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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

Reference number
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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 37, *Electrically propelled vehicles*.

This third edition cancels and replaces the second edition (ISO 23828:2013), which has been technically revised.

The main changes are as follows:

— deletion of Annexes A, B and C (regional tests) because their information is obsolete;

— harmonization of terms and definitions with ISO/TR 8713 and ISO 23274-1;

— addition of a method to correct the hydrogen amount in the external hydrogen supplying line;

— integration of externally chargeable FCHEV;

— calculation of driving range;

— calculation of contribution of RESS and hydrogen fuel for the driving range.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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

1   Scope

This document specifies the procedures for measuring the energy consumption and driving range of fuel cell passenger cars and light-duty trucks that use compressed hydrogen.

2   Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 10521 (all parts), *Road vehicles — Road load*

ISO 14687, *Hydrogen fuel quality — Product specification*

ISO/TR 8713, *Electrically propelled road vehicles — Vocabulary*

3   Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/TR 8713 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
applicable driving test
ADT
single driving test schedule which is specified for a relevant region

Note 1 to entry: Chassis dynamometer test schedules for a relevant region are the Worldwide Light-duty Test Cycle (WLTC) or the Urban Dynamometer Driving Schedule (UDDS), for example.

3.2
charge balance of RESS
change of charge in the *rechargeable energy storage system (RESS)* (3.13) during an *applicable driving test (ADT)* (3.1)

Note 1 to entry: Normally expressed in ampere hours (Ah).

3.3
charge-depleting state
CD state
operating mode of an HEV in which the vehicle runs by consuming the stored electric energy in the *rechargeable energy storage system (RESS)* (3.13) from an external electric power source or along with the fuel energy simultaneously or sequentially until *CS state* (3.4)

3.4
charge-sustaining state
CS state
operating mode where the HEV runs by consuming the fuel energy while sustaining the electric energy of the *rechargeable energy storage system (RESS)* (3.13)

3.5
energy balance of RESS
ΔE_{RESS}
change of *rechargeable energy storage system (RESS)* (3.13) energy state during an *applicable driving test (ADT)* (3.1)

Note 1 to entry: Normally expressed in watt hours (Wh).

Note 2 to entry: For practical use, the energy balance of the RESS is approximated by multiplying the *charge balance of RESS* (3.2) in ampere hours (Ah) with the nominal voltage of the RESS in volts (V).

3.6
externally chargeable FCHEV
externally chargeable fuel cell hybrid electric vehicle
fuel cell hybrid electric vehicle (FCHEV) (3.7) with a *rechargeable energy storage system (RESS)* (3.13) that is intended to be charged from an external electric energy source

Note 1 to entry: External charge for conditioning of the RESS is not included.

3.7
fuel cell hybrid electric vehicle
FCHEV
electrically propelled vehicle with a *rechargeable energy storage system (RESS)* (3.13) and a fuel cell system as power sources for vehicle propulsion

3.8
fuel cell vehicle
FCV
electrically propelled vehicle with a fuel cell system as the power source for vehicle propulsion

Note 1 to entry: An FCV may also have a *rechargeable energy storage system (RESS)* (3.13) or another power source for vehicle propulsion.

3.9
state of charge of hydrogen
density (or mass) ratio of hydrogen in the original hydrogen tank between the original hydrogen tank condition and the capacity at *nominal working pressure (NWP)* (3.11) when the system is equilibrated at 15 °C

Note 1 to entry: State of charge of hydrogen is expressed as a percentage and is computed based on the gas density according to formula below.

Note 2 to entry: The accuracy of the NIST formula has been quantified to be to within 0,01 % from 255 K to 1 000 K with pressures to 120 MPa at the time of publication of this document.

Note 3 to entry: (%) can be calculated as follows:

$$\frac{\rho_1}{\rho_2} \times 100$$

where

    ρ_1 is the density of hydrogen under the specific gas conditions;

    ρ_2 is the density of hydrogen at the nominal working pressure at a gas temperature of 15 °C.

The hydrogen densities at the two major nominal working pressures are:

— density of H_2 at 35 MPa and 15 °C = 24,0 g/l,

— density of H_2 at 70 MPa and 15 °C = 40,2 g/l.

Note 4 to entry: The ρ_1 function for hydrogen is available from the National Institute of Standards and Technology (NIST) at https://nvlpubs.nist.gov/nistpubs/jres/113/6/V113.N06.A05.pdf.

[SOURCE: ISO 19880-1:2020, 3.78, modified — The term was originally "state of charge" and "compressed hydrogen storage system (CHSS)" has been replaced by "original hydrogen tank".]

3.10
non-externally chargeable FCHEV
non-externally chargeable fuel cell hybrid electric vehicle
fuel cell hybrid electric vehicle (FCHEV) (3.7) with a *rechargeable energy storage system (RESS)* (3.13) that is not intended to be charged from an external electric energy source

3.11
nominal working pressure
NWP
container pressure, as specified by the container manufacturer, at a uniform gas temperature of 15 °C and full gas content

3.12
rated capacity
supplier's specification of the total number of ampere hours that can be withdrawn from a fully charged battery pack or system for a specified set of test conditions such as discharge rate, temperature, discharge cut-off voltage, etc.

3.13
rechargeable energy storage system
RESS
rechargeable system that stores energy for delivery of electric energy for the electric drive

EXAMPLE   Batteries or capacitors.

3.14
regenerative braking
braking with conversion of kinetic energy into electric energy for charging the *rechargeable energy storage system (RESS)* (3.13)

3.15
state of charge
SOC
available capacity of a *rechargeable energy storage system (RESS)* (3.13)or RESS subsystem expressed as a percentage of *rated capacity* (3.12)

4 Symbols and abbreviated terms

ADT   applicable driving test

CD   charge-depleting

CS   charge-sustaining

E energy

E_{CH2} energy of consumed hydrogen

ECU   electronic control unit

E_{RESS} energy of RESS

FCHEV   fuel cell hybrid electric vehicle

FCV   fuel cell vehicle

HEV   hybrid-electric vehicle

IEC   International Electrotechnical Commission

ISO   International Organization for Standardization

NWP   nominal working pressure

RESS   rechargeable energy storage system

SOC   state of charge

UDDS   Urban Dynamometer Driving Schedule

WLTC   Worldwide Light-duty Test Cycle

5   Hydrogen measurement accuracy

The hydrogen measurement device shall ensure an accuracy of ±1 % for the total mass of hydrogen consumption during the ADT, unless otherwise specified in the relevant regional ADT standard.

6   Hydrogen consumption measurement

6.1   General

Hydrogen consumption shall be measured using one of the following methods:

— pressure method (see Annex A);

— gravimetric method (see Annex B);

— flow method (see Annex C).

NOTE   The current method (see Annex D) can be used.

6.2   Pressure method

Hydrogen consumption is determined by measuring the pressure and temperature of gas in the 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. Pressure method shall be performed in accordance with Annex A.

6.3   Gravimetric method

Hydrogen consumption is calculated by measuring the mass of the hydrogen tank before and after the test. The gravimetric method shall be performed in accordance with Annex B.

6.4 Flow method

The amount of hydrogen supplied to a vehicle is measured by a flowmeter. The flow method shall be performed in accordance with Annex C.

7 Fuel consumption test

7.1 Test conditions

7.1.1 General

For test conditions, the following applies unless otherwise specified in the relevant regional ADT standard.

7.1.2 Ambient temperature

Tests shall be conducted at an ambient temperature of (25 ± 5) °C.

7.1.3 Vehicle conditions

7.1.3.1 Vehicle conditioning

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 the relevant regional ADT standard.

7.1.3.2 Vehicle appendages

Vehicles shall be tested with normal appendages (mirrors, bumpers, etc.). When the vehicle is on the dynamometer, certain items (e.g. hub caps) should be removed for reasons of safety, where necessary.

7.1.3.3 Vehicle test mass

The vehicle test mass shall be selected according to the relevant regional ADT standard.

7.1.3.4 Tyres

7.1.3.4.1 General

The correctly rated tyres as specified by the vehicle manufacturer shall be used.

7.1.3.4.2 Tyre pressure

The vehicle tyres shall be inflated to the pressure specified by the vehicle manufacturer according to the test chosen (track or chassis dynamometer).

7.1.3.4.3 Tyre conditioning

The tyres shall be conditioned as recommended by the vehicle manufacturer.

7.1.3.5 Lubricants

The lubricants specified by the vehicle manufacturer shall be used.

7.1.3.6 Gear shifting

If the vehicle is fitted with a manually shifted gear box, the gear shifting positions should be selected and determined in accordance with the vehicle manufacturer's specification.

NOTE   The shift positions can be referred to the relevant regional ADT procedure.

7.1.3.7 Regenerative braking

If the vehicle has regenerative braking, the regenerative braking system shall be enabled for all dynamometer testing except where specified in 7.1.4.4 chassis dynamometer conditions.

If the vehicle is tested on a single axle dynamometer and is equipped with systems such as an antilock braking system (ABS) or a traction control system (TCS), those systems can inadvertently interpret the non-movement of the set of wheels that are off the dynamometer as a malfunctioning system. If so, these systems shall be temporally disabled for adjustment to achieve normal operation of the remaining vehicle systems, including the regenerative braking system.

7.1.3.8 RESS conditioning

The RESS shall be conditioned with the vehicle as specified in 7.1.3.1 or by equivalent conditioning.

7.1.3.9 Test fuel

ISO 14687 or the equivalent regional standard shall apply to the test fuel.

7.1.4 Chassis dynamometer conditions

7.1.4.1 General

The vehicle should generally be tested on a single-axle chassis dynamometer. A vehicle with four-wheel drive 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.

Double-axle chassis dynamometer testing should be performed if a modification for single-axle chassis dynamometer testing is not possible for a specific four-wheel drive vehicle.

7.1.4.2 Dynamometer calibration

The dynamometer shall be calibrated in accordance with the specifications indicated in the service manual provided by the dynamometer manufacturers.

7.1.4.3 Dynamometer warm-up

The dynamometer shall be warmed up sufficiently prior to testing.

7.1.4.4 Determining the dynamometer load coefficient

The determination of vehicle road load and the reproduction on a chassis dynamometer shall conform to the ISO 10521 series. 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.

7.2 Test instrumentation

The test instrumentation shall have the accuracy levels as given in Table 1, unless otherwise specified in the relevant regional ADT standard.

Table 1 — Accuracy of measured values

Item	Unit	Accuracy
Time	s	±0,1 s
Distance	m	±0,1 %
Temperature	°C	±1 °C
Speed	km/h	±1 %
Mass	kg	±0,5 %
AC electric energy	Wh	±0,5 %
DC electric energy	Wh	±0,3 % [a]
DC current	A	±0,3 % [a]
DC voltage	V	±0,3 % [a]

[a]   Any errors in the DC electric energy measurement system shall be less than 1 % of the reading or 0,3 % of full scale. (Pulsed power electronics measurement needs wide dynamic range even if small power.)

For the DC current measurement without direct voltage sensing, wideband ampere-hour meter or wideband meter is required.

The wideband meter (power analyser) is an instrument for processing power and energy in pulsed power electronics by current and voltage inputs. Its bandwidth shall be at least ten times as high as the switching frequency of the pulsed power electronics, and update period of its outputs shall be 0,05 s or less to get enough time resolution.

Voltage probes and current sensors shall be installed in such a way as to measure voltage at RESS and FC terminals, and all current leaving and entering the RESS and leaving the FC.

The electronic control unit (ECU) shall be alternatively applied, if the accuracy of ECU data certifies corresponding accuracy in Table 1.

NOTE   If the ECU of the test vehicle has not enough accuracy, the accuracy of the data through the ECU appears on the data sheet. The accuracy of resultant specific energy consumption and range can be estimated and they are also on the data sheet.

7.3   Charging of the RESS of externally chargeable FCHEV

7.3.1   Application of a normal charge

7.3.1.1   Normal charging procedure

The charging of the RESS shall be carried out at an ambient temperature of (25 ± 5) °C. The normal charging procedure shall be in accordance with the vehicle manufacturer's specification for normal operation.

For the normal charging procedure all types of special charging shall be excluded, for example, RESS service charging.

7.3.1.2   End-of-charge criteria

The end-of-charge criteria shall correspond to a charging time of 12 h except if a clear indication is given to the driver by the standard instrumentation that the RESS is not yet fully charged. In this case, the maximum charging time shall be in accordance with the manufacturer's specification. After charging, the vehicle shall not be conductively connected to an external electric power source unless otherwise specified by the manufacturer.

7.3.1.3 Fully charged RESS

A RESS is fully charged when charged according to the normal charging procedure (see 7.3.1.1) and the end-of-charge criteria (see 7.3.1.2).

7.3.2 Charging the RESS and measuring energy

The vehicle shall be physically reconnected to an external electric power source within 2 h following completion of the appropriate test sequence unless otherwise specified for relevant region.

The RESS shall then be fully charged in accordance with the normal charging procedure (see 7.3.1.1).

The electric energy, E, in Wh, delivered from an external electric power source, as well as the charging time duration, shall be measured. The energy-measuring equipment shall be placed between the external electric power source and the vehicle power inlet.

7.4 Hydrogen consumption tests

7.4.1 General

Depending on the region concerned, the appropriate procedure shall be followed from the relevant regional ADT standard. Details and common procedures for each test mode are described below.

7.4.2 Vehicle preconditioning

There can be regional ADT standards that state the procedure for vehicle preconditioning, if necessary.

In the case of non-externally chargeable FCHEV, the RESS SOC may be pre-adjusted by charging or discharging, to obtain a suitable energy difference in RESS between the beginning and the end of test.

7.4.3 Vehicle soak

The vehicle shall be soaked in accordance with the relevant regional ADT standard.

In the case of externally chargeable FCHEV, the RESS is fully charged. The normal charging procedure shall be in accordance with the vehicle manufacturer's specification for normal operation. The soak should be continued until both, relevant regional ADT standard and full-charge of RESS, are completed.

7.4.4 Vehicle movement to the test room

When the vehicle is brought into the test room, and moved during the test if necessary, it shall be pushed or towed (neither driven nor regenerative recharged). The test vehicle shall be set on the chassis dynamometer after the chassis dynamometer has warmed up just before the test. The vehicle shall not be activated during soak until right before starting the test.

7.5 Measurement and calculation over applicable driving test (ADT)

7.5.1 CD state

The measurement method of energy consumption at CD state for an externally chargeable FCHEV is specified in Annex J, and optionally described in Annex K. Annex K is applied for estimating the electricity and hydrogen contribution for the driving range.

7.5.2 CS state

For the measurement of hydrogen consumption at CS state for both, an externally chargeable FCHEV and a non-externally chargeable FCHEV, the test vehicle shall be driven on the chassis dynamometer in accordance with the relevant regional ADT standard. The hydrogen consumption shall be measured by

one of the methods described in Annex A, B or C or by an alternative method that provides equivalent accuracy.

The hydrogen consumption per unit distance is determined by the following formula:

$$C_{\text{H2}} = \frac{w}{L} = \frac{b_{\text{t0}} \times \dfrac{m}{22,414}}{L} \tag{1}$$

where

C_{H2} is the hydrogen consumption per unit distance, in g/km;

L is the distance, in km;

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

w is the hydrogen consumption, in g;

m is the molecular mass of hydrogen (2,016 g/mol).

NOTE   In the standard state (273,15 K, 101,325 kPa), the ideal gas molar volume is V_{m} = 22,413 968 (20) × 10^{-3} m³/mol (=l/mol). See ISO 80000-9:2019.

7.6 Correction of the test results for FCHEV

7.6.1 General

Measured hydrogen consumption shall be corrected if these test results are influenced by RESS energy balance during the test. However, the correction is not necessary if the RESS energy balance satisfies the conditions in 7.6.2.

7.6.2 Allowable range of RESS energy balance

The correction of the test results is not necessary for the following range of the RESS energy balance:

$$|\Delta E_{\text{RESS}}| \leq 0,01 \times E_{\text{CH2}} \tag{2}$$

where

ΔE_{RESS} is the energy change in the RESS over the ADT expressed in Wh;

E_{CH2} is the energy of consumed hydrogen over the ADT expressed in Wh.

ΔE_{RESS} shall be calculated in accordance with Annex G.

7.6.3 Correction procedure by correction coefficient

The vehicle manufacturer shall deliver the correction coefficient to calculate the fuel consumption at ΔE_{RESS} = 0. The correction coefficient shall be obtained in accordance with Annex H. When the measured value is independent of ΔE_{RESS}, a correction is not required.

8 Calculation of driving range

8.1 Non-externally chargeable FCHEV

Driving range of non-externally chargeable FCHEV is calculated using Formula (3):

$$L_{\text{NEXC}} = \frac{M \times 1\ 000}{C_{\text{H2}}} \tag{3}$$

where

L_{NEXC} is the driving range for non-externally chargeable FCHEV, expressed in km;

C_{H2} is the hydrogen consumption at CS state expressed in g/km, described in 7.5.2;

M is the usable amount of hydrogen of FCV expressed in kg, specified in Annex L.

8.2 Externally chargeable FCHEV

The driving range of an externally chargeable FCHEV expressed in km, is the sum of driving range at CD state and at CS state as Formula (4).

$$L_{\text{EXC}} = L_{\text{CD}} + L_{\text{CS}} \tag{4}$$

where

L_{EXC} is the total driving range for externally chargeable FCHEV, expressed in km;

L_{CD} is the driving range at CD state, expressed in km;

L_{CS} is the driving range at CS state, expressed in km.

Driving range at CD state (L_{CD}) shall be measured according to Annex J.

Driving range at CS state is calculated using Formula (5):

$$L_{\text{CS}} = \frac{M \times 1\ 000 - w_{\text{CD}}}{C_{\text{H2}}} \tag{5}$$

where

L_{CS} is the driving range at CS state, expressed in km;

C_{H2} is the hydrogen consumption at CS state, expressed in g/km;

M is the usable amount of hydrogen of FCV, expressed in kg;

w_{CD} is the consumed hydrogen at CD state, expressed in g, described in Annex J.

Annex L is applied if the driving range is estimated by using the on-board hydrogen tank.

9 Calculation of contribution of electricity and hydrogen for the driving range

Annex K can be used for calculating contribution of electricity and hydrogen for the driving range for externally chargeable FCHEV.

10 Presentation of results

Regional regulations can specify requirements regarding how to record the test results. See Annex F for an example.

Test procedures of hydrogen consumption, RESS energy consumption and driving range for either externally or non-externally chargeable FCVs are listed in Table 2.

The results listed in Table 2 are obtained from the measurement of CD state and CS state.

Table 2 — Summary of test procedure of hydrogen consumption, RESS energy consumption and driving range

		FC system (Hydrogen consumption)	RESS system (Electric energy consumption)	Driving range	Contribution of electricity / hydrogen for the driving range
Externally chargeable FCHEV	CD state	Measured See Annex J	Measured See Annex J	Calculated or run-out See 8.2	See Annex K
	CS state	See 7.5.2			
Non-externally chargeable FCHEV		Measured See 7.5.2		Calculated See 8.1	

Annex A
(normative)

Pressure method

An example of instrumentation is shown in Figure A.1. An additional external tank is used to measure the hydrogen consumption. An example of tank specification is shown in Table A.1. The additional external tank shall be connected to the vehicle.

For preconditioning, the originally installed tank or an external source of hydrogen shall be used as shown in Figure A.1.

The refuelling pressure of the additional external tank shall be adjusted according to the manufacturer's recommended values.

The following items are given as requirements for the additional external tank. The internal volume of the tank and accessories (hydrogen lines, for example) upstream of the pressure regulator shall be known.

A device to measure the internal gas pressure and gas temperature shall be available. The volume change of the additional external tank during the test 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 E.

Key
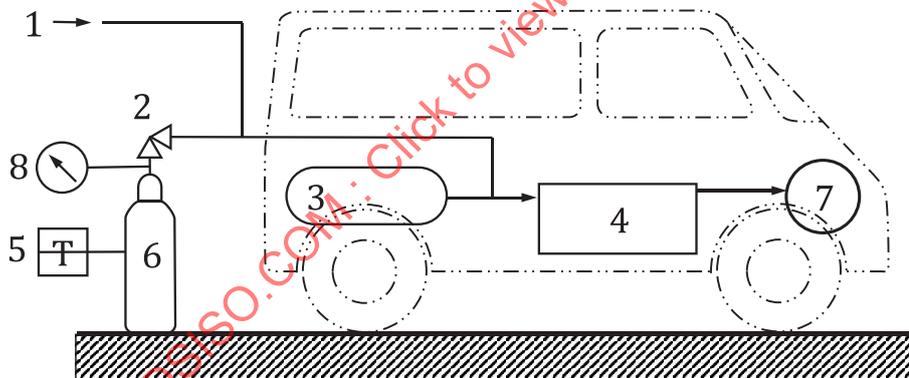
1   external hydrogen supply for warming up if necessary
2   pressure regulator
3   original tank
4   fuel cell system
5   temperature gauge
6   additional external tank
7   electric drive
8   pressure gauge

Figure A.1 — Example of instrumentation

Table A.1 — Example of an additional external tank

Internal volume (measured)	40,872 l
Material	Cr-Mo steel
Maximum refuelling pressure	14,7 MPa
Tank diameter (outside) × tank length	Ø 232 × 1 170 mm
Mass	about 42 kg

The measurement procedure is as described below.

a) At the start of the measuring run, the gas pressure and gas temperature of the additional external tank shall be measured.

b) At the end of the measuring run, the gas pressure and gas temperature of the additional external tank shall be measured.

c) Hydrogen consumption in mass, w, expressed in g, is calculated by the measured gas pressure and temperature before and after the test using the following formulae:

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

$$w = m \times \frac{V}{R} \times \left(\frac{P_1}{Z_1 \times T_1} - \frac{P_2}{Z_2 \times T_2} \right) \times 1\,000$$ (A.2)

where

w is the hydrogen consumption, in g;

m is the molecular mass of hydrogen (2,016 g/mol);

n_1 is the molecular number of the gas in the tank at the start of measurement;

n_2 is the molecular number of the gas in the tank at the end of measurement;

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

R is the gas constant with the value of 8,314 46 J/ (mol · K);

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

Z_1 is the compression factor at P_1, T_1;

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

P_2 is the pressure, in MPa, of the gas in the tank at the end of measurement;

Z_2 is the compression factor at P_2, T_2;

T_2 is the temperature, in K, of the gas in the tank at the end of measurement.

When a separate hydrogen supply line is used in addition to that for the hydrogen tank for the pressure method, the gas supply pressures in both lines shall be maintained equal so that there is no input or output of gas when the lines are switched.

Annex B
(normative)

Gravimetric method

An example of instrumentation is shown in Figure B.1. An additional external tank is used to measure the hydrogen consumption. The additional external tank shall be connected to the vehicle.

For preconditioning, the originally installed tank or an external source of hydrogen shall be used as shown in Figure B.1.

The refuelling pressure shall be adjusted to the manufacturer's recommended value.

Since measurement of a small mass difference is necessary, it can be affected by vibration, convection, and ambient temperature. An appropriate device for reducing the effects of these factors, such as a damping table, wind barrier, etc., shall be provided.

The mass of the additional external tank shall be minimized as much as possible because the mass of hydrogen to be measured is small in comparison to the mass of the tank.

Key
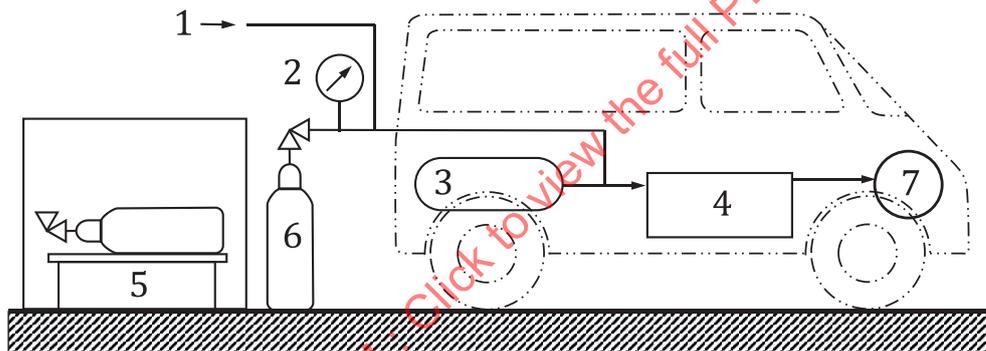
1 external hydrogen supply for warming up if necessary
2 pressure gauge
3 original tank
4 fuel cell system
5 precise balance
6 additional external tank
7 electric drive

Figure B.1 — Example of instrumentation

The test procedure is as described below.

a) Measure the mass of the additional external tank before starting the ADT.

b) Connect the additional external tank. The pressure of the connecting point shall be adjusted so that hydrogen consumed during the ADT shall be supplied from the additional external tank. It is necessary to prevent pressure difference between the fuel lines from influencing accuracy of the measurement.

c) Conduct the test by fuelling from the additional external tank.

d) Remove the additional external tank from the line and measure the mass after the test.

e) Calculate the hydrogen consumption in mass, *w*, expressed in g, from the measured mass before and after the test, using the following formula:

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

where

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

  g_2 is the mass of the tank, in g, at the end of the test.

f) The change in weight of the hydrogen in the auxiliary line between keys 2 and 4 in Figure B.1 (Δg) due to changes in temperature and pressure may be taken into consideration.

A method to correct the hydrogen amount in the external hydrogen supplying line is as follows:

$$\Delta g = m \times \frac{V}{R} \times \left(\frac{P_2}{Z_2 \times T_2} - \frac{P_1}{Z_1 \times T_1} \right) \times 1\,000 \tag{B.2}$$

$$w = g_1 - g_2 - \Delta g \tag{B.3}$$

where

  w   is the hydrogen consumption, in g;

  m   is the molecular mass of hydrogen (2,016 g/mol);

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

  R   is the gas constant with the value of 8,314 46 J/ (mol·K);

  P_1 is the pressure, in MPa, of the gas at the start of measurement;

  T_1 is the temperature, in K, of the gas at the start of measurement;

  P_2 is the pressure, in MPa, of the gas at the end of measurement;

  T_2 is the temperature, in K, of the gas at the end of measurement;

  Z_1 is the compression factor at P_1, T_1;

  Z_2 is the compression factor at P_2, T_2.

NOTE   Compression factor *z* is given in References [5] and [6].

Annex C
(normative)

Flow method

An example of instrumentation is shown in Figure C.1.

A flowmeter shall be installed to measure the amount of hydrogen supplied to the fuel cell system during the test.

NOTE 1   It is possible to calibrate the flowmeter with hydrogen. Improvement of accuracy is reported. See detail information in Reference [7].

NOTE 2   The accuracy of the flowmeter is affected by pulsation in the fuel line in some cases. It is effective to install a device to decrease the pulsation between the flowmeter and vehicle fuel line. See the detailed information in Reference [7].

Key
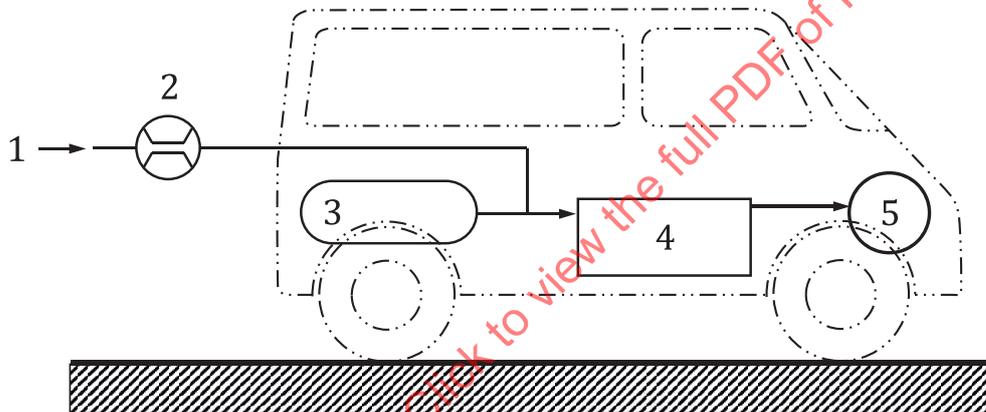
1   external hydrogen supply
2   flowmeter
3   fuel tank
4   fuel cell system
5   electric drive

Figure C.1 — Example of instrumentation

The hydrogen consumption in mass, w, expressed in g, shall be calculated by integrating the flow rate using the following formulae:

$$b_{t0} = \int_0^t Q \mathrm{d}t \tag{C.1}$$

$$w = b_{t0} \times \frac{m}{22,414} \tag{C.2}$$

where

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

Q is the measured hydrogen flow rate in test, in l/s;

t is the measurement time, in s;

w is the hydrogen consumption, in g;

m is the molecular mass of hydrogen (2,016 g/mol).

NOTE   22,414 is the constant value of the molar volume and it is expressed in l/mol.

Annex D
(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, for example, hydrogen used for purging and lost through permeation. Therefore, if these losses are found to be significant, a different hydrogen consumption measurement method needs to be used.

An example of instrumentation is shown in Figure D.1. A current sensor shall be installed on the output wire of the fuel cell stack at a point near the fuel cell stack.

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 ADTs.
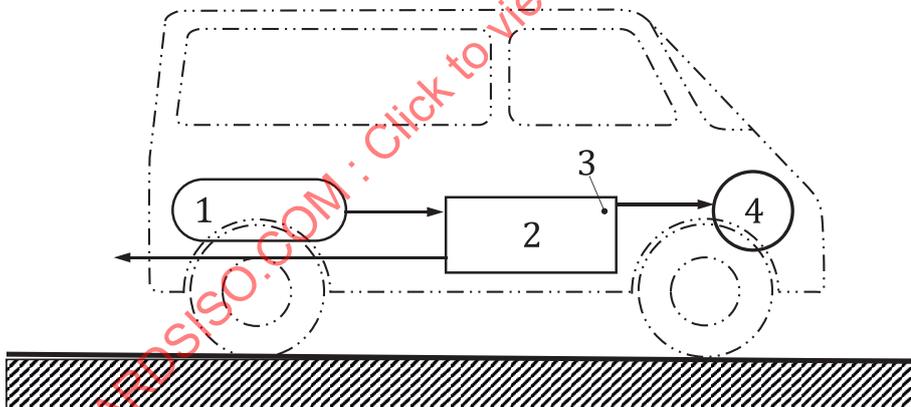
Key
1   fuel tank
2   fuel cell system
3   electric current sensor
4   electric drive

Figure D.1 — Example of instrumentation

From the integrated value of electrical current during the ADT, the quantity of hydrogen consumption in volume, b_i, expressed in l, (assuming 273 K and 101,3 kPa) is calculated according to the following formula:

$$b_i = \int_0^t I \mathrm{d}t \; \frac{22,414}{v \times F} \times n \tag{D.1}$$

where

I is the current of the fuel cell stack, in A;

t is the measurement time, in s;

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.

NOTE   22,414 is the constant value of the molar volume and it is expressed in l/mol.

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

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

where

w is the hydrogen consumption, in g;

m is the molecular mass of hydrogen (2,016 g/mol).

NOTE   22,414 is the constant value of the molar volume and it is expressed in l/mol.

Annex E
(informative)

Determination of tank surface temperature measuring points

E.1 General

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

E.2 Test conditions

The ambient conditions such as the temperature and atmospheric pressure in the test room shall conform to the fuel consumption test conditions for the vehicle.

E.3 Test method

E.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 E.1).

As shown in Figure E.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.
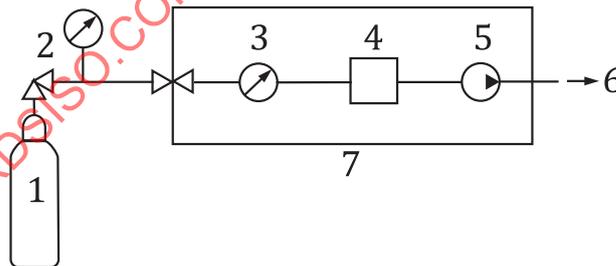
Key
1   test tank
2   pressure regulator
3   pressure controller
4   sonic nozzle
5   suction pump
6   hydrogen
7   standard flow rate generator

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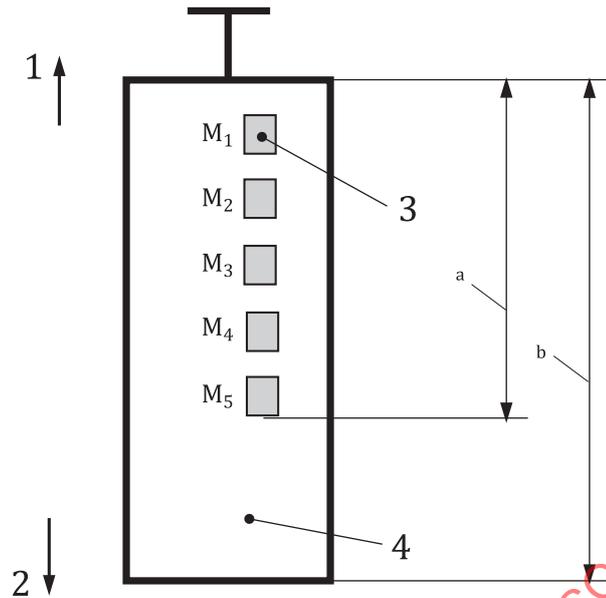
Key

1   tank top

2   tank bottom

3   temperature sensor

4   test tank

$M_1...M_5$ temperature measurement points

a   Approximately 2/3 of overall tank length.

b   Overall tank length.

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

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 discharge 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 discharge while the tank is being soaked.

d)   Calculate the quantity of discharged hydrogen, w, expressed in g, by applying the measured pressure and temperature to the following formula:

$$w = m \times \frac{V}{R} \times \left(\frac{P_1}{Z_1 \times T_1} - \frac{P_2}{Z_2 \times T_2} \right) \times 1\ 000 \tag{E.1}$$

where

   w is the hydrogen consumption, in g;

   m is the molecular mass of hydrogen (2,016 g/mol);

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

R is the gas constant with the value of 8,314 46 J/ (mol• K);

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

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

P_2 is the pressure, in MPa, of the gas in the tank at the end of measurement;

T_2 is the temperature, in K, of the gas in the tank at the end of measurement;

Z_1 is the compression factor at P_1, T_1;

Z_2 is the compression factor at P_2, T_2.

e)   Determine the error of hydrogen quantity calculated in d) above by means of comparison with the integrated value of standard flow rates. Plot the error of each temperature measuring point against soak time, as illustrated in Figure E.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 soak time for each temperature measurement point.
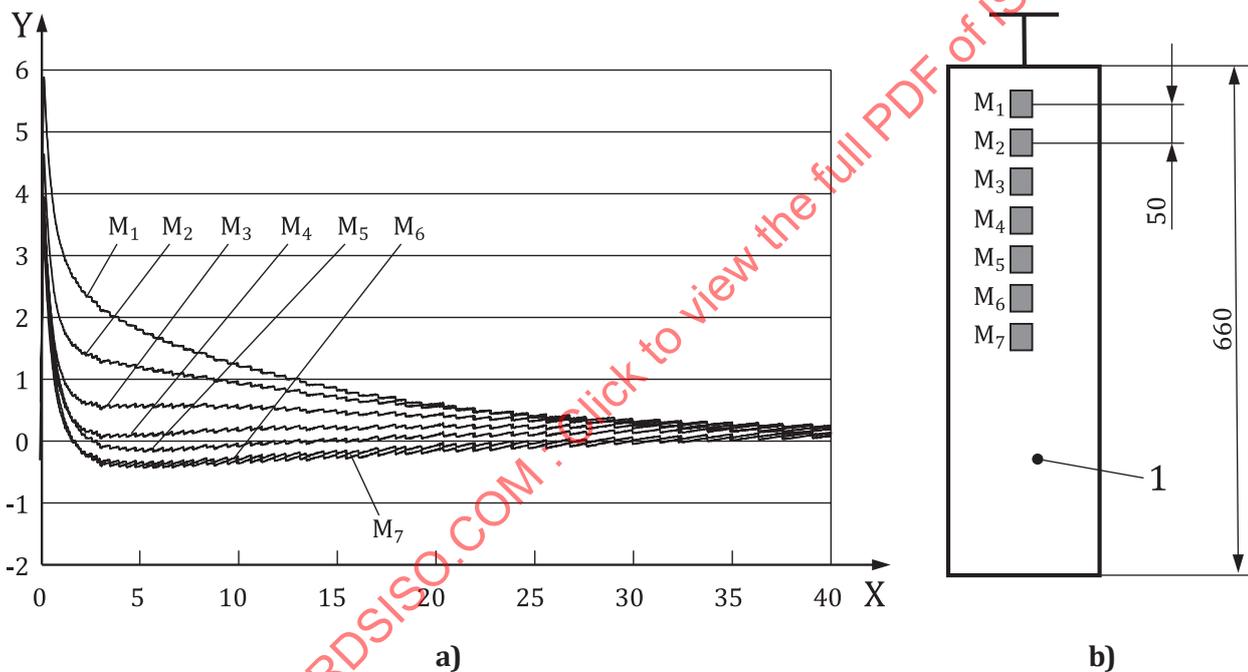
Key

X   soak time (min)

Y   error from integrated value of standard flow rates (%)

1   test tank

M_1...M_7 temperature measurement points

Figure E.3 — Example of error versus soak time/measurement points

f)   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 e) 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 %. An example of the plot is shown in Figure E.4.

22

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 soak.
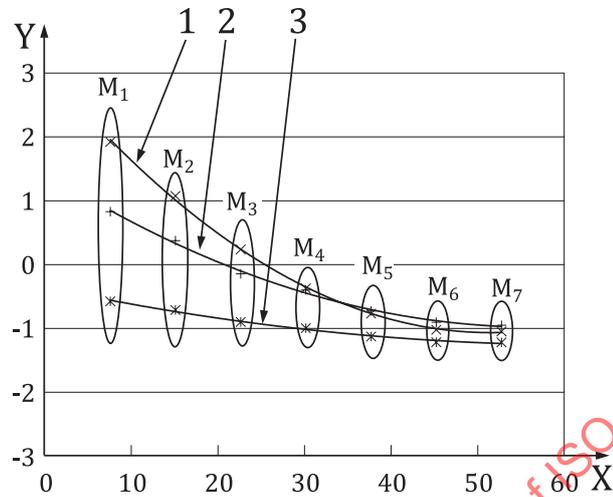
Key

X	sensor position on tank (%)
Y	error from integrated value of standard flow rates (%)
1	release quantity 500 l (normal), tank initial pressure 14 MPa
2	release quantity 500 l (normal), tank initial pressure 8 MPa
3	release quantity 500 l (normal), tank initial pressure 5 MPa
$M_1...M_7$	temperature measurement points

Figure E.4 — Example of error versus measurement points under wide range of initial tank pressure

Annex F
(informative)

Test results of hydrogen and electric energy consumption and driving range of test vehicle

Date   Test site   Person responsible

Test vehicle:

    Name and model: ....

    Chassis number: ....

    Total mileage: ....km

    Vehicle mass: ....kg

    Equivalent inertia mass (set value): ....kg

    Transmission: ....

If the vehicle is modified to adjust to the dynamometer in accordance with 7.1.4, details about the modification should be reported.

    Tyre pressure of drive wheels: ....kPa

RESS:

Rated capacity: .... Wh   Nominal voltage: V

Instruments for hydrogen consumption measurement:

Hydrogen tank for pressure method: Internal volume according to Annex A, ... l

Hydrogen tank for gravimetric method (including accessories): mass .... kg

Balance: Model: ...., Minimum readability: .... g, Maximum measuring mass: .... kg

Flowmeter: Model: ...., Type: ....

Test results:

ADT:

Start-up time: .... h .... min

Test temperature in test room: ....°C

Relative humidity in test room: .... %

Atmospheric pressure in test room: .... hPa

Driven distance: .... km

Usable amount of hydrogen:

Tank volume according to Annex I: l

Nominal working pressure: .... MPa

Usable amount of hydrogen according to Annex I: .... kg

CD state of externally chargeable FCHEV:

Driving range at CD state: .... km

Electric energy charged from external electric power source: .... Wh

Hydrogen consumption at CD state: .... g

Non-externally chargeable FCHEV or CS state of externally chargeable FCHEV:

Pressure method	Tank pressure, temperature
	(Before test) .... MPa, ... °C
	(After test) .... MPa, ... °C
Gravimetric method	Mass of the tank (Before test) .... g, (After test) .... g
Flow method	Flow volume supplied to vehicle .... l at 273 K, 101,3 kPa

Measured hydrogen amount: .... g

ΔE_{RESS}: .... Wh

If the measured result is corrected in accordance with 7.6, calculate the hydrogen consumption as described in Annex H.

Hydrogen consumption: .... g

Hydrogen consumption (per unit mass): .... g/km

Driving range at CS state: .... km

Driving range of FCHEV or FCV: .... km

Remarks:

Annex G
(normative)

Calculation of allowable range of RESS energy change

G.1 General

The allowable energy change in the RESS calculated by Formula (4) may be rewritten as follows using the net heating value (NHV) of fuel.

$$|\Delta E_{RESS}| \leq \frac{0{,}01 \times J_{NHV} \times w_{H2}}{3{,}6 \times 10^6} \tag{G.1}$$

where

ΔE_{RESS} is the energy change in RESS over the ADT, in Wh;

J_{NHV} is the net heating value (per consumable fuel analysis), in J/kg;

w_{H2} is the total mass of fuel consumed over the ADT, in g.

G.2 Batteries

The energy balance in a battery over the ADT, ΔE_{RESS}, in Wh, can be calculated from the measured charge balance, ΔQ, and expressed as follows:

$$\Delta E_{RESS} = \Delta Q \times V \tag{G.2}$$

where

ΔQ is the charge balance of the battery over the ADT, in Ah;

V is the nominal voltage of battery system, in V.

Annex H
(normative)

Linear correction method using a correction coefficient

H.1 General

This annex describes the calculation procedure to determine the fuel consumption at $\Delta E_{\text{RESS}} = 0$.

H.2 Method for correcting the fuel consumption

H.2.1 Data required for correction coefficient

The hydrogen consumption test shall be repeated several times to determine the correction coefficient defined in H.2.2.1 (see Figure H.1). The ΔE_{RESS} shall be measured during the test. The SOC and ΔE_{RESS} should be in the normal range specified by the vehicle manufacturer.

Key

X1 energy balance (Wh), discharge

X2 energy balance (Wh), charge

Y   consumed hydrogen

1   ○ × data ($C_i, w_{\text{R}i}$)

2   pre-measured line for determination of correction coefficient

3   hydrogen consumption correction coefficient K_{MF}

4   △ measured value ($C_s, w_{\text{R}, s}$)

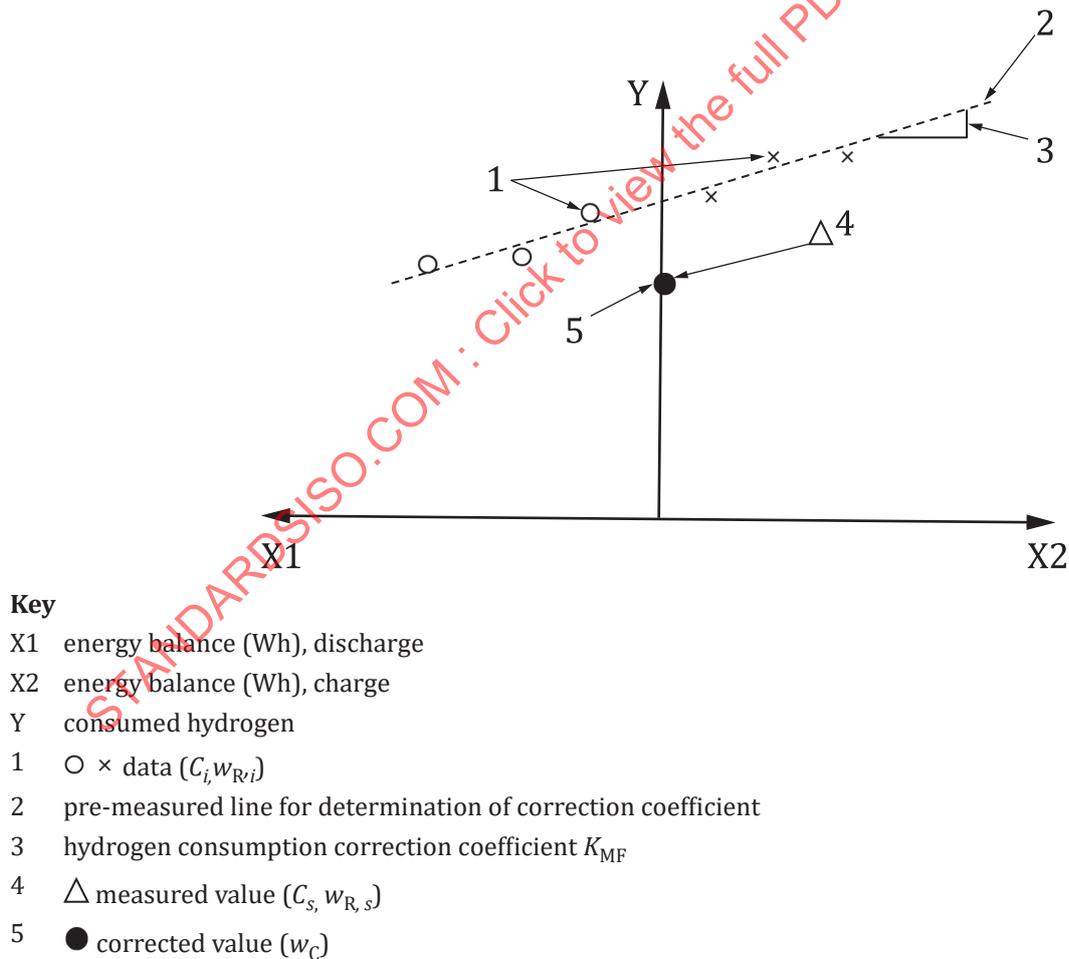5   ● corrected value (w_{C})

Figure H.1 — Example data collected from ADT

H.2.2 Corrections

H.2.2.1 Correction coefficient, K_{MF}

The hydrogen consumption correction coefficient, K_{MF}, in g/Wh, shall be calculated using the following Formula (H.1):

$$K_{MF} = \frac{n \times \sum C_i w_i - \sum C_i \times \sum w_i}{n \times \sum C_i^2 - (\sum C_i)^2} \tag{H.1}$$

where

    w_i is the hydrogen consumption of the test, in g;

    C_i is the energy balance at the hydrogen consumption test, in Wh (use the minimum unit);

    n is the number of data.

H.2.2.2 Hydrogen consumption at ($\Delta E_{RESS} = 0$), w_C

The amount of hydrogen consumption at ($\Delta E_{RESS} = 0$), w_C, expressed in g, is derived from Formula (H.2):

$$w_c = w_s - K_{MF} \times C_s \tag{H.2}$$

where

    w_s is the hydrogen consumption, in g;

    C_s is the energy balance of RESS, in Wh, (use the minimum unit).
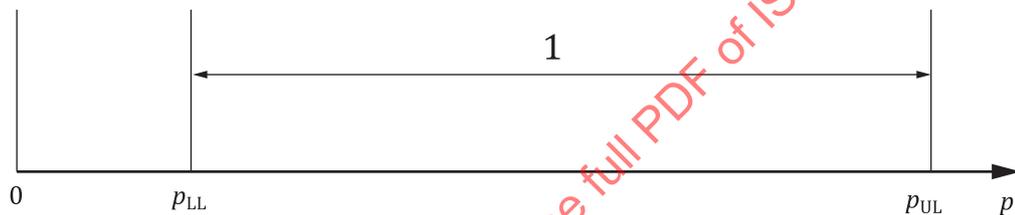
Annex I
(normative)

Usable amount of hydrogen of FCV and FCHEV

I.1 General

This annex describes the calculation procedure to determine the usable amount of hydrogen of fuel cell vehicles, including FCV and FCHEV.

I.2 Basic concept of "usable amount of hydrogen"

The "usable amount of hydrogen", M, expressed in kg is calculated according to I.4.

Key

1   pressure range of usable amount of hydrogen

P pressure of original hydrogen tank at 15 °C, expressed in MPa

P_{LL} lower limit pressure of original hydrogen tank at 15 °C

P_{UL} upper limit pressure of original hydrogen tank at 15 °C, the same as nominal working pressure (NWP)

Figure I.1 — Schematic diagram of "usable amount of hydrogen"

$$F_{H2} = \rho\,(P, T)/\rho\,(P_{NWP}, T_{15}) \times 100 \tag{I.1}$$

where

F_{H2} is the state of charge of hydrogen, expressed in %;

$\rho\,(P,T)$ is the gas density at the given pressure P and temperature T, in g/l;

P is the gas pressure, in MPa;

T is the gas temperature, in °C;

P_{NWP} is the gas pressure at the nominal working pressure, in Mpa;

T_{15} is 283,15 K (15 °C).

The lower limit of pressure may be obtained according to I.3 experimentally. The obtained value includes pressure drop.

I.3 Measurement of the lower limit

a)   The vehicle manufacturer offers the lower limit pressure for vehicle.