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Basic considerations for the safety of hydrogen systems

Considérations fondamentales pour la sécurité des systèmes à l'hydrogène

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Contents

Page

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).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

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

This second edition cancels and replaces the first edition (ISO/TR 15916:2004), which has been technically revised.

Introduction

The focus of this Technical Report is on the relatively new hydrogen energy applications. The intent is to provide, those unfamiliar with the technology, a basis upon which to understand the safety issues. This Technical Report concerns itself with applications that derive their utility from the chemical reactions of hydrogen and does not apply to applications based on nuclear processes.

Traditionally, hydrogen has been used extensively in the petrochemical and chemical industries and in smaller quantities in the electronics, steel-producing, glass-making, and food hydrogenation industries. In energy applications, the first significant use of hydrogen has appeared in space programmes. This is changing, given the promise that hydrogen brings as an efficient energy carrier and a fuel with minimal environmental impact. Systems are being developed that produce hydrogen using variety of energy sources and feedstocks such as sunlight, wind, biomass, hydro power and fossil fuels, for use in energy applications for home and office heating, generation of electricity and transportation.

The safe use of hydrogen as a fuel is a primary ISO goal as it seeks to facilitate the rapid emergence of these hydrogen technologies. A key element in the safe use of hydrogen is to understand its unique safety-related properties and related phenomena, and that there are acceptable engineering approaches to controlling the hazards and risks associated with the use of hydrogen. This Technical Report describes the hazards associated with the use and presence of hydrogen, discusses the properties of hydrogen relevant to safety, and provides a general discussion of approaches taken to mitigate hydrogen hazards. The aim of this Technical Report is to promote the acceptance of hydrogen technologies by providing key information to regulators and by educating people involved with hydrogen safety issues.

The development of International Standards to eliminate barriers to international trade and to simplify the arduous regulatory process by providing hydrogen-specific standards to allow implementation for rapidly emerging technologies was among the needs identified by the ISO/TC 197. This Technical Report is one of many documents that have been developed, or are in the process of being developed, by ISO. Detailed safety requirements associated with specific hydrogen applications are treated in separate International Standards. This Technical Report provides an informative reference for those separate standards as a common, consistent source of safety-related hydrogen information. This should result in a reduction in duplication and possible inconsistencies in these separate standards.

The considerations presented in this Technical Report are broad, general, and attempt to address most aspects of hydrogen safety. The degree to which these guidelines are applied will vary according to the specifics of the application (such as the conditions and quantity of hydrogen involved, and the way in which the hydrogen is used). Industrial users may find large portions of the guidelines, presented herein, applicable for their operations. It is not expected that the general public will be required to apply this degree of knowledge to safely operate a hydrogen appliance. It is anticipated that good appliance design, coupled with appropriate care in installation, will reduce the degree of safety considerations to levels that are deemed acceptable by the public for common appliances. The manufacturers of hydrogen appliances will need to consider these guidelines to tailor sufficient specific information for the operation of their appliances, in the environment in which they are to be used, and for the audience that will use them. Readers are encouraged to keep these points in mind as they consider the information presented in this Technical Report. Hydrogen has been safely used in many different applications over many years. Adherence to the principles presented in this Technical Report can lead to a continuation of the safe and sustainable use of hydrogen.

Basic considerations for the safety of hydrogen systems

1 Scope

This Technical Report provides guidelines for the use of hydrogen in its gaseous and liquid forms as well as its storage in either of these or other forms (hydrides). It identifies the basic safety concerns, hazards and risks, and describes the properties of hydrogen that are relevant to safety. Detailed safety requirements associated with specific hydrogen applications are treated in separate International Standards.

"Hydrogen" in this paper means normal hydrogen ($^{1}H_2$), not deuterium ($^{2}H_2$) or tritium ($^{3}H_2$).

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 11114-4, *Transportable gas cylinders — Compatibility of cylinder and valve materials with gas contents — Part 4: Test methods for selecting metallic materials resistant to hydrogen embrittlement*

ISO 11119 (all parts), *Gas cylinders — Refillable composite gas cylinders and tubes — Design, construction and testing*

ISO 14687 (all parts), *Hydrogen fuel — Product specification*

ISO 16110 (all parts), *Hydrogen generators using fuel processing technologies*

ISO 16111, *Transportable gas storage devices — Hydrogen absorbed in reversible metal hydride*

ISO 17268, *Gaseous hydrogen land vehicle refuelling connection devices*

ISO 19880-1[1)], *Gaseous hydrogen — Fueling stations — Part 1: General requirements*

ISO 19881[2)], *Gaseous hydrogen — Land and vehicle fuel tanks*

ISO 19884[3)], *Gaseous hydrogen — Cylinders and tubes for stationary storage*

ISO 22734 (all parts), *Hydrogen generators using water electrolysis process*

ISO 26142, *Hydrogen detection apparatus — Stationary applications*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
ambient conditions
AIT
local surrounding conditions characterized by the temperature and pressure at a particular location, such as a city or facility

Note 1 to entry: See *normal temperature and pressure* (3.71).

1) Under development.

2) Under development.

3) Under development.

3.2
annealing
heat treatment process used to soften hard steel so that it can be machined or cold-worked

3.3
arrested flame
combustion process which is stopped or flame which is put out

3.4
auto-ignition
Ignition which does not require external ignition energy because the thermal energy of the molecules alone is enough to overcome the activation threshold for combustion initiation

3.5
auto-ignition temperature
lowest temperature at which *auto-ignition* (3.4) occurs; 858 K for hydrogen

3.6
backfill
process by which a desired gas is used to replace an undesired gas in a system volume

Note 1 to entry: Typically, the undesired gas is first removed by evacuation with a vacuum pump, then the desired gas is put in.

3.7
back-flow
flow of a fluid in the direction opposite to the normal flow direction

Note 1 to entry: This term is used to describe the entry (diffusion) of atmospheric air into a hydrogen vent line.

3.8
ball valve
valve that functions with a ported sphere in a housing

Note 1 to entry: On-off flow control is achieved by rotation of the sphere 90°.

Note 2 to entry: Diverter ball valves are available for split-flow and other special applications.

3.9
blast wave
intense pressure wave set in motion by the *shock waves* (3.94) and/or hot product gases of a fast *deflagration* (3.22) or *detonation* (3.25) that impinges upon the surroundings, typically air

3.10
bourdon tube
thin-wall curved tube that is closed at one end and attached to a pressure source at the other end

Note 1 to entry: Pressure changes cause a change in the curvature of the Bourdon tube that is used to indicate the pressure in the system.

3.11
buoyancy
vertical force exerted on a body of less dense gas by the surrounding heavier static gas, typically air

3.12
catalytic converter
catalyst that is used for converting ortho-hydrogen to para-hydrogen in a liquefaction process so that the liquid hydrogen produced is mostly para-hydrogen

Note 1 to entry: Some commonly used catalysts in this conversion process are hydrous ferric oxide, chromic oxide on alumina particles, and nickel-based compounds.

3.13
check valve
valve that operates on differential pressure and allows flow in one direction only

3.14
collimate
make parallel or line up in a straight line

3.15
combustion
reaction process by which a flammable substance is oxidized, producing hot product gases, heat, radiation, and possibly pressure waves

Note 1 to entry: An *explosion* (3.38) in the sense of this Technical Report is a combustion process.

3.16
component
any part of a complete item or system

3.17
confined space
space not normally occupied by personnel

Note 1 to entry: Confined space has limited or restricted openings for entry and exit, may lack adequate ventilation, and may contain or produce "dangerous air contamination". Therefore, it may not be safe for entry.

3.18
confinement
physical restriction, sufficient to influence the combustion process or to facilitate the accumulation of hydrogen

3.19
convection current
motion or circulation of a fluid involving the transport of mass from one location to another driven by temperature dependent density gradients

Note 1 to entry: See *natural convection* (3.68).

3.20
cryogenic
condition involving very low temperatures in the vicinity of the *normal boiling point* (3.69)

3.21
cryopumping
process that consists of cooling a surface to a temperature of less than 120 K so that gases and vapours condense on the surface

Note 1 to entry: This process, though usually undesirable in the context here, is also used as a vacuum pump.

3.22
deflagration
combustion process in which a flame or chemical reaction moves through a flammable mixture at a rate less than the speed of sound in the unburned mixture

Note 1 to entry: Fast deflagrations are characterized by velocities in the hundreds of metres per second, and their effects to not differ much from those of a *detonation* (3.25).

Note 2 to entry: Laminar deflagration waves are characterized by velocities in the several metres per second and do not cause significant over pressures in the open.

3.23
deflagration-to-detonation-transition
DDT
event, often caused by turbulence, in which a *deflagration* (3.22) initiates a *detonation* (3.25)

3.24
deluge system
water spray system that is used to keep equipment, especially hydrogen storage vessels, cool in the event of a fire

3.25
detonation
shock stabilized combustion process resulting in a combustion phenomenon propagating faster than the speed of sound

Note 1 to entry: A detonation is an explosion, but the reverse is not true.

Note 2 to entry: The thermal energy of the reaction sustains the shock wave, and the shock wave compresses unreacted material, producing the high temperatures necessary to drive the reaction.

3.26
detonation cell
fundamental part of the mechanism for energy release within a *detonation* (3.25)

Note 1 to entry: The spatial arrangement of the shock front and acoustic waves moving behind and transverse to the shock front defines a cellular region of combustion that is observed experimentally as a "fish-scale" shaped track on sooted foils exposed to the detonation.

Note 2 to entry: The width of this diamond shape denotes the cell size, and its length can be empirically related to the formulae that can predict the energy required to directly initiate detonation and the physical dimensions of the structures that prohibit detonation.

3.27
detonation limits
maximum and minimum concentrations of a gas, vapour, mist, spray or dust, in air or oxygen, for stable *detonation* (3.25) to occur

Note 1 to entry: The limits are in reality controlled not only by the concentration of the mixture but also by the size and geometry of the environment as well as the means by which ignition occurs. There is no standard procedure for their determination.

Note 2 to entry: See *flammability limits* (3.47)

3.28
deuterium
D or ^{2}H
isotope of hydrogen having a nucleus containing one neutron and one proton

3.29
diffusion
flux of a fluid through another fluid or material due to concentration gradient

EXAMPLE The motion of hydrogen gas through air, or the movement of hydrogen gas through the wall of a rubber hose.

Note 1 to entry: The diffusion coefficient is the mass of material diffusing across a unit of area in a unit of time at a unit concentration gradient.

3.30
diluent
inert component within a gas mixture that reduces the concentration of the remaining (active) materials

3.31
dual-fault-tolerant
system design in which the failure of two elements to perform as intended does not cause an entire system to function unpredictably or catastrophically

Note 1 to entry: The faults may be in two related areas or two areas which function completely independently, and the system should continue to function as intended.

3.32
ductility
<of a material> percentage elongation to failure or the reduction in cross-sectional area of a specimen in a simple tensile test

Note 1 to entry: Materials may make a ductile-to-brittle transition at low temperatures.

3.33
electrolyser
device that performs *electrolysis* (3.34)

3.34
electrolysis
process in which electric current is used to promote a chemical reaction

Note 1 to entry: In the case of water, an example is the separation of hydrogen from oxygen.

3.35
emergency
unintended circumstance, bearing clear and present danger to personnel or property, which requires an immediate response

3.36
emissivity
relative amount of radiant heat emitted by a surface when compared to a black body at the same temperature

Note 1 to entry: The emissivity of a hydrogen/air combustion is small compared to other familiar sources of heat, such as a wood fire.

3.37
enthalpy
thermodynamic property of a material that is equivalent to the sum of the internal energy and the product of the pressure and the volume

3.38
explosion
self-sustained combustion of a gas mixture releasing heat, and hot combustion products when the rate of reaction in a reacting mixture increases with time until either the fuel or oxidizer is consumed or nearly so

Note 1 to entry: This definition excludes pressure sources not related to chemical reactions (like burst of a pressure vessel, BLEVE, etc.).

Note 2 to entry: There is neither a standard terminology nor another generally acknowledged definition for the term “explosion”, but different sources give different definitions, some of them not even requiring that combustion takes place.

Note 3 to entry: When hydrogen and an oxidizer (air) are allowed to form a mixture prior to ignition (premixed mixture), after ignition, the ensuing chemical reaction (combustion wave) will propagate through the flammable region. The resulting combustion process releases heat. The resulting dilatation of the products, if fast enough, can cause a pressure wave to propagate from the source. See References [9] and [11] in the Bibliography for more information.

3.39
facility
group of buildings or equipment used for specific operations at one geographic location

3.40
fail-safe
ability to sustain a failure without causing loss of equipment, injury to personnel, or loss of operating time

3.41
fatigue
gradual deterioration of a material that is subjected to repeated loading and unloading

Note 1 to entry: See *load cycle* (3.62).

3.42
fire
sustained burning of a fuel jet as manifested by any or all of the following: light, flame, heat, and smoke

3.43
fire triangle
visual concept showing the requirements for combustion depicting a fuel, an oxidizer and an ignition source as the three sides of a triangle, where combustion cannot occur if any one side is not present

3.44
flame
zone of combustion of a gas or vapour from which light and heat are emitted

Note 1 to entry: A flame may be stationary with the flammable mixture fed into the reaction zone, or a flame may propagate through the flammable mixture, as in a *deflagration* (3.22).

Note 2 to entry: Unlike hydrocarbon flames, hydrogen flames are weakly radiating. They radiate in the near UV (faint blue) and in the near IR (reddish). Only if particles are entrained into the flow from the surroundings will the flame thermally radiate producing a yellow color. Because hydrogen weakly radiate in the near UV and IR, they are often difficult to see in the daylight.

3.45
flame front
region of burning or chemical reaction (typically from fractions to several millimetres across) that separates burned and unburned regions

3.46
flammability
degree to which a material is ignitable in an oxidizing atmosphere

3.47
flammability limits
explosion limits
lower (LFL) and upper (UFL) concentration thresholds of fuel gas in a flammable mixture at a given temperature and pressure that will sustain propagation of a combustion wave

Note 1 to entry: These limits are functions of temperature, pressure, diluents, fluid dynamics, and ignition energy.

Note 2 to entry: These limits are usually expressed as percent (volume fraction of fuel gas).

Note 3 to entry: The values given in this paper (see Table B.1) are determined according to standardized procedures. The measurement of the “Explosion limits” as defined e.g. in Reference [5] in the Bibliography leads essentially to the same results as that of the “Flammability limit” in this paper, as e.g. Reference [6] in the Bibliography.

