 1\,190$	1 130
$1\,190 < m_V \leqslant 1\,305$	1 250
$1\,305 < m_V \leqslant 1\,420$	1 360
$1\,420 < m_V \leqslant 1\,530$	1 470
$1\,530 < m_V \leqslant 1\,640$	1 590
$1\,640 < m_V \leqslant 1\,760$	1 700
$1\,760 < m_V \leqslant 1\,870$	1 810
$1\,870 < m_V \leqslant 1\,980$	1 930
$1\,980 < m_V \leqslant 2\,100$	2 040
$2\,100 < m_V \leqslant 2\,210$	2 150
$2\,210 < m_V \leqslant 2\,380$	2 270
$2\,380 < m_V \leqslant 2\,610$	2 270
$2\,610 < m_V$	2 270

B.2.3 Test equipment for hydrogen measurement methods

For specific test equipment for the hydrogen measurement methods, see Clause 5 and Annexes D, E and F.

B.3 Test vehicle

B.3.1 General

The test vehicle shall be in running order, as determined by the manufacturer, with all the equipment provided as standard.

B.3.2 Test mass

The mass of the vehicle under test (referred to as "reference mass" in UNECE R 83, 2.2) shall be the "unloaded mass" plus a uniform figure of 100 kg. The "unloaded mass" (see UNECE R 83, 2.2.1) is the mass of the vehicle in running order, without load and persons, but with the hydrogen tank 90 % full.

B.3.3 Tyres

The tests shall be performed with standard width tyres, as provided by the vehicle manufacturer. Alternatively, the prescription of UNECE R 83, Annex 4, Appendix 3, 4.1.2, may be applied, i.e. only the widest of the standard widths or the widest minus one (in case of more than three standard widths) shall be chosen.

The tyre pressure shall comply with the vehicle manufacturer specification, but may be increased by up to 50 % when the test is carried out on a two roller dynamometer (see UNECE R 83, Annex 4, 5.3.2).

B.4 Test cycle

The test cycle to be applied shall be the same as that prescribed for the Type I test. This test, including allowable tolerances, is described in UNECE R 83, Annex 4, Appendix 1.

The test cycle is made up of one Part 1 (urban) cycle, consisting of four elementary urban cycles, and one Part 2 (extra-urban) cycle, as illustrated roughly in Figure B.1 and described in Table B.2.
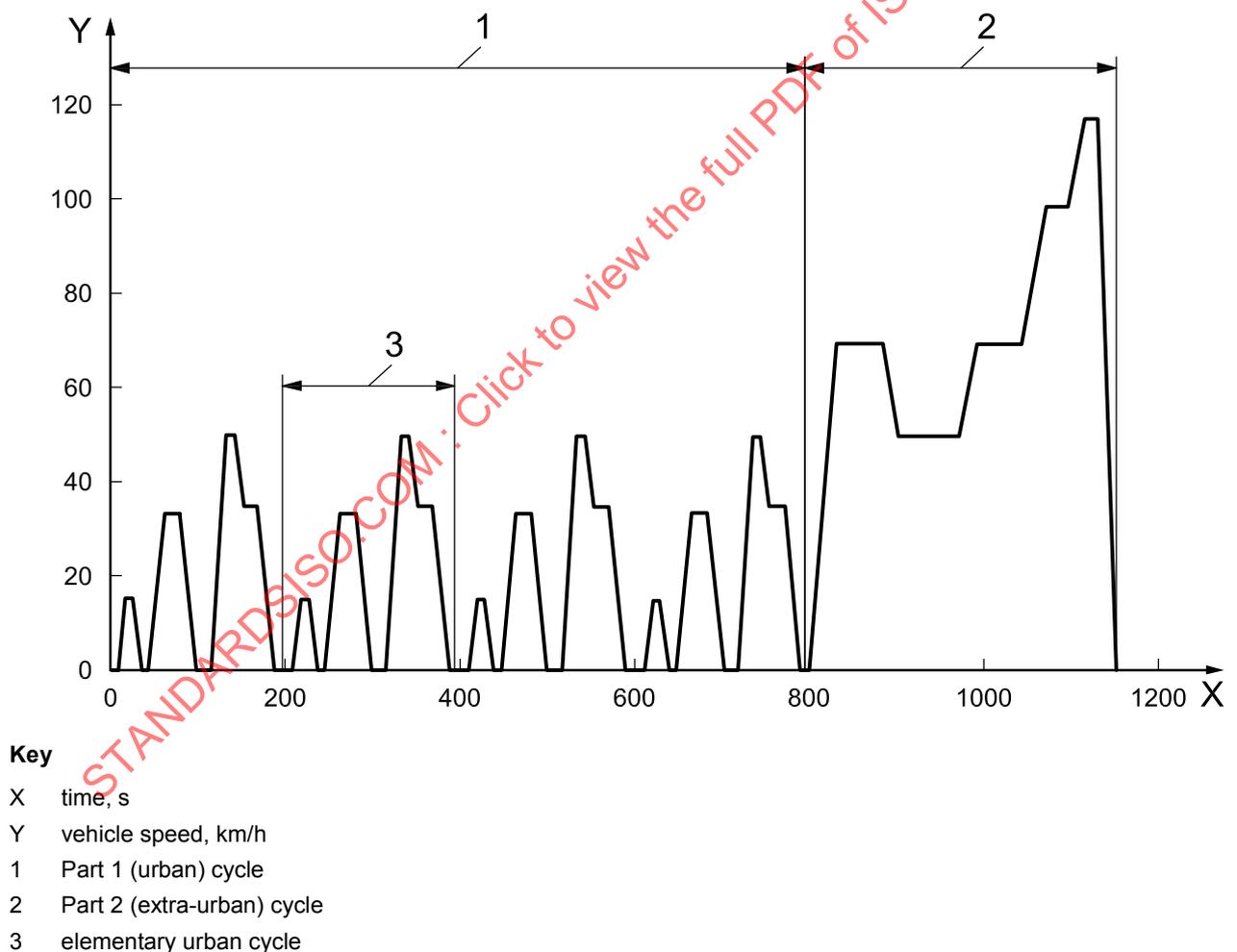

Key

X   time, s

Y   vehicle speed, km/h

1   Part 1 (urban) cycle

2   Part 2 (extra-urban) cycle

3   elementary urban cycle

Figure B.1 — Test cycle

Table B.2 — General information on the test cycle

Parameter	Urban cycle	Extra-urban cycle
Average speed	19 km/h	62,6 km/h
Maximum speed	50 km/h	120 km/h
Effective running time	4×195 s = 780 s (13 min)	400 s (6 min 40 s)
Theoretical distance	$4 \times 1\ 013$ km = 4 052 km	6 955 km

B.5 Test procedure

B.5.1 Preconditioning of the vehicle

The vehicle shall be stabilized in accordance with the vehicle manufacturer's specification, followed by two consecutive full test cycles (see Clause B.4).

B.5.2 Conditioning of the vehicle

After preconditioning in accordance with B.5.1, the vehicle shall be kept in a room with a relative constant temperature of between 20 °C and 30 °C for at least 6 h, until the lubricant and coolant temperatures are within ±2 °C of the room temperature.

B.5.3 Performance of the test

B.5.3.1 General

After preconditioning and conditioning in accordance with B.5.1 and B.5.2, respectively, one complete test cycle shall be run in accordance with Clause B.4. The test equipment shall comply with Clause B.2 and the test vehicle shall comply with Clause B.3. The following requirements also shall be met during the test.

B.5.3.2 Additional conditions

The temperature shall be between 20 °C and 30 °C and the absolute humidity between 5,5 g and 12,2 g H_2O/kg dry air.

B.5.3.3 Performing the different steps of the test cycle

The test shall be performed in accordance with the prescriptions of the vehicle manufacturer, starting with the activation of the propulsion system and followed by applying the test cycle. To match the allowable tolerances of the test cycle, the procedure recommended by the vehicle manufacturer should be applied.

The hydrogen consumption shall be measured using one of the methods described in Clause 5 and Annexes D, E and F, respectively, and in the case of FCHEV it shall be corrected, if necessary.

Annex C
(informative)

Test procedure in the USA

C.1 Background

This annex describes the test procedure recommended for use in the USA and in other countries that use SAE (Society of Automotive Engineers, Inc.) methods, for measuring fuel consumption and range of fuel cell and hybrid fuel cell electric vehicles fuelled by compressed gaseous hydrogen. This annex makes reference to SAE J2572:2006 as the specific governing document.

C.2 General

This annex prescribes the uniform chassis dynamometer test procedures for fuel cell and hybrid fuel cell electric vehicles designed to be driven on public roads. Low speed vehicles are not covered in this annex. Instructions are given for measuring and calculating the fuel consumption and range using two test types:

⎯ the "city" fuel consumption test using the Urban Dynamometer Driving Schedule (UDDS), and

⎯ the "highway" fuel consumption test using the Highway Fuel Economy Driving Schedule (HFEDS).

This annex covers only fuel cell vehicles fuelled with compressed gaseous hydrogen and hybrid fuel cell electric vehicles, also fuelled with compressed gaseous hydrogen, and which have a rechargeable energy storage system (RESS) (battery or capacitor).

C.3 General test information

C.3.1 Driving schedules

The driving schedules to be used for vehicle testing provided by the United States Environmental Protection Agency (EPA) are the Urban Dynamometer Driving Schedule (UDDS) and the Highway Fuel Economy Driving Schedule (HFEDS). The City Fuel Economy Test, which uses the UDDS, is detailed in SAE J2572:2006, 6.1. The Highway Fuel Economy Test, which uses the HFEDS, is detailed in SAE J2572:2006, 6.2.

C.3.2 Battery state of charge

If the net energy of the battery/capacitor system increases or decreases by less than or equal to 1 % of the total hydrogen energy consumed by the vehicle during the course of the test, the application of a correction equation is not necessary, i.e. no correction calculation is necessary if

$$\left| \frac{\Delta \text{ stored electrical energy}}{\text{total fuel energy consumed}} \right| \leqslant 1\%$$

where both the change in stored electrical energy (ΔE_{RESS}) and the total fuel (H_2) energy consumed, reported to one decimal point (e.g. 0,1 g), are expressed in units of energy (J). The lower net heating value for hydrogen gas is used to convert the total hydrogen consumed into units of A·h, using a factor of 120 000 J/g.

Expressed in terms of the energy content of hydrogen per unit of weight, the calculation is as follows:

$$|\Delta E_{RESS}| \leqslant 0{,}01 \times M \times 120\,000 \tag{C.1}$$

where M is the total mass of hydrogen consumed over each phase of the test (MUDDS1, MUDDS2, MHWFET), in g.

All mass values are reported to the nearest 0,1 g.

All distances are reported to the third decimal place (0,001 km).

All fuel consumption values are reported to the nearest 0,000 1 kg/km.

C.4 Test requirements

C.4.1 Vehicle condition

C.4.1.1   General

Prior to initiation of testing and during testing, the overall condition and configuration of the vehicle shall be as delineated in SAE J2572:2006, 4.1 and subsequent subclauses, all of which are represented below.

C.4.1.2   Vehicle stabilization

Prior to testing, the test vehicle shall be stabilized as determined by the manufacturer to a minimum of 1 600 km (1 000 miles), but not more than 9 978 km (6 200 miles) using the durability driving schedule specified in CFR Title 40, Part 86, Appendix IV, section (a), or an equivalent schedule. For all preparations and testing, hydrogen complying with fuel specified by the SAE or the appropriate U.S. government agency shall be used, and that fuel shall comply with the fuel quality guidance specified in SAE J2719.

C.4.1.3   Vehicle appendages

Vehicles shall be tested with normal appendages (mirrors, bumpers, etc.). Certain items (e.g. hub caps) may be removed where necessary for safety on the dynamometer. If an off-board fuel source is used for the test, the test vehicle may include a connector to receive the fuel from that source.

C.4.1.4   Accessories

All accessories shall be turned off.

C.4.1.5   Vehicle test mass

The vehicle shall be tested at loaded vehicle weight [curb weight plus 136 kg (300 lb)].

C.4.1.6   Tyres

Manufacturer's recommended tyres shall be used. For dynamometer testing, tyre pressures should be set at the beginning of the test at the pressure used to establish the dynamometer road-load coefficients (see C.4.3) and shall not exceed levels necessary for safe operation. Tyres shall be conditioned as recommended by the vehicle manufacturer, have accumulated a minimum of 100 km (62 miles) and have at least 50 % of the original usable tread depth remaining.

C.4.1.7   Lubricants

The vehicle lubricants normally specified by the manufacturer shall be used.

C.4.1.8   Regenerative braking

If the vehicle has regenerative braking, the regenerative braking system shall be enabled for all chassis dynamometer testing, except for track coast down testing. If the regenerative braking level is adjustable, it shall be set in accordance with the manufacturer's specification prior to starting dynamometer testing. Operation of the regenerative braking system shall not cause speed and time tolerances specified by the test driving schedule to be exceeded.

C.4.1.9   Vehicle capability

The test vehicle shall be able to maintain the speed and distance tolerances required by the UDDS and HFEDS schedules.

C.4.1.10   Fuel cell stack condition

The stack shall have been aged with the vehicle as detailed in C.4.1.2, or equivalent conditioning.

C.4.1.11   Propulsion battery/capacitor condition

The propulsion system battery/capacitor shall have been aged with the vehicle, as detailed in C.4.1.2, or equivalent conditioning. The vehicle shall have an access point for measurement of current readings into and out of the energy storage device. Reading from a vehicle onboard current measurement system may be used provided that ± 1 % NIST (National Institute of Standards and Technology) traceability can be demonstrated.

C.4.2   Environmental conditions

All test sequences shall be conducted with an ambient temperature within the range of 20 °C to 30 °C (68 °F to 86 °F).

C.4.3   Dynamometer

Use of an electric 48-inch single roll chassis dynamometer, or equivalent, is required for fuel cell vehicle and hybrid fuel cell electric vehicle testing. All factors concerning the dynamometer, specifically its capability requirements, configuration, calibration, warm-up and settings, are presented in SAE J2572:2006, 4.5 and subsequent subclauses, and these give further reference to other specific requirements as contained in CFR Title 40, Part 86, section 135-90 (i). The determination of the dynamometer load coefficients shall be as specified in SAE J2264.

C.4.4   Instrumentation

All instrumentation requirements for the test, including the list of instruments and instrument accuracy requirements, are presented in SAE J2572:2006, 4.6 and subsequent subclauses. All instrumentation calibration must be NIST traceable to within $\pm 1,0\%$ of the full scale of the appropriate range.

C.5   Required data collection

The data that must be collected regarding the vehicle, test conditions, instrumentation, fuel consumed and the dynamometer type, settings and results, are detailed in SAE J2572:2006, 5.1, 5.2 and subsequent subclauses.

C.6   Testing the vehicle

C.6.1   General

The driving schedules provided by the U.S. Environmental Protection Agency (EPA) are used for the tests.

C.6.2 City fuel economy test

The driving cycle used for the city fuel economy test, illustrated in Figure C.1, represents U.S. city driving and consists of a series of non-repetitive idle, acceleration, cruise and deceleration modes of various time sequences throughout an interval of 1 372 s, as detailed in the EPA Urban Dynamometer Driving Schedule (UDDS). Full detail is provided in SAE J2572:2006, 6.1. Specific speed tolerance and fuel consumption considerations for the test sequence are presented in SAE J2572:2006, 6.3 and 6.4.
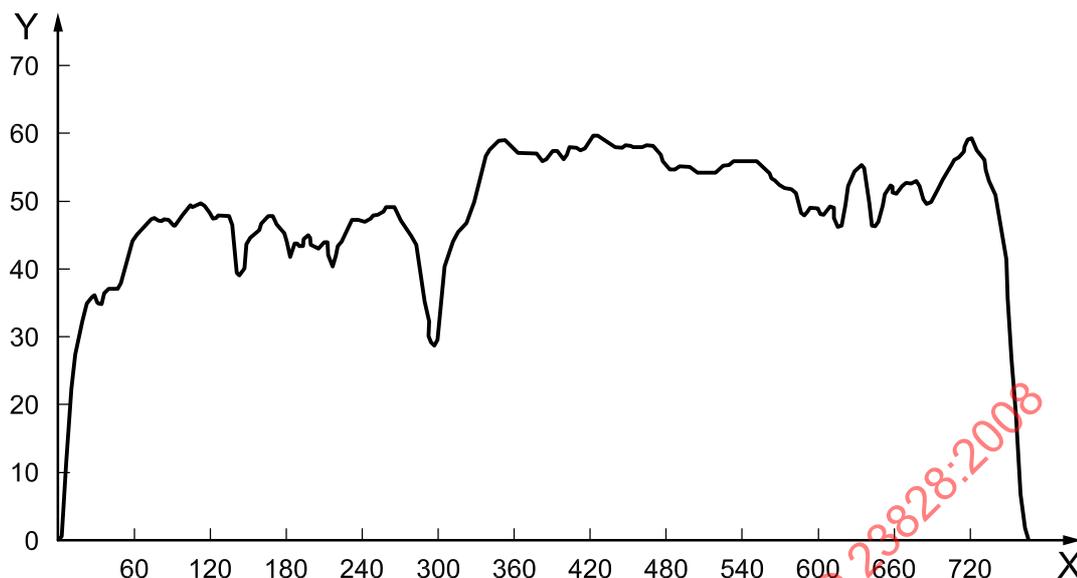

Key
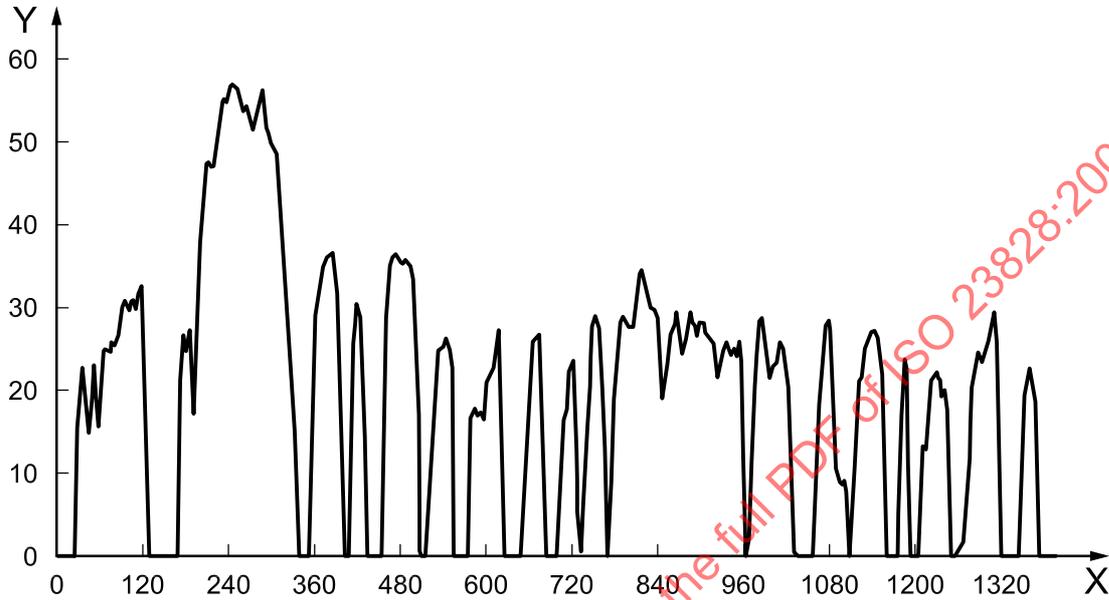
X   time, s

Y   vehicle speed, miles/h

Figure C.1 — Driving cycle used for the city fuel economy test

C.6.3 Highway fuel economy test

The driving cycle used for the highway fuel economy test, illustrated in Figure C.2, represents U.S. highway driving and consists of a series of non-repetitive acceleration, cruise and deceleration modes of various time sequences throughout an interval of 765 s, as detailed in the EPA Highway Fuel Economy Driving Schedule (HFEDS). Full detail is provided in SAE J2572:2006, 6.2. Specific speed tolerance and fuel consumption considerations for the test sequence are presented in SAE J2572:2006, 6.3 and 6.4.

Key

X   time, s

Y   vehicle speed, miles/h

Figure C.2 — Driving cycle used for the highway fuel economy test

C.7 Vehicle fuel consumption

C.7.1 Test method

Fuel consumed by a vehicle under test is determined by operating the vehicle on a dynamometer using prescribed driving cycles.

C.7.2 Measurement of fuel consumption

The fuel consumed is reported as the mass quantity of hydrogen consumed per distance travelled, specifically as kg/km. Three methods are available for determining the net change in mass of hydrogen during testing:

— stabilized pressure and temperature for a fixed volume pressure vessel taken before and after each test,

— the gravimetric method for weighing auxiliary fuel tanks, and

— the use of an appropriate fuel flow meter.

These three methods are presented in detail in SAE J2572:2006, 7.2.1, 7.2.2 and 7.2.3, respectively.

C.7.3 Calculation of fuel consumption rate

Equations 2 and 3 in SAE J2572:2006, 7.3, are used to calculate fuel consumption, expressed in kg/km, for city driving and for highway driving, respectively.

C.7.4 Dynamometer coefficients

Dynamometer target coefficients shall be determined as prescribed in SAE J2264.

C.7.5 Dynamometer test procedure for city fuel consumption measurement

All specifics of the test procedure, including fuelling, temperature stabilization, vehicle preparation and preconditioning, dynamometer preparation, etc., as well as the details of the tests to be conducted, are presented in SAE J2572:2006, 7.5.1 to 7.5.13.

C.7.6 Dynamometer test procedure for highway fuel economy measurement

All specifics of the test procedure, including fuelling, temperature stabilization, vehicle preparation, dynamometer preparation, etc., as well as the details of the tests to be conducted, are presented in SAE J2572:2006, 7.6.1 to 7.6.13.

C.7.7 Fuel consumption calculation correction to account for battery/capacitor effect

For hybrid fuel cell electric vehicles, a method is provided to correct for the battery/capacitor influence on fuel consumption for the case where the final system state of charge has increased or decreased by more than 1 % from the initial system state of charge. For the case where there is an increase in battery/capacitor energy at the end of a test, the manufacturer has the option not to apply the correction calculation. Details of the calculation methods are presented in SAE J2572:2006, 7.7 and subsequent subclauses, for a hybrid vehicle equipped with a battery system, for the city (UDDS) test and for the highway (HFEDS) test, as well as for the case of a hybrid vehicle equipped with a capacitor system.

C.8 Calculation of vehicle range

C.8.1 General

The driving range of a fuel cell vehicle and of a hybrid fuel cell electric vehicle is determined from the testing and calculation methods used to develop the fuel consumption information.

C.8.2 City range

City range, expressed in km, is determined by dividing the usable fuel amount (the difference in mass between the total fuel capacity and the unusable fuel amount) by the city fuel consumption (from SAE J2572:2006, 7.3, Equation 2). [See CFR Title 40, Part 600, section 209-95 (a)(2)(i) regarding U.S. labelling purposes.]

C.8.3 Highway range

Highway range, reported in kilometres, is determined by dividing the usable fuel amount by the corrected highway fuel consumption (from SAE J2572:2006, 7.3, Equation 3). [See CFR Title 40, Part 600, section 209-95 (b)(2)(i) regarding U.S. labelling purposes.]

C.8.4 Combined range

Combined range, reported in kilometres, is determined by dividing the usable fuel amount contained in the fuel tank, by the combined fuel consumption. [See CFR Title 40, Part 600, section 209-95 (d)(2)(i).]

Annex D
(normative)

Pressure method

Either the internal tank or an external tank may be used to measure the hydrogen consumption. If an external tank is used, it shall be connected to the vehicle by a bypass line.

For preconditioning, the internal hydrogen tank or an alternative source of hydrogen may be used as shown in Figure D.1.

The bypass line should be securely installed to prevent breakage or release by vibration and inclusion of air.

The refuelling pressure should be adjusted within the manufacturer's recommended values.

The following items are given as requirements for the pressure method hydrogen tank.

The internal volume of the high-pressure section of the tank shall be known, and the internal volume of accessories (pressure regulators, hydrogen lines, etc.) may be neglected if small enough not to affect the test result.

A means to measure the internal gas pressure and gas temperature shall be available. The volume change of the hydrogen tank during high-pressure refuelling shall be small enough not to affect the test result.

NOTE   If gas temperature cannot be measured directly, an alternative method can be used, e.g. as described in Annex H.
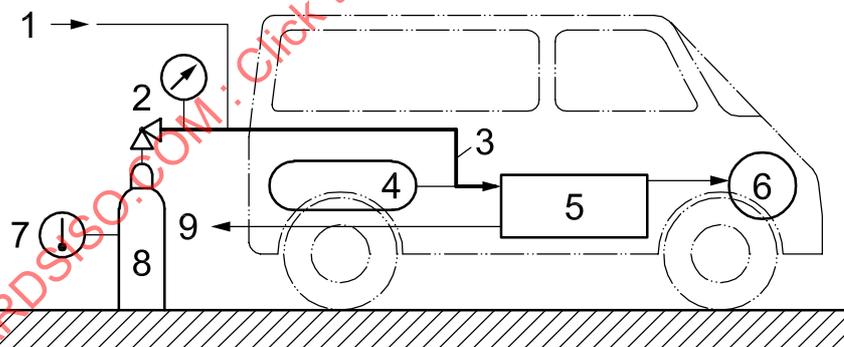
Key

1   external hydrogen supply
2   regulator
3   bypass line
4   fuel tank
5   fuel cell system
6   electric drive
7   temperature gauge
8   additional tank
9   exhaust emission

Figure D.1 — Example of instrumentation

Table D.1 — Example of hydrogen tank for pressure method

Internal volume (measured)	40,872 dm^3
Material	Cr-Mo steel
Refuelling gas	Pure hydrogen
Maximum refuelling pressure	14,7 MPaG
Tank diameter (external) multiplied by tank length	Ø 232 × 1170mm
Mass	approximately 42 kg

The measurement method is as described below.

a) Prior to the initiation of the measuring run, the gas pressure and gas temperature of the tank for the pressure method shall be measured.

b) Upon completion of the measuring run, the gas pressure and gas temperature of the tank for the pressure method shall be measured.

c) To calculate by means of the pressure method the hydrogen consumption in mass, w, expressed in g, apply the measured gas pressure and temperature before and after the test to the following equations:

$$w = m \times (n_1 - n_2)$$
(D.1)

$$w = m \times \frac{V}{R} \times \left(\frac{P_1}{z_1 \times T_1} - \frac{P_2}{z_2 \times T_2} \right)$$
(D.2)

where

m is the molecular weight of hydrogen (2,016);

V is the volume, in l, of the high-pressure section of the hydrogen tank and if necessary, accessories (pressure regulators, hydrogen lines, etc.);

R is the gas constant 0,008 314 5 (MPa·l/mol·K);

n_1 is the mol number of the gas in the tank at the time of initiation of measurement;

P_1 is the pressure, in MPa, of the gas in the tank at the time of initiation of measurement;

T_1 is the temperature, in K, of the gas in the tank at the time of initiation of measurement;

n_2 is the mol number of the gas in the tank upon completion of measurement;

P_2 is the pressure, in MPa, of the gas in the tank upon completion of measurement;

T_2 is the temperature, in K, of the gas in the tank upon completion of measurement;

z_1 is the compression factor at P_1, T_1;

z_2 is the compression factor at P_2, T_2.

When an error is anticipated in measuring temperature due to a difference in the gas temperature before and after the test, the tank should be sufficiently soaked until the gas temperature in the tank becomes equal to the ambient temperature, so that the hydrogen consumption can be determined from the pressure and temperature of gas after soaking. When a separate hydrogen supply line other than that for the hydrogen tank for the pressure method is also used, the gas supply pressures in both lines should be maintained equal, so that there is no input or output of gas when the lines are switched.

Annex E
(normative)

Gravimetric method

Either the internal tank or an external tank may be used to measure the hydrogen consumption. If an external tank is used, it shall be connected to the vehicle by a bypass line.

For preconditioning, the internal hydrogen tank or an alternative source of hydrogen may be used as shown in Figure E.1.

The bypass line should be securely installed to prevent breakage or release by vibration and inclusion of air.

The refuelling pressure should be adjusted to the manufacturer's recommended values.

Since measurement of a small weight difference can be affected by vibration, convection and ambient temperature, an appropriate means for reducing the effects of these factors, such as a damping table, wind barrier, etc., should be provided.

The weight of the hydrogen tank should be minimized as much as possible because the weight of hydrogen to be measured is small in comparison to the weight of the hydrogen tank.
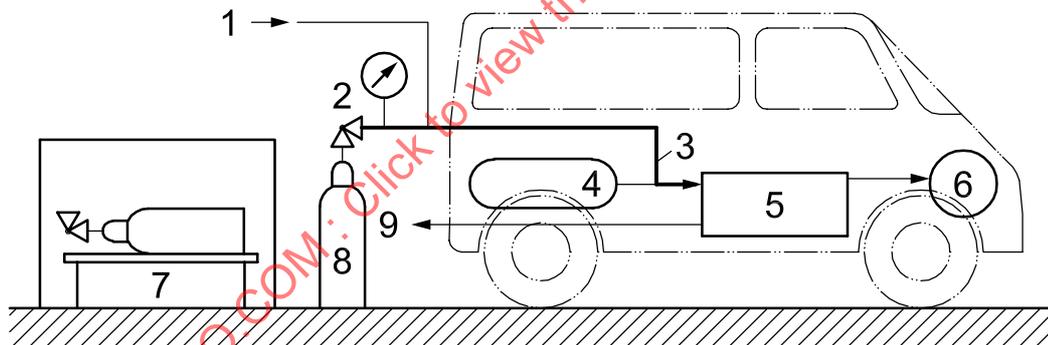
Key

1 external hydrogen supply
2 regulator
3 bypass line
4 fuel tank
5 fuel cell system
6 electric drive
7 precise balance
8 additional tank
9 exhaust emission

Figure E.1 — Example of instrumentation

The measurement method is as described below.

a)   Measure the weight of the tank using a balance before starting the measuring run.

b)   The gas supply pressure from the hydrogen tank should be set equal to the pressure of the line so that there is no input or output of gas when the connection is made.

c)   Remove the hydrogen tank from the hydrogen line and measure the mass after the test using a balance.

d)   To calculate the hydrogen consumption in mass, w, expressed in g, from the measured mass before and after the test, use the following equation:

$$w = g_1 - g_2 \tag{E.1}$$

where

g_1 is the weight of the tank, in g, at the start of the test;

g_2 is the r weight of the tank, in g, at the completion of the test.

When a separate hydrogen supply line other than that for the hydrogen tank for the gravimetric method is also used, the gas supply pressures in both lines should be maintained equal, so that there is no input or output of gas when the lines are switched.
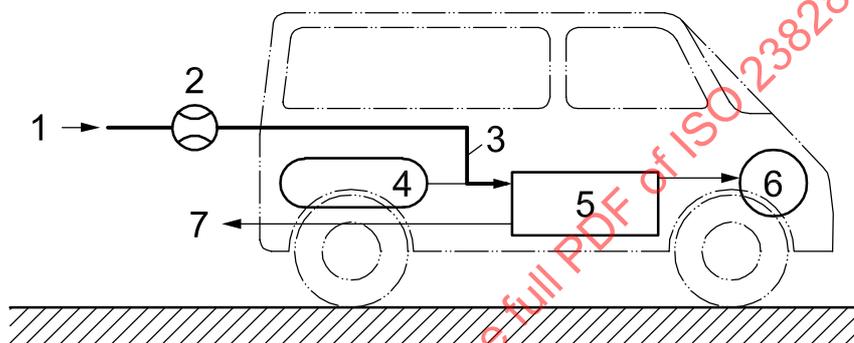
Annex F
(normative)

Flow method

The hydrogen shall be supplied at a manufacturer's recommended pressure.

A flow meter shall be installed to measure the hydrogen flow supplied to the fuel cell system during the test.

The flow meter and bypass line should be securely installed to prevent breakage or release by vibration and inclusion of air.

Key

1 external hydrogen supply
2 flow meter
3 bypass line
4 fuel tank
5 fuel cell system
6 electric drive
7 exhaust emission

Figure F.1 — Example of instrumentation

The measurement method is as described below.

a) The amount of hydrogen consumed by the vehicle shall be determined from flow meter measurement results.

b) The hydrogen consumption in mass, w, expressed in g, shall be calculated by applying the measured flow volume to following equation:

$$w = b_{t0} \times \frac{m}{22,414}$$

(F.1)

where

b_{t0} is the fuel consumption in volume, in l, at 273 K, 101,3 kPa;

m is the molecular weight of hydrogen (2,016).

Annex G
(informative)

Current method

The electrical current method is designed to determine the quantity of hydrogen consumed, by measuring electrical current output from the fuel cell stack. Based on the principle that the amount of electrical current generation by a fuel cell stack is proportional to the quantity of hydrogen consumed, it is possible to determine hydrogen consumption by integrating electrical current values. However, the electrical current method cannot determine the quantity of the hydrogen that is not used in power generation, e.g. hydrogen used for purging and lost through leakage. Therefore, if these losses are recognized to be significant, a different hydrogen consumption measurement method needs to be used.

In the current method, a current sensor shall be installed on the output wire of the fuel cell stack at a point near the fuel cell stack (see Figure G.1).

In the case of a clamp type current sensor susceptible to the influence of a large current and magnetic field, care should be taken to avoid such influence and to ensure that there is no gap or foreign material in the clamp area when the sensor is installed, and any offset shall be compensated.

A current sensor shall be selected such that, in addition to its satisfactory measurement accuracy, its power input and sampling frequency can fully trace the current variations caused by the load variations of test cycles.
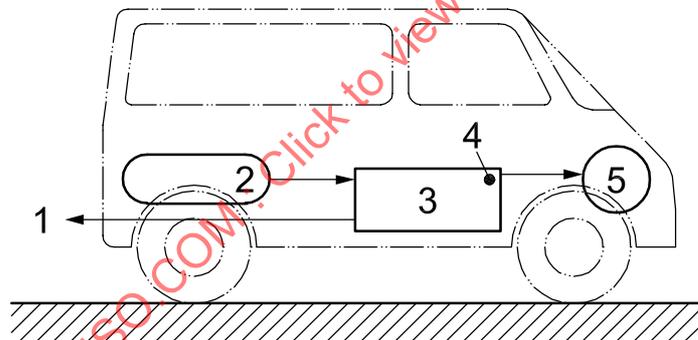
Key

1   exhaust emission

2   fuel tank

3   fuel cell system

4   electric current sensor

5   electric drive

Figure G.1 — Example of instrumentation

The measurement method is as described below.

a) Simultaneously with the start of the measurement drive, integration of output current values from the fuel cell stack is started.

b) Simultaneously with the end of the measurement drive, integration of output current values from the fuel cell stack is ended.

c) From the integrated value of electrical current, the quantity of hydrogen consumption in volume, b_i, expressed in l, (conversion assuming 273 K and 101,3 KPa) is calculated according to the following equation:

$$b_i = \int_0^t I_{dt} \frac{22,414}{v \times F} \times n \tag{G.1}$$

where

$\int_0^t I_{dt}$ is the integrated current of the fuel cell stack, in A·s;

t is the measurement time;

v is the number of valence electrons (2 electrons);

F is the faraday constant $9,648\ 5 \times 10^4$, in C/mol;

n is the number of cells in the fuel cell stack.

Conversion from fuel consumption volume to mass is determined by applying the following equation.

$$w = b_i \times \frac{m}{22,414} \tag{G.2}$$

where

w is the fuel consumption in mass, in g;

m is the molecular weight of hydrogen (2,016).

Annex H
(informative)

Determination of tank surface temperature measuring points

H.1 General

This annex describes a method of determining the tank surface temperature measuring points and tank soaking time.

H.2 Test conditions

The atmospheric pressure, the temperature inside the test room, the test equipment and the conduct of the test shall conform to the fuel consumption test conditions for fuel cell vehicles.

H.3 Test method

H.3.1 Test equipment

A standard flow rate generator shall be used that has the capability to generate a stable flow of hydrogen at a constant flow rate within ±1 % from a set value and that has a flow rate integration function (see Figure H.1).

As shown in Figure H.2, the test tank shall be affixed with temperature sensors for measuring its external surface temperature. Sensors shall be affixed at points equidistant from one another and ranging over about two-thirds of the overall length (height) of the tank. Each sensor shall be covered with a heat insulating material for minimizing the influence of atmospheric temperature and shall be set in full contact with the tank surface.
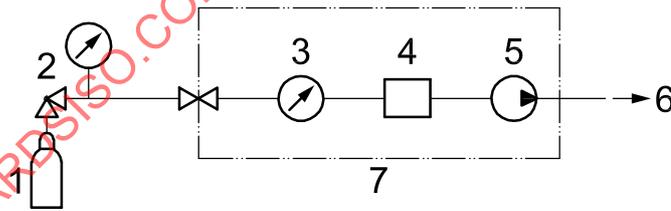
Key

1 test tank
2 pressure regulator
3 pressure controller
4 sonic nozzle
5 suction pump
6 hydrogen
7 standard flow rate generator

Figure H.1 — Example of standard flow rate generator
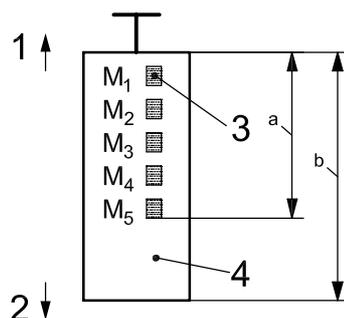
Key

1   tank top
2   tank bottom
3   temperature sensor
4   test container
M_1 ... M_5 temperature measurement points

a   Approximately 2/3 of overall tank length.

b   Overall tank length.

Figure H.2 — Temperature measuring points on the test tank

H.3.2 Test procedure

The test procedure is as described below.

a) Soak the test tank before the test until the internal gas temperature is stabilized to examine the effect of the measurement point of the tank surface temperature.

b) Activate the standard flow rate generator to release hydrogen from the tank at a constant flow rate. The flow rate, measuring time and initial pressure of the hydrogen shall be set equivalent to those for the applied fuel consumption test.

c) Continue the measurements even after the end of gas release while the tank is being soaked.

d) The test room temperature shall be kept within the range specified in the given fuel consumption measurement.

e) The quantity of released hydrogen, w, expressed in g, shall be calculated by means of the following equation:

$$w = m \times \frac{V}{R} \times \left(\frac{P_1}{z_1 \times T_1} - \frac{P_2}{z_2 \times T_2} \right) \tag{H.1}$$

where

m is the molecular weight of hydrogen (2,016);

V is the volume, in l, of the high-pressure section of the hydrogen tank and, if necessary, accessories (e.g. pressure regulators, hydrogen lines);

R is the gas constant 0,008 314 5 (MPa·l/mol·K);

P_1 is the pressure, in MPa, of the gas in the tank at the time of initiation of measurement;

T_1 is the temperature, in K, of the gas in the tank at the time of initiation of measurement;

P_2 is the pressure, in MPa, of the gas in the tank upon completion of measurement;

T_2 is the temperature, in K, of the gas in the tank upon completion of measurement;

z_1 is the compression factor at P_1, T_1;

z_2 is the compression factor at P_2, T_2.

f) The pressure method error is determined from the integrated value of standard flow rates. Plot the error of each temperature measuring point against soaking time, as illustrated in Figure H.3. Select the area (point) where the error converges on around 0 % for each line of every measurement point of the tank. The time corresponding to the selected area is determined as the soaking time in the fuel consumption measurement.
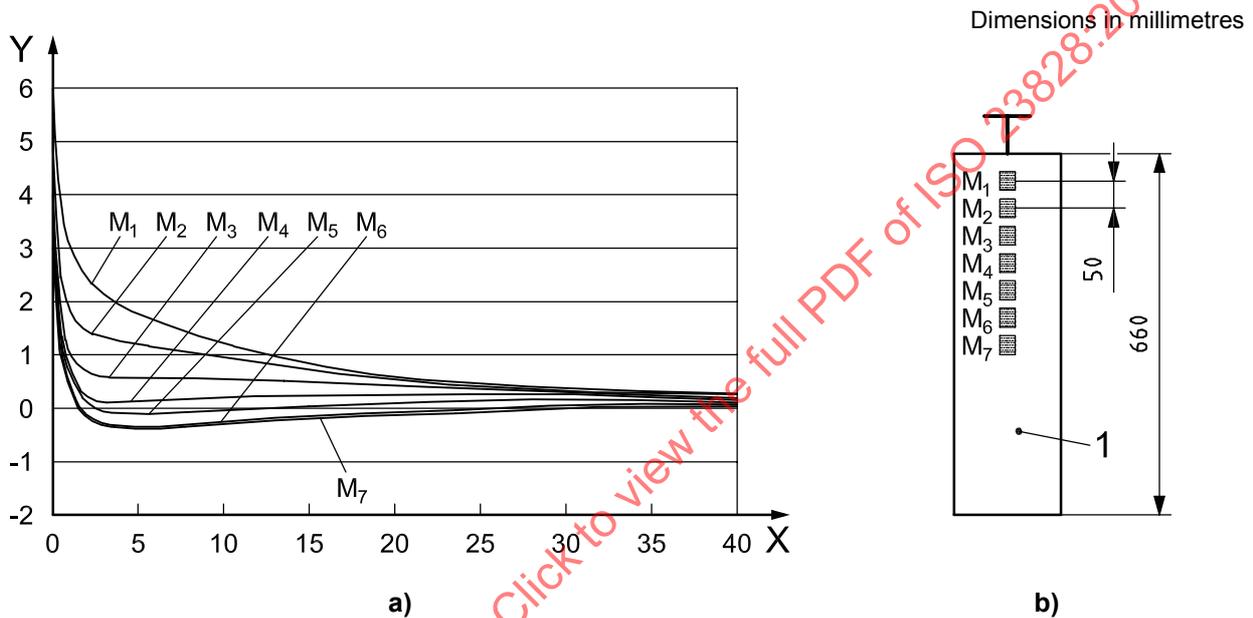
Key

X	soaking time (min)
Y	pressurized method error from integrated value of standard flow rates (%)
1	test tank
$M_1 ... M_7$	temperature measurement points

Figure H.3 — Example of error versus soaking time/measurement points

g) In cases where the tank experiences a wide range of conditions such as flow rate, measuring time and initial pressure of the hydrogen, repeat b) to f) under different conditions. Plot the data of pressure method errors against the temperature measuring points under the different test conditions. Derive the error distribution of the pressure method for each measuring temperature point. Set the points where the temperature sensors should be attached to target the error range of ±1 %, as shown in the example in Figure H.4.