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Safety of pressure swing adsorption systems for hydrogen separation and purification

Système d'adsorption modulée en pression pour la séparation et la purification de l'hydrogène

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Foreword

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This document was prepared by Technical Committee ISO/TC 197, *Hydrogen technologies*.

Safety of pressure swing adsorption systems for hydrogen separation and purification

1 Scope

This document identifies safety measures and applicable design features that are used in the design, commissioning, and operation of pressure swing adsorption systems for hydrogen separation and purification. It applies to hydrogen pressure swing adsorption systems that process all kinds of impure hydrogen streams as feed, including both stationary and skid-mounted pressure swing adsorption systems for hydrogen separation and purification in commercial or industrial use. This document also applies to small-scale PSA hydrogen system installed within containers, where allowed by local regulations.

The scope of this document includes the equipment depicted within the dashed lines in Figure 1.

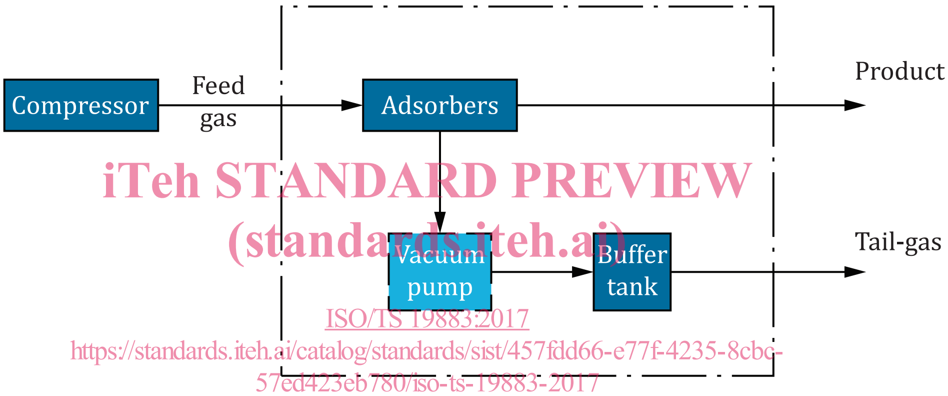

Figure 1 — Example of typical equipment in PSA system for hydrogen separation and purification

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 4126-1, *Safety devices for protection against excessive pressure — Part 1: Safety valves*

ISO 11114-1, *Gas cylinders — Compatibility of cylinder and valve materials with gas contents — Part 1: Metallic materials*

ISO 11114-2, *Gas cylinders — Compatibility of cylinder and valve materials with gas contents — Part 2: Non-metallic materials*

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*

IEC 60079-0, *Explosive atmospheres — Part 0: Equipment — General requirements*

IEC 60079-10-1, *Explosive atmospheres — Part 10-1: Classification of areas — Explosive gas atmospheres*

IEC 60079-14, *Explosive atmospheres — Part 14: Electrical installations design, selection and erection*

IEC 60204-1, *Safety of machinery — Electrical equipment of machines — Part 1: General requirements*

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

IEC 60364-4, *Low-voltage electrical installations — Part 4: Protection for safety*

NFPA 56, *Standard for Fire and Explosion Prevention during Cleaning and Purging of Flammable Gas Piping Systems*

3 Terms and definitions

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

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

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

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

3.1
pressure swing adsorption method
PSA method
gas separation method that takes advantage of the selective adsorption of a solid *adsorbent* (3.5) for different gases and the ability of solid adsorbents to adsorb more impurities at high pressure and to reject impurities at low pressure

Note 1 to entry: PSA, as practiced commercially, is a batch process utilizing multiple adsorbent-loaded vessels for the continuous purification of a gas stream.

3.2
vacuum pressure swing adsorption
system for hydrogen separation and purification that relies on desorption at sub-atmospheric pressure (achieved with vacuum pumps) to improve the performance of the system

3.3
pressure swing adsorption system for hydrogen separation and purification
hydrogen generation system that separates and purifies hydrogen from an impure hydrogen stream through the pressure swing adsorption process

3.4
adsorber
vessel in which the *adsorbent* (3.5) used for hydrogen separation and purification is contained, which can be vertical vessels

3.5
adsorbent
solid materials used to adsorb gas impurities from the impure hydrogen streams, thereby realizing the separation of the hydrogen from the other gases

3.6
process control valves
operational devices that can open or close to regulate flow in response to a signal from the *control system* (3.7)

3.7
control system
system that performs operations such as opening and closing *process control valves* (3.6), system troubleshooting, product quality control, or optimization of process parameters

3.8
tail gas
gas remaining after the impure hydrogen mixture is purified through the PSA system

Note 1 to entry: Other names for tail gas are desorbed gas, purge gas, or off gas.

3.9
stationary PSA system for hydrogen separation and purification
PSA system in which all equipment and piping are permanently mounted to the equipment foundation(s) and piping support structure

3.10
skid-mounted PSA system for hydrogen separation and purification
PSA system in which some or all of the equipment and piping are affixed to one or more skids, or moveable bases

3.11
fire separation distance
distance between the PSA system and nearby *buildings* (3.15) that is required in order to prevent fire from spreading from a PSA system to nearby buildings

3.12
buffer tank
vessel that receives the desorbed gas from the *adsorbers* (3.4) (PSA system) or from the *vacuum pumps* (3.13) (VSA system) and minimizes the composition and pressure variation of the desorbed gas

Note 1 to entry: A buffer tank may also be referred to as a surge drum.

3.13
vacuum pump
device used for evacuating the *adsorbers* (3.4) during the desorption stage, allowing the *adsorbents* (3.5) to be desorbed and regenerated at sub-atmospheric pressure to improve performance of a PSA system

3.14
container
enclosed construction or bracing structure fabricated to avoid the effects of specific environmental and climatic conditions, or protect personnel and livestock from accidental contact with the dangerous components of a small hydrogen PSA system

3.15
building
structure that has a roof and walls, with the similar function as a *container* (3.14) for a hydrogen PSA system or the components of a hydrogen PSA system

3.16
hydrogen embrittlement
degradation of metal material properties due to the presence of a hydrogen environment

4 Basic specification

4.1 Feed stream pressure

PSA systems for hydrogen generation and purification typically have feed gas pressures ranging from 0,3 MPa to 6,0 MPa. The operating pressure cycles from full feed gas pressure during adsorption to near atmospheric pressure (0,03 MPa) or vacuum (−0,09 MPa) during desorption.

4.2 Working temperature

The normal working temperature is between 5 °C and 40 °C for a PSA system for hydrogen separation and purification.

4.3 Assembly

A PSA system for hydrogen separation and purification can be stationary or skid-mounted based on the end use of the hydrogen product and on the hydrogen throughput. Small PSA systems may be installed within containers, if allowed by local regulations.

4.4 Material properties

4.4.1 Feed stream pressure

Metallic and non-metallic materials used in the construction of internal or external parts of a PSA system for hydrogen separation and purification should be suitable for all physical, chemical, and thermal conditions, both test conditions and operating conditions, for the design lifetime of the equipment. The compatibility of materials shall be evaluated to comply with ISO 11114-1, ISO 11114-2, ISO/TR 15916 or local regulations.

4.4.2 Working temperature

When ferrous metal is used in a PSA system, adequate consideration and analysis shall be taken according to ISO/TR 15916, ISO 11114-4 or the local regulations. For the non-metal materials contacting with hydrogen, the hydrogen permeability shall be considered.

5 Safety requirements of the PSA system

5.1 General hazards associated with the PSA system

5.1.1 General hazards associated with hydrogen gas

Hydrogen is colourless, odourless, and highly flammable; it burns with a nearly invisible flame in daylight. It can form an explosive mixture with air, and its lower and upper explosive limits in air are 4 % and 75 % (percent by volume) at atmospheric temperature and pressure.

Hydrogen in air will displace oxygen and may result in asphyxia if the partial pressure of oxygen in air reduces due to high hydrogen concentration.

5.1.2 General hazards associated with system leakage

Due to its low molecular weight and small size, hydrogen leaks easily from flanges and other sealing surfaces (e.g. vent valves). Hydrogen is highly buoyant due to its low specific gravity, and it can form large areas of flammable or explosive gas. Because hydrogen is colourless, the extent of a flammable area is not readily identifiable.

5.1.3 Hazards related to pressure

Normal pressure swings during the PSA process will cause alternating stress on the adsorbers, process control valves, and piping, which could lead to cracks in the vessels or piping or to another failure mode.

The failure of hydrogen PSA equipment or piping can result in the rapid release of energy due to the high pressure of the equipment. The resulting shock wave may damage surrounding equipment.

5.1.4 Hazards related to ignition of hydrogen

Ignition of hydrogen due to a leak to atmosphere from a hydrogen PSA system will cause energy/heat release or explosion. As heat is released through combustion of hydrogen, the gas within the PSA system will expand due to the increase in external temperature, and the material properties of the PSA system may degrade. The combination of increasing temperature and pressure and degradation of the material properties could cause piping or vessel failure.

5.2 Safety specifications in the field

5.2.1 General hazards

Feed gases of the PSA systems for hydrogen separation and purification include syn-gas generated from natural gas, ammonia cracking gas, coal gas, coke oven gas, ammonia tail-gas, methanol off-gas, refinery off-gas, etc., and the hydrogen content may be more than 25 %. The oxygen content in the feed stream shall be restricted to ensure combustible gases, such as hydrogen, are away from their flammable limit.

PSA hydrogen systems shall be sited according to the requirements of the applicable national safety standards and the construction and materials requirements shall be based on the partial pressure of hydrogen. PSA designs shall account for all circumstances that are anticipated during the life of their operation. The PSA control system should be designed to move the PSA to a safe state on detection of a failure via the PSA control system.

A fire protection system shall be considered for a hydrogen PSA system. Possible fire protection measures include a means to shut down the PSA quickly (either automatic or manual), a sprinkler system, a deluge system, or a dry-chemical extinguishing system. Small fires may be extinguished by dry-chemical extinguishers, carbon-dioxide extinguishers, nitrogen, or steam. Water may be used to cool equipment adjacent to a hydrogen fire.

5.2.2 Layout considerations

The layout of equipment and buildings associated with a PSA system for hydrogen separation and purification shall conform to local requirements for fire separation distance.

When a valve skid is designed such that the piping and valves are arranged in multiple levels that cover a large horizontal area, platforms constructed of steel grating should be used to prevent a confined space where hydrogen could build a flammable atmosphere.

A PSA hydrogen system installed within a container shall be designed and constructed to avoid any reasonably foreseeable risk of fire or explosion posed by the system itself, or by the feed gas, product gas, or tail gas.

The containers shall have the strength, stability, durability, resistance to corrosion, and other physical properties to support and protect all PSA hydrogen system components and piping. Containers should also meet the requirements of storage, transport, installation, and final location conditions in accordance with ISO 16110-1 or other applicable national or local regulations.

Containers intended for indoor use shall be designed and tested to meet a minimum degree of protection of IP 20 as per IEC 60529. The PSA hydrogen system used in outdoor locations shall be designed and tested to meet a minimum degree of protection of IP 44 as per IEC 60529.

5.2.3 Buildings and ventilation

5.2.3.1 General

Small PSA systems for hydrogen separation and purification may be enclosed within a building. Other equipment associated with hydrogen PSA systems may be enclosed within one or more standalone buildings. Examples include valve skids, vacuum pump for desorbed gas, control systems, and analyzers.

5.2.3.2 Buildings

Buildings shall be designed to the appropriate hazardous area designation based on the potential for hydrogen to be present due to leaks or other breakdown (e.g. Zone 2 per IEC 60079-10-1).

The distances between buildings, structures and equipment shall comply with local requirements for fireproof distance.

Enclosed buildings, if utilized, shall be designed as explosion-proof type. Alternately, for non-explosion proof buildings, the ratio between the pressure relief area and the building volume shall comply with local regulations. The area used for pressure relief could be a light roof, a wall, a door, or a window.

5.2.3.3 Ventilation of buildings

Buildings shall be designed with ventilation equipment that is interlocked with flammable or toxic gas detectors.

When the provided ventilation influences the type of area classification, that area should be purged with a minimum of five air changes prior to energizing the devices. Alternatively, the system may be provided with composition measurement capabilities that control the amount of purging required to achieve levels below 25 % of the LEL.

Purging need not be performed if the atmosphere within the compartment and associated ducts can be demonstrated by design to be non-hazardous.

Appropriate methods shall be adopted to prevent non-essential staff from entering buildings and approaching equipment. The main entrance shall be constructed according to applicable specifications and regulations. Fire-fighting equipment shall be readily accessible.

Any building that staff can enter shall be equipped with an emergency exit opening outwards. Any door with a latch should be equipped with a rapid unlocking mechanism such that the door can be opened without delay.

5.2.3.4 PSA hydrogen systems installed within containers

Containers housing PSA hydrogen systems shall be mechanically ventilated. Failure of ventilation, confirmed by measurement of flow, pressure, or the current of the ventilating device, shall trigger an audible or visible alarm and may trigger a PSA hydrogen system shutdown. In systems intended for outdoor use, containers may be positive pressure ventilated as per IEC 60079-2 or other applicable code or regulation. The maximum concentration of any flammable gas in the system ventilation exhaust should be below 25 % of the LFL during all operation conditions.

5.2.4 Explosion-proof area and explosion-proof grade

Classification of all areas associated with the hydrogen PSA system that have an explosion hazard shall comply with IEC 60079-10-1 or other applicable local regulations.

Outdoor areas near PSA equipment and well-ventilated areas inside buildings shall be classified based on the potential for hydrogen to be present due to leaks or other breakdown (e.g. Zone 2 per IEC 60079-10-1).

The explosion-proof grade of electrical equipment should not be lower than the grade and group of explosive hydrogen mixture: IIC T1.

Electrical equipment and wiring in areas with explosion hazard shall be selected and configured in accordance with IEC 60079-0 and IEC 60079-14 or other applicable local code or regulations.

5.2.5 Electrostatic grounding

5.2.5.1 General

Electrostatic grounding shall be carried out for the objects that can result in electrostatic hazard because the PSA system for hydrogen separation and purification may generate and accumulate static electricity. Dedicated electrostatic grounding connectors shall have a resistance to ground according to the requirements of IEC 60204-1, IEC 60364-4 or applicable local code or regulations. When other grounding devices are used for electrostatic grounding, their grounding resistances shall be selected based on applicable local code or regulations covering such grounding devices.

5.2.5.2 Adsorber and buffer tank

Enclosures of adsorber, buffer tank and other stationary pressure vessels shall be subject to electrostatic grounding. Equipment with diameter of not less than 2,5 m and volume of not less than 50 m^3 should have at least two grounding points and the grounding points should be evenly distributed along the periphery of the equipment with an interval of not more than 30 m.

5.2.5.3 Piping system

Electrostatic grounding should be provided at the inlet and outlet of the unit, at the boundary of areas with different explosion hazards, at pipe branches, and every 80 m to 100 m along straight pipes. When the net distance between parallel pipes is less than 100 mm, jumpers should be provided every 20 m to prevent a spark jumping from one pipe to another. When the distance between two pipes that cross each other is less than 100 mm, a jumper should be provided where the pipes cross.

Metal flanges fastened with metal bolts or clamps are usually not provided with additional electrostatic wire, but it is required to ensure good conductive contact between four bolts or clamps at a minimum.

5.2.6 Flammable and toxic gas detection alarm

Combustible gas detectors shall be installed in unit areas. When toxic gas exists and may result in injuries to personnel if leaks form, toxic gas detector(s) shall be installed.

The monitoring points should be located at such places where gas tends to accumulate and sampling and detection can be carried out easily in accordance with physical and chemical properties of gases, features of release source, layout of production area, geographical conditions, environment and climate, operation and inspection routes, etc.

Some of the places where combustible or toxic gas leakage or accumulation may occur:

— seals of vacuum pumps or compressors;

— gas sampling ports and associated analysers;

— drains and vents;

— equipment or piping flanges;

— valve packing;

— buildings or containers associated with the PSA system.

When combustible gas in the air is 25 % of its lower explosive limit, or when the toxic gas concentration reaches 25 % of the permissible exposure limit, audible and visual detection alarm shall be activated at site. In addition, the alarm signal shall be sent to the control room or operation room.

The number of flammable and toxic gas monitoring points should depend on the location of possible release sources and the ventilation conditions.

