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Hydrogen fuel quality — Product specification

CD stage

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Foreword

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The committee responsible for this document is ISO/TC 197, Hydrogen technologies.

ISO 14687 was prepared by combining the following three standards, incorporating their revisions at the same time under the general title Hydrogen fuel quality— Product specification:

Part 1: All applications except proton exchange membrane (PEM) fuel cells for road vehicles

Part 2: Proton exchange membrane (PEM) fuel cell applications for road vehicles

Part 3: Proton exchange membrane (PEM) fuel cell applications for stationary appliances

Introduction

The purpose of this standard is to combine the existing three standards on hydrogen quality, ISO14687-1, ISO14687-2 and ISO14687 -3 into one document, incorporating their revisions at the same time.

NOTE:

ISO14687-1, All applications except proton exchange membrane (PEM) fuel cells for road vehicles

ISO14687-2, Proton exchange membrane (PEM) fuel cell applications for road vehicles

ISO14687-3, Proton exchange membrane (PEM) fuel cell applications for stationary appliances

In recent years, PEM fuel cell technologies have shown a remarkable progress such as lowering of Pt-loading, thinned electrolyte membrane, operation with high current density, and operation under low humidity. With this progress, it has become necessary to reconsider the tolerances of hydrogen impurities for the PEM fuel cells which are given in ISO 14687-2 and -3.

Therefore, ISO 14687 has been mainly revised based on the research and development of PEM fuel cells focusing on the following items;

- PEM fuel cell catalyst and fuel cell tolerance to hydrogen fuel impurities;
- Effects/mechanisms of impurities on fuel cell power systems and components;
- Impurity detection and measurement techniques for laboratory, production, and in-field operations; and,
- Fuel cell vehicle demonstration and stationary fuel cell demonstration results.

Since the hydrogen application technologies are developing rapidly, ISO 14687 will need to be further revised in future according to technological progress as necessary. Technical Committee ISO/TC 197, Hydrogen Technologies, will monitor this technology trend.

Hydrogen fuel quality — Product specification

1 Scope

This International Standard specifies the quality characteristics of hydrogen fuel in order to assure uniformity of the hydrogen product as produced and distributed for utilization in vehicular and stationary applications.

It is applicable to hydrogen fuelling applications, which are listed in Table 1 of this International Standard.

2 Normative references

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

ISO 19880-8, *Gaseous Hydrogen — Product specification — Part 8: Fuel Quality Control*

ISO 21087, *Hydrogen fuel — Analytical methods — Proton exchange membrane (PEM) fuel cell applications for road vehicles*

ISO/TR 15916, *Basic considerations for the safety of hydrogen systems*

IEC/TS 62282-1, *Fuel cell technologies — Terminology*

3 Terms and definitions

3.1

boundary point

point between the hydrogen fuel supply equipment and the PEM fuel cell power system at which the quality characteristics of the hydrogen fuel are to be determined

3.2

constituent

component (or compound) found within a hydrogen fuel mixture

3.3

contaminant

impurity that adversely affects the components within the fuel cell system or the hydrogen storage system

Note 1: An adverse effect can be reversible or irreversible.

3.4

customer

impurity that adversely affects the components within the fuel cell system or the hydrogen storage system

3.5

detection limit

the lowest quantity of a substance that can be distinguished from the absence of that substance with a stated confidence limit

3.6

determination limit

the lowest quantity which can be measured at a given acceptable level of uncertainty

3.7

fuel cell

electrochemical device that converts the chemical energy of a fuel and an oxidant to electrical energy (DC power), heat and other reaction products

3.8

fuel cell system

power system used for the generation of electricity on a fuel cell vehicle, typically containing the following subsystems: fuel cell stack, air processing, fuel processing, thermal management and water management

3.9

gaseous hydrogen

GH2

hydrogen that has been produced to gaseous form, and brought to essentially ambient conditions as an quilibrium mixture of ortho-hydrogen and para-hydrogen, purified to a minimum mole fraction of 98 %

Note 1: The gaseous form is produced typically by any number of methods, including petrochemical, thermochemical, solar, electrolytic or biological processes.

3.10

hydrogen fuel (PEM fuel cell for stationary fuel cell applications)

gas containing a concentration of hydrogen equal to or larger than 50 % used for PEM fuel cell for stationary fuel cell applications.

3.11

hydrogen fuel index

fraction or percentage of a fuel mixture that is hydrogen

3.12

hydrogen fuel supply equipment

equipment used for the transportation or on-site generation of hydrogen fuel, and subsequently for delivery to the fuel cell power system, including additional storage, vaporization, and pressure regulation as appropriate

3.13

irreversible effect

effect, which results in a permanent degradation of the fuel cell power system performance that cannot be restored by practical changes of operational conditions and/or gas composition

3.14
liquid hydrogen
LH2

hydrogen that has been liquefied, i.e. brought to a liquid state (para)

Note 1 to entry: Liquefaction may be carried out by either chilling and compression or other means such as the magnetocaloric effect.

3.15
on-site fuel supply

hydrogen fuel supplying system with a hydrogen production system in the same site

3.16
off-site fuel supply

hydrogen fuel supplying system without a hydrogen production system in the same site, receiving hydrogen fuel which is produced out of the site

3.17
particulate

solid or aerosol particle including oil mist that can be entrained somewhere in the delivery, storage, or transfer of the hydrogen fuel entering a fuel cell systems.

3.18
reversible effect

effect, which results in a temporary degradation of the fuel cell power system performance that can be restored by practical changes of operational conditions and/or gas composition

3.19
slush hydrogen
SLH2

hydrogen that is a mixture of solid and LH2 at the eutectic (triple-point) temperature

3.20
stationary proton exchange membrane (PEM) fuel cell power system

self-contained assembly of integrated PEM fuel cell systems used for the generation of electricity which is fixed in place in a specific location, typically containing the following subsystems: fuel cell stack, air processing, thermal management, water management, and automatic control system and which is used in applications such as: distributed power generation, back-up power generation, remote power generation, electricity and heat co-generation for resident and commercial applications

Note 2: For the purposes of this part of ISO 14687, the PEM fuel cell power system does not contain a fuel processing system due to the location of the boundary point.

3.21
system integrator

integrator of equipment between the PEM fuel cell power system and the hydrogen supply

4 Classification and application

4.1 Classification

Hydrogen fuel shall be classified according to the following types and grade designations:

a) Type I (grades A, B, C, D and E): Gaseous hydrogen

b) Type II (grades C and D): Liquid hydrogen

c) Type III: Slush hydrogen

4.2 Application

The following information as shown in Table 1 characterizes representative applications of each type and grade of hydrogen fuel. It is noted that suppliers shall take measures not to contaminate the each grade of hydrogen with the other grade(s) of hydrogen.

Table 1 — Hydrogen classification by application

Type	**Grade**	**Category**	**Applications**
I Gas	A	—	Internal combustion engines for transportation; Residential/commercial appliances except PEM fuel cell stationary appliances;
	B	—	Industrial fuel for power generation and heat generation
	C	—	Aircraft and space-vehicle ground support systems
	D	—	PEM fuel cells for road vehicles
	E	1	PEM fuel cells for stationary appliances
		2	
		3	
Ⅱ Liquid	C	—	Aircraft and space-vehicle on-board propulsion and electrical energy requirements; Off-road vehicles.
	D	—	PEM fuel cells for road vehicles
Ⅲ Slush	—	—	Aircraft and space-vehicle on-board propulsion

NOTE 1: PEM: Proton Exchange Membrane

NOTE 2: Grade D may be used for other fuel cell applications for transportation including forklifts and other industrial trucks if agreed upon between supplier and customer.

5 Requirements for the PEM fuel cell application for road vehicles

5.1 Fuel quality specification

The fuel quality requirements at the dispenser nozzle applicable to the aforementioned grades of hydrogen fuel for PEM fuel cells in road vehicles shall meet the requirements of Table 2. The fuel specifications are not process or feed stock specific. Non-listed contaminants have no guarantee of being benign.

NOTE Annex A provides the rationale for the selection of the impurities specified in Table 2.

Table 2 — Fuel quality specification for the PEM fuel cell application for road vehicles

Constituents (assay)	**Type I, Type II** **Grade D**
Hydrogen fuel index (minimum mole fraction)[a]	99,97 %
Total non-hydrogen gases	300 µmol/mol
Maximum concentration of individual contaminants	
Water (H_2O)	5 µmol/mol
Total hydrocarbons except Methane [b] (C1 equivalent)	2 µmol/mol
Methane (CH_4)	100 µmol/mol
Oxygen (O_2)	5 µmol/mol
Helium (He)	300 µmol/mol
Nitrogen (N_2)	300 µmol/mol
Argon (Ar)	300 µmol/mol
Carbon dioxide (CO_2)	2 µmol/mol
Carbon monoxide (CO)	0,2 µmol/mol
Total sulfur compounds[c] (S1 equivalent)	0,004 µmol/mol
Formaldehyde (HCHO)	0,01 µmol/mol
Formic acid (HCOOH)	0,2 µmol/mol
Ammonia (NH_3)	0,1 µmol/mol
Total halogenated compounds[d] (Halogen ion equivalent)	0,05 µmol/mol
Maximum particulates concentration	1 mg/kg
For the constituents that are additive, such as total hydrocarbons and total sulfur compounds, the sum of the constituents shall be less than or equal to the acceptable limit.	

[a] The hydrogen fuel index is determined by subtracting the "total non-hydrogen gases" in this table, expressed in mole percent, from 100 mole percent.

[b] Total hydrocarbons include oxygenated organic species. Total hydrocarbons shall be measured on a C1 equivalent (µmolC/mol).

[c] As a minimum, total sulphur compounds include H_2S, COS, CS_2 and mercaptans, which are typically found in natural gas.

[d] Total halogenated compounds include, for example, hydrogen bromide (HBr), hydrogen chloride (HCl), chlorine (Cl_2), and organic halides (R-X). Total halogenated compounds shall be measured on a halogen ion equivalent (µmolC/mol).

5.2 Analytical method

The analytical methods for measuring constituents for the PEM fuel cell application for road vehicles listed in Table 2 are specified in ISO 21087, Hydrogen fuel — Analytical methods — Proton exchange membrane (PEM) fuel cell applications for road vehicles.

5.3 Hydrogen fuel qualification test

Quality verification requirements for the qualification tests shall be performed utilizing ISO19880-8 Gaseous hydrogen -- Fueling stations -- Part 8: Hydrogen quality control.

5.4 Sampling

The hydrogen sampling methods for PEM fuel cell vehicles are specified in ISO19880-1 Gaseous hydrogen -- Fueling stations -- Part 1: General requirement.

5.5 Hydrogen quality control

The protocol for ensuring the quality of the gaseous hydrogen quality at hydrogen distribution bases and hydrogen fueling stations is given in ISO 19880-8 which provides reasonable and affordable methods and procedure to comply with hydrogen quality required by this standard.

6 Requirements for the PEM fuel cell application for stationary appliances

6.1 Fuel quality specification

The fuel quality at the boundary point set between the hydrogen fuel supply equipment and the PEM fuel cell power system, as applicable to the aforementioned grades of hydrogen fuel for stationary appliances, shall meet the requirements of Table 3.

NOTE 1 Please see Annex B for the selection of the boundary point.

NOTE 2 Annex C provides the rationale for the selection of the impurities specified in Table 3.

Type I, grade E hydrogen fuel for PEM fuel cell applications for stationary appliances specifies the following subcategories for the convenience of both PEM fuel cell manufacturers and hydrogen fuel suppliers:

- Type I, grade E, Category 1
- Type I, grade E, Category 2
- Type I, grade E, Category 3

These categories are defined to meet the needs of different stationary applications, depending on the requirements specified by the manufacturer.

Table 3 — Fuel quality specification for stationary appliances

Constituents[a] (assay)	**Type I, grade E**		
	Category 1	**Category 2**	**Category 3**
Hydrogen fuel index (minimum mole fraction)	50 %	50 %	99,9 %
Total non-hydrogen gases (maximum mole fraction)	50 %	50 %	0,1%
Water (H_2O)[b]	Non-condensing at all ambient conditions	Non-condensing at all ambient conditions	Non-condensing at all ambient conditions
Maximum concentration of individual contaminants			
Total hydrocarbons (C_1 equivalent)[c]	10 µmol/mol	2 µmol/mol	2 µmol/mol
Oxygen (O_2)	200 µmol/mol	200 µmol/mol	50 µmol/mol
Nitrogen (N_2), Argon (Ar), Helium (He) (mole fraction)	50 %	50 %	0,1 %
Carbon dioxide (CO_2)	Included in total non-hydrogen gases	Included in total non-hydrogen gases	2 µmol/mol
Carbon monoxide (CO)	10 µmol/mol	10 µmol/mol	0,2 µmol/mol
Total sulphur compounds [d]	0,004 µmol/mol	0,004 µmol/mol	0,004 µmol/mol
Formaldehyde (HCHO)	3,0 µmol/mol	0,01 µmol/mol	0,01 µmol/mol
Formic acid (HCOOH)	10 µmol/mol	0,2 µmol/mol	0,2 µmol/mol
Ammonia (NH_3)	0,1 µmol/mol	0,1 µmol/mol	0,1 µmol/mol
Total halogenated compounds [e]	0,05 µmol/mol	0,05 µmol/mol	0,05 µmol/mol
Maximum particulates concentration	1 mg/kg	1 mg/kg	1 mg/kg
Maximum particle diameter	75 µm	75 µm	75 µm

NOTE For the constituents that are additive (*i.e.* total hydrocarbons, total sulphur compounds and total halogenated compounds), the sum of the constituents shall be less than or equal to the specifications in the table. It is therefore important that the analytical method used measures the *total* concentration of these families of compounds, and not the concentration of single compounds within these families, which are subsequently summed to give a total amount of fraction. The latter approach risks a false negative being reported.

[a] Maximum concentration of impurities against the total gas content shall be determined on a dry-basis.

[b] Each site shall be evaluated to determine the appropriate maximum water content based on the lowest expected ambient

temperature and the highest expected storage pressure.

[c] Total hydrocarbons are measured on a carbon equivalent (μmolC/mol). The specification for total hydrocarbons includes oxygenated hydrocarbons. The measured amount fractions of all oxygenated hydrocarbons shall therefore contribute to the measured amount fraction of total hydrocarbons. Specifications for some individual oxygenated hydrocarbons (e.g. formaldehyde and formic acid) are also given in the table - these however also contribute to the measured amount fraction of total hydrocarbons. These species have been assigned their own specifications based on their potential to impair the performance of PEM fuel cells. Total hydrocarbons may exceed the limit due only to the presence of methane, in which case the methane shall not exceed 5 % for Category 1, 1 % for Category 2 or 100 μmol/mol of hydrogen fuel for Category 3.

d As a minimum, total sulphur compounds include H_2S, COS, CS_2 and mercaptans, which are typically found in natural gas.

e Includes, for example, hydrogen bromide (HBr), hydrogen chloride (HCl), chlorine (Cl_2), and organic halides (R-X).

6.2 Hydrogen production guidance

Hydrogen fuel may be produced in a number of ways, including reformation of fossil fuels or other hydrocarbons, the electrolysis of pure water and alkaline water, and numerous biological methods. Hydrogen fuel can be generated on-site, generally in relatively small quantities, or in a larger scale production system off-site, then transported under pressure or as a liquid to the point of use.

NOTE It should be recognized that biological sources of hydrogen can contain additional constituents that affect fuel cell performance (e.g. siloxanes and mercury). Such constituents are not included in Table 3 due to insufficient information.

6.3 Quality Verification

6.3.1 General requirements

Quality verification requirements shall be determined at the boundary point using the sampling methods specified in Subclause 6.4 of this International Standard. The analytical methods listed in ISO 21087, Hydrogen fuel — Analytical methods — Proton exchange membrane (PEM) fuel cell applications for road vehicles, may be used for this application. Alternatively, the quality verification may be performed at other locations or under other methods by written agreement between the supplier and the customer.

Analyses of all fuel quality specifications in Table 3 need not be necessary for all hydrogen production methods, if acceptable to the customer.

All analyses conducted under this International Standard shall be undertaken using gaseous calibration standards (or other calibration devices) that are traceable to the International System of Units (SI) via national standards, where such standards are available.

6.3.2 Analytical requirements of the qualification tests

The frequency of testing and analytical requirements for the qualification tests shall be specified by the supplier and the customer. Consideration shall be given to the consistency of hydrogen supply in determining test frequency and constituents to be tested.

NOTE Annex D provides a recommended practice of the quality assurance for steam methane reforming (SMR) hydrogen production processes using pressure swing adsorption (PSA) purification.

6.3.3 Report results

The detection and determination limits for analytical methods and instruments used shall be reported along with the results of each test and date the sample was taken.

6.4 Sampling

6.4.1 Sample size

Where possible, the quantity of hydrogen in a single sample container should be sufficient to perform the analyses for the hydrogen fuel quality specification. If a single sample does not contain a sufficient quantity of hydrogen to perform all of the analyses required to assess the quality level, additional samples from the same lot shall be taken under similar conditions. A large sample or sample with a greater pressure, where applicable, may be required if multiple tests are to be conducted.

6.4.2 Selection of the sampling point

A boundary point shall be established so that gaseous samples are representative of the hydrogen supplies to the PEM fuel cell power systems.

NOTE Annex B provides guidance to assist in the identification of the party responsible for the quality of hydrogen at the boundary point and also the selection of the boundary point.

6.4.3 Sampling procedure

Gaseous hydrogen samples shall be representative of the hydrogen supply, withdrawn from the boundary point through a suitable connection into an appropriately sized sample container. No contamination of the hydrogen fuel shall be introduced between the boundary point and the sample container (a suitable purge valve may be used).

NOTE Attention shall be paid to ensure that the sampled hydrogen is not contaminated with residual gases inside the sample container by evacuating it. If evacuation is not possible, the sample container shall be cleaned using repeated purge cycles.

Sampled gases are flammable and potentially toxic. Measures shall be taken to avoid hazardous situations as per ISO/TR 15916, Basic considerations for the safety of hydrogen systems.

6.4.4 Particulates in gaseous hydrogen

Particulates in hydrogen shall be sampled from the boundary point, using a filter, if practical, under the same conditions (pressure and flow rate) as employed in the actual hydrogen supplying condition. Appropriate measures shall be taken for the sample gas not to be contaminated by particulates coming from the connection device and/or the ambient air.

7 Requirements for applications except PEM fuel cells for road vehicles and stationary appliances

7.1 Fuel quality specification

The fuel quality specification, outlined in Table 4, specifies the requirements applicable to each type and grade of hydrogen fuel except PEM fuel cell use. A blank indicates no maximum limiting characteristic. The absence of a maximum limiting characteristic in a listed quality level does not imply that the component is or is not present, but merely indicates that the test need not to be performed for compliance with this International Standard.

Table 4 — Fuel quality specification for applications except PEM fuel cells

Dimensions in micromoles per mole unless otherwise stated

Constituents	**Type I**			**Type II**	**Type III**
(assay)	**Grade A**	**Grade B**	**Grade C**	**Grade C**	
Hydrogen fuel index [g] (minimum mole fraction, %)	98,0	99,90	99,995	99,995	99,995
Para-hydrogen (minimum mole fraction, %)	NS	NS	NS	95,0	95,0
Impurities (maximum content)					
Total gases			50	50	
Water (cm^3/m^3)	NC [a]	NC	[b]	[b]	
Total hydrocarbon	100	NC	[b]	[b]	
Oxygen	[a]	100	[c]	[c]	
Argon	[a]		[c]	[c]	
Nitrogen	[a]	400	[b]	[b]	
Helium			39	39	
CO_2			[d]	[d]	
CO	1		[d]	[d]	
Mercury		0,004			
Sulfur	2,0	10			
Permanent particulates	[f]	[e]	[e]	[e]	
Density					[e]

NOTE 1 NS: Not specified

NOTE 2 NC: Not to be condensed

[a] Combined water, oxygen, nitrogen and argon: maximum mole fraction of 1,9 %.

[b] Combined nitrogen, water and hydrocarbon: max. 9 µmol/mol.

[c] Combined oxygen and argon: max. 1 µmol/mol.

[d] Total CO_2 and CO: max. 1 µmol/mol.

[e] To be agreed between supplier and customer.

[f] The hydrogen shall not contain dust, sand, dirt, gums, oils, or other substances in an amount sufficient to damage the fuelling station equipment or the vehicle (engine) being fuelled.

g The hydrogen fuel index is determined by subtracting the "total non-hydrogen gases" in this Table, expressed in mole percent, from 100 mole percent.

7.2 Quality verification

7.2.1 Sample size

The supplier shall assure, by standard practice, the verification of the quality level of hydrogen. The sampling and control procedures described in Subclause 7.2.3.1 and 7.2.3.2 and in Subclause 7.3. As for the analysis methods for these applications, ISO 21087, Hydrogen fuel — Analytical methods — Proton exchange membrane (PEM) fuel cell applications for road vehicles, may be applied. Other control procedures not listed in this International Standard are acceptable if agreed upon between the supplier and the customer.

7.2.2 Production qualification tests

7.2.2.1 General requirements

Production qualification tests are a single analysis or a series of analyses that shall be performed on the product to assure the reliability of the production facility to supply hydrogen of the required quality level. This production qualification may be achieved by verifying the analytical records of product from the supplier, or, if required, by performing analyses of representative samples of the product from the facility at appropriate intervals as agreed between the supplier and the customer. Production qualification tests may be performed by the supplier or by a laboratory agreed upon between the supplier and the customer.

7.2.2.2 Analytical requirements of the production qualification tests

The analytical requirements for the production qualification tests shall include the determination of all hydrogen fuel quality specification of hydrogen.

7.2.3 Lot acceptance tests

7.2.3.1 Applicability

Lot acceptance tests are analyses that shall be performed on the hydrogen in the delivery container, or a sample thereof, which is representative of the lot.

7.2.3.2 Lot definitions

Lot acceptance tests are analyses that shall be performed on the hydrogen in the delivery container, or a sample thereof, which is representative of the lot.

a) no specific quantity, or any quantity of hydrogen agreed upon between the supplier and the customer;

b) all of the hydrogen supplied, or containers filled, during the contract period;

c) all of the hydrogen supplied, or containers filled, during a calendar month;

d) all of the hydrogen supplied, or containers filled, during seven consecutive days;

e) all of the hydrogen supplied, or containers filled, during a consecutive 24-h period;

f) all of the hydrogen supplied, or containers filled, during one continuous shift;

g) all of the hydrogen supplied in one shipment;

h) all of the hydrogen supplied in one delivery container;

i) all of the hydrogen in the container(s) filled on one manifold at the same time.

7.2.3.3 Number of samples per lot

The number of samples per lot shall be in accordance with one of the following:

a) one sample per lot;

b) any number of samples agreed upon by the supplier and the customer.

7.3 Sampling

7.3.1 Sample size

The quantity of hydrogen in a single sample container shall be sufficient to perform the analyses for the fuel quality specifications. If a single sample does not contain a sufficient quantity of hydrogen to perform all of the analyses required to assess the quality level, additional samples from the same lot shall be taken under similar conditions.

7.3.2 Gaseous samples

Gaseous samples shall be representative of the hydrogen supply. Samples shall be obtained using one of the following procedures.

a) Fill the sample container and delivery containers at the same time, on the same manifold and in the same manner.

b) Withdraw a sample from the supply container through a suitable connection into the sample container. No regulator shall be used between the supply and the sample containers (a suitable purge valve may be used).

For safety reasons, the sample container and sampling system shall have a rated service pressure at least equal to the pressure in the supply container.

c) Connect the container being sampled directly to the analytical equipment using suitable pressure regulation to prevent over-pressurizing this equipment.

d) Select a representative container from the containers filled in the lot.

7.3.3 Liquid samples (vaporized)

Vaporized liquid samples shall be representative of the liquid hydrogen supply. Samples shall be obtained using one of the following procedures:

a) by vaporizing, in the sampling line, liquid hydrogen from the supply container;

b) by flowing liquid hydrogen from the supply container into or through a suitable container in which a representative sample is collected and then vaporized.

Annex A (informative)
Rational for the selection of hydrogen impurities to be measured for PEM fuel cell application for road vehicles

A.1 Water content

Water (H_2O) generally does not affect the function of a fuel cell, however; it provides a transport mechanism for water-soluble contaminants such as K+ and Na+ when present as an aerosol. Both K+ and Na+ are recommended not to exceed 0,05 µmol/mol. In addition, water may pose a concern including ice formation for onboard vehicle fuel and hydrogen dispensing systems under certain conditions. Water should remain gaseous throughout the operating conditions of systems.

A.2 Total hydrocarbon content

Different hydrocarbons have different effects on fuel cell performance. Generally aromatic hydrocarbons adsorb more strongly on the catalyst surface than other hydrocarbons inhibiting access to hydrogen. Methane (CH_4) is considered an inert constituent since its effect on fuel cell performance is to dilute the hydrogen fuel stream.

A.3 Oxygen content

Oxygen (O_2) in low concentrations does not adversely affect the function of the fuel cell system; however, it may be a concern for some onboard vehicle storage systems, for example, by reaction with metal hydride storage materials.

A.4 Helium, nitrogen and argon contents

Inert constituents, such as helium (He), nitrogen (N_2) and argon (Ar) do not adversely affect the function of fuel cell components or a fuel cell system. However, they dilute the hydrogen gas. N_2 and Ar especially can affect system operation and efficiency and can also affect the accuracy of mass metering instruments for hydrogen dispensing.

A.5 Carbon dioxide content

Carbon dioxide (CO_2) does not typically affect the function of fuel cells. However, CO_2 may adversely affect onboard hydrogen storage systems using metal hydride alloys. With CO_2, at levels very much higher than the specification, a reverse water gas shift reaction can occur under certain conditions in fuel cell systems to create carbon monoxide.

A.6 Carbon monoxide content

Carbon monoxide (CO) is a severe catalyst poison that adversely affects fuel cell performance and needs to be kept at very low levels in hydrogen fuel. Although its effect can be reversed through mitigating strategies, such as material selection of membrane electrode assembly (MEA), system design and operation, the life time effects of CO on performance is a strong concern. Lower catalyst loadings are particularly susceptible to catalyst poisoning contaminants.

A.7 Total sulfur compounds contents

Sulfur containing compounds are severe catalyst poisons that at even very low levels can cause irreversible degradation of fuel cell performance. The specific sulfur compounds that are addressed are in particular: hydrogen sulfide (H_2S), carbonyl sulfide (COS), carbon disulfide (CS_2), methyl mercaptan (CH_3SH). Lower catalyst loadings are particularly susceptible to catalyst poisoning contaminants.

A.8 Formaldehyde and formic acid contents

Formaldehyde (HCHO) and formic acid (HCOOH) have a similar effect on fuel cell performance as CO and are thus considered as reversible contaminants. The effect of HCHO and HCOOH on fuel cell performance can be more severe than that of CO due to slower recovery kinetics and their specifications are lower than that for CO. Lower catalyst loadings are particularly susceptible to catalyst poisoning contaminants.

A.9 Ammonia content

Ammonia (NH_3) causes some irreversible fuel cell performance degradation by affecting the ion exchange capacity of the ionomer of the proton exchange membrane and/or electrode.

A.10 Total halogenated compounds contents

Halogenated compounds cause irreversible performance degradation. Potential sources include chlor-alkali production processes, refrigerants used in processing, and cleaning agents.

A.11 Particulates

A maximum particulate concentration is specified to ensure that filters are not clogged and/or particulates do not enter the fuel system and affect operation of valves and fuel cell stacks. A maximum particulate size diameter is not specified but should be addressed in fuelling station and/or component standards. Particulate sizes should be kept as small as possible. It is noted that a specific threshold for particulate size which causes degradation has not been made clear and it is influenced by the particulate in ambient air while sampling and refuelling process.

Annex B (informative)
Guidance on the selection of the boundary point for PEM fuel cells for stationary appliances

B.1 Purpose

The following guidance is provided to assist in the identification of the boundary point and who is responsible for the quality of hydrogen at the boundary point.

B.2 Identification of the party responsible for hydrogen quality at the sampling point

It is recognised that provision of hydrogen to a fuel cell power system may involve numerous parties.

The following text and figure provide examples for information purposes, but are not intended to be comprehensive. Hydrogen delivery systems that incorporate different equipment or hydrogen feedstock should use these examples as a basis for determining responsibility for the quality of hydrogen at the boundary point and if appropriate, additional sampling points.

The following are examples of parties involved in and responsible for the supply of hydrogen:

- Gaseous hydrogen supplier (cylinders or tube trailers)
- Liquid hydrogen supplier
- Hydrogen via pipeline distributer
- Reformer manufacturer
- Electrolyser manufacturer

Depending on the form of the hydrogen supply, there may be a requirement for system integrators to provide equipment between the source of the hydrogen and the inlet to the fuel cell power system. Such equipment may comprise, as applicable, the following, shown in Figure B. 1:

- Pressure regulators
- Liquid hydrogen storage, cryogenics pumps and vaporizers
- Gaseous hydrogen buffer storage
- Additional manifolds from hydrogen source to fuel cell power system inlet

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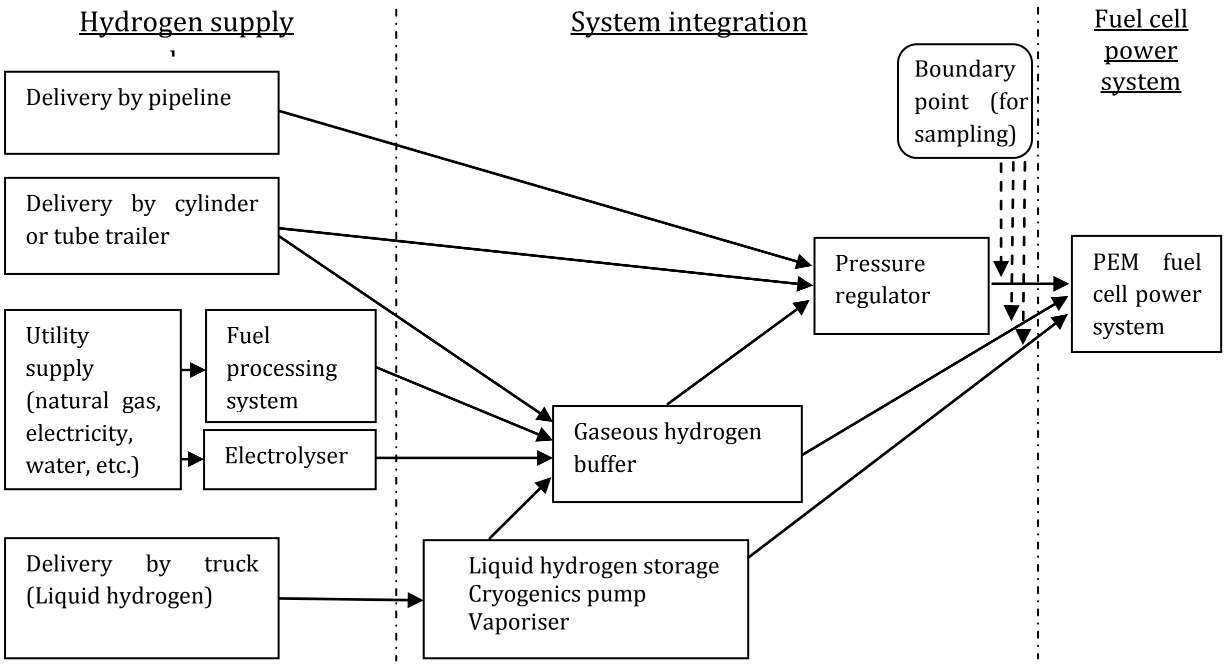


Figure B. 1 — Examples showing the supply of hydrogen to a fuel cell power system and position of the boundary point

It should be recognised that the system integrator is responsible for the quality of hydrogen at the boundary point, immediately prior to the inlet of the fuel cell power system. If the system integrator and fuel cell power system operator are the same party, one or more appropriate alternative sampling points for meeting hydrogen quality characteristics should be determined by agreement between the hydrogen supplier and the customer.

In some cases, the system integrator may also be the hydrogen supplier, in which case the responsibility for the hydrogen quality characteristics at the boundary point is that of the hydrogen supplier unless otherwise specified by agreement between the hydrogen supplier and the customer.

Where the system integrator and hydrogen supplier are different parties, the responsibility for the hydrogen quality characteristics at the boundary point is that of the system integrator. In such cases, the analytical requirements (periodicity, impurities, and appropriate interface test point) for the hydrogen supply should be determined by agreement between the hydrogen supplier, the system integrator and the customer.

It may also be the case that the hydrogen supplier provides some aspects of on-site system integration but does not directly interface with the fuel cell power system. In such cases, the hydrogen supplier is responsible for meeting the hydrogen quality characteristics at the supplier interface to the additional equipment that connects to the fuel cell power system, while the integrator interfacing with the fuel cell power system is responsible for the analytical requirements of the hydrogen quality at the boundary point. The analytical requirements (periodicity, impurities) at any additional sampling points appropriate to the system should be specified by agreement between the system integrator and the hydrogen supplier.

Where system maintenance is to be carried out by an additional party, the requirements for hydrogen quality assurance following completion of such maintenance should be determined by agreement between the system integrator, the party responsible for maintenance and the fuel cell operator.

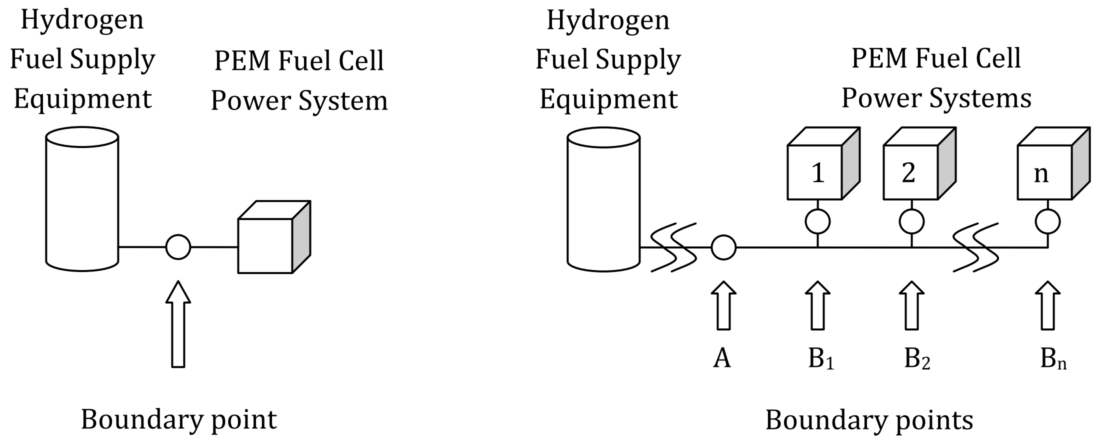
B.3 Selection of the sampling point

In the case of a single fuel cell power system, as shown in Figure B. 2a), the boundary point should be as close as practical to the fuel inlet to the fuel cell power system.

In the case of multiple fuel cell power systems in parallel, as shown in Figure B. 2b), the location of the boundary point should be determined by agreement between the system integrator and the fuel cell operator, subject to national and local regulations.

Examples for the location of the sampling point may include:

- Boundary point A - the supply for fuel cell power systems 1 to n.
- A single boundary point between B_1 and B_n, representing the worst case.
- All boundary points B_1 through B_n.



a) Single fuel cell power system

b) Multiple fuel cell power system in parallel

Figure B. 2 — Positioning of sampling point

Annex C (informative)
Rational for the selection of hydrogen impurities to be measured for PEM fuel cells for stationary appliances

C.1 Water content

Water (H_2O) generally does not affect the function of a fuel cell, however; it provides a transport mechanism for water-soluble contaminants such as K+ and Na+ when present as an aerosol. Both K+ and Na+ are recommended not to exceed 0,05 µmol/mol for Category 3. In addition water may pose a concern under sub-zero ambient conditions and affect valves. Thus, water shall remain gaseous throughout the encountered ambient temperature conditions.

C.2 Total hydrocarbon content

Different hydrocarbons have different effects on fuel cell performance. Generally aromatic hydrocarbons adsorb more strongly on the catalyst surface than alkanes, inhibiting access to hydrogen. Methane (CH_4) is considered an inert gas since its effect on fuel cell performance is to dilute the hydrogen fuel stream.

C.3 Oxygen content

Oxygen (O_2) in low concentrations does not adversely affect the function of the fuel cell power system, but high concentration oxygen causes degradation of the fuel cell. In the future, if long-term durability such as 100.000 hours is desired, it is necessary to review the value.

C.4 Helium, nitrogen and argon contents

Inert constituents, such as helium (He), nitrogen (N2) and argon (Ar) do not adversely affect the function of fuel cell components or a fuel cell power system. However, they dilute the hydrogen gas.

C.5 Carbon dioxide content

Carbon dioxide (CO_2) does not typically affect the function of fuel cells. It dilutes the hydrogen fuel thereby affecting the efficiency of the fuel cell power system. A high CO_2 content in hydrogen fuel (> 1000 ppm) will result in the formation of CO via a reverse water gas shift reaction which, depending on the material selection and/or system design and operation, could further impact fuel cell performance.

C.6 Carbon monoxide content

Carbon monoxide (CO) is a severe catalyst poison that adversely affects fuel cell performance and thus needs to be kept at very low levels in hydrogen fuel. While the impact on performance can be reversed by changing operating conditions and/or gas composition, these measures may not be practical. In reformate applications (Categories 1 and 2) the impact of the inherently higher CO levels is mitigated through material selection, and/or system design and operation, nonetheless the long term effect of CO on fuel cell durability is a concern, specifically for low anode catalyst loadings.

C.7 Total sulphur concentration

Sulphur containing compounds are catalyst poisons that at even very low levels can cause some irreversible degradation of fuel cell performance. The minimum specific sulphur compounds that need to be included in the testing are: hydrogen sulphide (H_2S), carbonyl sulphide (COS), carbon disulphide (CS_2), mercaptans (e.g. methyl mercaptan), which may be found in hydrogen reformed from natural gas. It is recommended that total sulphur concentration be monitored. Lower catalyst loadings are particularly susceptible to catalyst poisoning contaminants. In the future, if long-term durability such as 100.000 hours is desired, it is necessary to review the value for a possible reduction.

C.8 Formaldehyde and formic acid contents

Formaldehyde (HCHO) and formic acid (HCOOH) have a similar effect on fuel cell performance as CO and are thus considered as reversible contaminants. The effect of HCHO and HCOOH on fuel cell performance can be more severe than that of CO due to slower recovery kinetics and their specifications are lower than that for CO. Lower catalyst loadings are particularly susceptible to catalyst poisoning contaminants.

C.9 Ammonia content

Ammonia (NH_3) causes some irreversible fuel cell performance degradation by contaminating the proton exchange membrane/ionomer and reacting with protons in the membrane/ionomer to form NH^{4+} ions. Test data for ammonia tolerance should include ion exchange capacities of membrane and/or electrodes. Lower catalyst loadings imply lower ion exchange capacities within the electrode.

C.10 Total halogenated compounds contents

Halogenated compounds cause irreversible performance degradation. Potential sources include chlor-alkali production processes, refrigerants used in processing, and cleaning agents.

C.11 Particulates

A maximum particulate concentration and size are specified to ensure that filters are not clogged and/or particulates do not enter the PEM fuel power system and affect the operation of valves and fuel cell stacks. Potassium and sodium ions present in aerosols cause irreversible performance degradation by contaminating the proton exchange membrane/ionomer. Iron-containing particulates, even at very low concentrations, cause severe membrane/ionomer degradation.

Annex D (informative)
Pressure swing adsorption and applicability of CO as canary species for PEM fuel cell for stationary appliances

D.1 Canary species: major impurities from different H2 production and purification processes

For SMR-PSA production and purification, CO can serve as a canary species for the presence of other impurities listed in Table 3. Canary species can serve as an indicator of the presence of other chemical constituents because it has the highest probability of presence in a fuel produced by a given process. Confirmation that CO content is less than its specified limit indicates that other impurities, except inerts, are present at less than their specified limits.

The maximum content of inerts in the product hydrogen can be estimated by using the maximum content of inerts in the feedstock specified by the supplier and the flow increase in the SMR system and the flow decrease in the PSA system. The flow increase in the SMR system and the flow decrease in the PSA system can be calculated from the feedstock composition, steam to carbon ratio, and the hydrogen conversion rate.

D.2 In-line monitoring of the canary species

In-line monitoring of CO is strongly recommended to show that its content in the hydrogen fuel is less than the specification on real-time basis, which indicates that other contaminants are less than their specifications on real-time basis. For this purpose, commercially available infrared CO analyzers can be used. In the case of a SMR-PSA system, the analyzer should be placed just after the SMR-PSA system to avoid contamination of the equipment downstream.

D.3 Batch analysis

For back-up of in-line monitoring of CO content, batch sampling of product hydrogen and laboratory analyses of all impurities constituents as listed in Table 3 are also recommended. The batch sample should be taken at the boundary point. The frequency of sampling and analysis is determined by the hydrogen supplier. The analytical methods as described in Subclauses 6.3 and 6.4 of this International Standard should be applied.