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HYDROGEN PRESSURE SWING ADSORBER (PSA) MECHANICAL INTEGRITY REQUIREMENTS

SECOND EDITION

PREFACE

As part of a program of harmonization of industry standards, the Compressed Gas Association (CGA) has published CGA H-13, *Hydrogen Pressure Swing Adsorber (PSA) Mechanical Integrity Requirements*, jointly produced by members of the International Harmonization Council.

This publication is intended as an international harmonized standard for the worldwide use and application of all members of the Asia Industrial Gases Association (AIGA), Compressed Gas Association (CGA), European Industrial Gases Association (EIGA), and Japan Industrial and Medical Gases Association (JIMGA). Each association's technical content is identical, except for regional regulatory requirements and minor changes in formatting and spelling.

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NOTE—Technical changes from the previous edition are underlined.

NOTE—Appendix A (Normative) is a requirement.

NOTE—Appendix B (Informative) is for information only.

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1 Introduction

Industrial gas companies operate and maintain hydrogen production facilities. Pressure swing adsorption (PSA) exists as the primary method of product purification in most large-scale hydrogen production facilities. The maintenance and inspection of PSA equipment is critical to the overall reliability and safe operation of the facility. Mechanical integrity of the vessels, piping, and piping components is crucial to ensure that this equipment is fit for service.

2 Scope and purpose

This publication is an industry-wide guideline for in-service mechanical integrity of PSA units and is intended to contribute to the operational safety and reliability of these units. This publication is not intended to address the details of design and installation of PSA vessels and piping.

This publication applies to PSA units with reformer syngas, refinery off-gas, and other hydrogen containing off-gases. This publication is focused on the parts of the PSA that are subjected to pressure cycles, although some consideration is given to the noncyclic portions of the PSA system. This publication is limited to piping and vessels designed and constructed to a recognized code or standard, for example:

- American Society of Mechanical Engineers *Boiler and Pressure Vessel Code* (ASME Code) [1];¹
- European Committee for Standardization CEN; European Standard EN 13445, *Unified Pressure Vessels* [2];
- Standardization Administration of China GB 150, *Pressure Vessels* [3];
- German Association of Steam Boiler, Pressure Vessel and Piping Manufacturers AD 2000, *Pressure Vessel Code* [4].
- British Standards Institution (BSI) PD 5500, *Specification for unfired, fusion welded pressure vessels* [5]; and
- Standards Australia AS1210, *Pressure Vessels* [6].

This publication applies to piping and vessels from the feed line isolation (i.e., flange or manual valve) to the valve skid, up to and including the surge drum outlet isolation (i.e., flange or manual valve) and the hydrogen product isolation (i.e., flange or manual valve), to downstream equipment. See Figure 1.

3 Definitions

For the purpose of this publication, the following definitions apply.

3.1 Publication terminology

3.1.1 Shall

Indicates that the procedure is mandatory. It is used wherever the criterion for conformance to specific recommendations allows no deviation.

3.1.2 Should

Indicates that a procedure is recommended.

3.1.3 May

Indicates that the procedure is optional.

3.1.4 Will

Is used only to indicate the future, not a degree of requirement.

3.1.5 Can

Indicates a possibility or ability.

¹ References are shown by bracketed numbers and are listed in order of appearance in the reference section.

3.2 Technical definitions

3.2.1 Audible surveillance

Routine action by plant operations personnel to closely monitor PSA systems for leaks by listening for unusual hissing or whistling noises. The decibel level of the noise will depend on leak size.

3.2.2 Competent person

Person with professional technical ability to relate inspection findings to appraisals of vessel integrity, safe working parameters, and future use.

3.2.3 Cycle time

Amount of time required for the pressure to cycle from a maximum to a minimum and then return to the maximum pressure. For PSA vessels, this is typically the amount of time from start of adsorption through vessel depressurization and regeneration steps, to start of adsorption.

3.2.4 Cyclic service

Service in which stresses fluctuate due to changes in pressure, thermal, or other loading.

3.2.5 Fatigue

Mechanical form of degradation that occurs when a component is exposed to cyclical stresses for an extended period.

3.2.6 Fracture mechanics analysis (FMA)

Method of characterizing the fracture behavior of cracked structural components to predict crack growth.

3.2.7 Nondestructive examination (NDE)

Inspection methodologies that detect defects without destroying or altering the materials.

NOTE—Also known as nondestructive testing (NDT).

3.2.8 Offset

Misalignment of the cylindrical plate or pipe surface (i.e., inner or outer) on either side of a weld joint (i.e., hi-lo, mismatch) as measured normal to the two surfaces. An out of tolerance condition of this type at any one point on a round vessel shell or pipe can be due to misaligned axes (i.e., not concentric), thickness variation or an out of roundness condition.

3.2.9 Operating pressure range

Range of pressures over which the system normally operates. For PSAs this is nominally the difference between the feed pressure ($P_{\max}$) and the tail gas pressure ($P_{\min}$).

3.2.10 Out of roundness

Deviation in the radial dimension of a cylindrical surface from the center axis. The tolerance zone is described by two concentric circles with slightly different radii.

3.2.11 Peaking

Localized, out-of-round condition along both sides of a longitudinal weld in a vessel or pipe. This is a deviation from round caused by incomplete rolling or weld shrinkage. As viewed from the outside, the deviation can be outward (resembles the peak of a roof) or inward (resembles a V).

3.2.12 Pressure pumping

Process used to free a container or conduit of flammable gas or air. Pressure pumping is a method of purging using inert gas to dilute a flammable gas or air by repeatedly pressurizing and venting the container or conduit.

3.2.13 Postweld heat treatment

Heating a pipe, vessel, or fitting after welding to relieve stresses built up from the welding operation.

3.2.14 Robotic crawler

Remotely controlled device containing instruments with data collection capabilities used to inspect a PSA vessel. The device typically uses magnetic wheels to attach to the vessel.

4 Description of pressure swing adsorption systems

4.1 General

The PSA system is a multiple fixed bed gas purification process that uses materials that selectively adsorb one or more gas species from a mixture. A PSA uses selective adsorbents to preferentially remove impurities from a hydrogen-rich feed stream. Impurities are typically absorbed by the system at elevated pressure and desorbed at a low pressure. Different adsorbents are layered in a vessel in order to remove specific impurities from the raw hydrogen feed. The system is typically comprised of a number of adsorbent vessels that operate in various stages of adsorption and desorption. Purified hydrogen gas is collected in a high pressure product header. Low pressure contaminant-rich rejection stream (i.e., tail gas) is collected in a low pressure header and sent to the surge drum.

In order to achieve continuous feed and product flow, a PSA system consists of multiple adsorber vessels and one or more surge drums. An adsorber vessel contains adsorbent material to collect impurities and periodically cycles in pressure to expel the impurities and regenerate the adsorbent material. The pressure in each adsorber vessel will cycle from feed pressure to tail gas pressure and back to feed pressure. Typically, one common feed line connects to a feed header that splits into multiple lines that connect the header to each adsorber vessel. A similar arrangement exists on the product side: a product line from each vessel connects to a product header, and the product header connects to the product piping. Tail gas from the adsorber vessels will also flow through lines from each adsorber vessel that connect into a header, which feeds one or more surge drums. The surge drums (i.e., tail gas drum, off-gas drum, purge gas drum) provide volume to reduce the variability of the tail gas pressure and composition. Other lines and headers may exist for pressurization and purging of the vessels.

Carbon steel is the typical material of construction for the entire PSA system, although stainless steel is sometimes used for chemical feeds.

4.2 Pressure swing adsorption system limit

The limits of a representative PSA system are illustrated in Figure 1. The feed header isolation (i.e., flange or manual valve) is the start of the PSA system. On the product side, the product header isolation (i.e., flange or manual valve) is the end of the PSA system. The surge drum outlet isolation (i.e., flange or manual valve) marks the end of the PSA system on the tail gas side. All of the manual and automatic valves that exist on the various headers and individual lines to the adsorber vessels are considered part of the PSA system and are often constructed on a valve skid.

4.3 Adsorbents

Purification of hydrogen using a PSA is possible because most adsorbents preferentially adsorb most other gases over hydrogen. The primary adsorbents employed in hydrogen PSAs are activated alumina, silica gel, activated carbon, and molecular sieve. Each of the adsorbents will remove specific impurities.

4.4 Cyclic service versus noncyclic service

The PSA vessels and the piping between the PSA vessels and the switch valves cycle between high pressure during adsorption and low pressure during desorption. Most of the piping and vessels in this area of the PSA system are in cyclic service and subject to fatigue damage mechanisms. There are sections of piping that connect between vessels to equalize pressure that could be in cyclic service and subject to fatigue damage mechanisms. These vessels and piping and their cyclic operation should be considered when designing the piping system and the subsequent mechanical integrity program. The remaining parts of the PSA system mildly fluctuate in pressure and are typically deemed to be noncyclic. Criteria for when fatigue analysis is necessary, and the methodology to conduct the analysis, are provided in the relevant design codes and standards (e.g., ASME Code, Section VIII, Division 2; EN 13445; EN 13480; PD 5500; ASME B31.3; ASME B31.12) [1, 2, 7, 5, 8, 9]. An example of the boundaries of the cycling portions of a PSA system are illustrated in Figure 1.

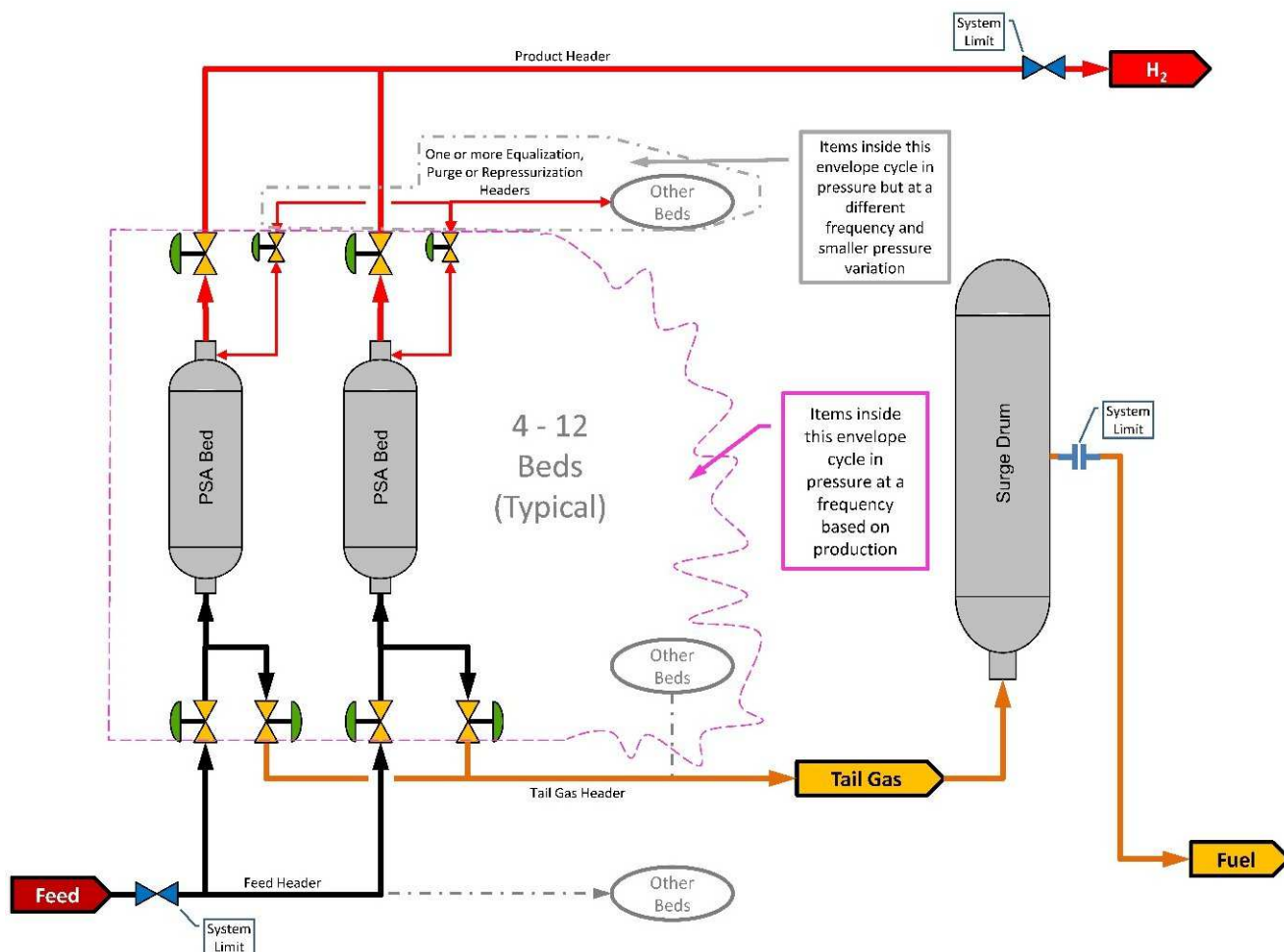


Figure 1—PSA system schematic

4.5 Feedgas considerations

The primary impurities in the feed depend heavily on the source of the feedgas. For steam methane reformer processes, impurities include carbon dioxide, methane, carbon monoxide, water, and nitrogen. Refinery off-gases are primarily hydrocarbons, although they often contain other constituents. Chemical off-gases can contain all of the impurities previously mentioned, as well as impurities specific to the upstream chemical process. These impurities shall be taken into account in the design and mechanical integrity program.

5 General safety considerations

5.1 Purging equipment and piping

Thorough purging of the PSA system prior to maintenance and before returning the system to service is essential. During normal operation, the PSA vessels and piping contain flammable and potentially toxic gas, depending on the composition of the feed. The PSA system is purged with nitrogen to avoid the possibility of forming a flammable mixture.

Prior to purging out of service, the system shall be depressurized to minimize the chance of reverse flow into the nitrogen system and potential contamination or over-pressurization. Purging in a top down direction is necessary to prevent water migration from the lower adsorbent layer into the molecular sieve layer, since water deactivates the sieve. Pressure pumping may be required if there is insufficient time for effective purging at low flow and pressure.

During purging, the valve lineup will differ from that of normal operation and verification of valve alignments/positions shall be completed to ensure that no path is available for unintended gas flow. Highlighting the desired flow path on a piping and instrumentation diagram and identifying which valves should be open and which valves should be closed is one method for determining the correct orientation of valves.

Purging shall reduce the flammable gas concentration to less than 25% of the lower explosive limit (LEL), see NFPA 56, *Standard for Fire and Explosion Prevention During Cleaning and Purging of Flammable Gas Piping Systems* or equivalent for guidance [10]. Sufficient vent and drain points in a given circuit shall be checked for flammable gas, since purging is not always effective in removing pockets of trapped gas. Particular attention shall be given to dead legs and the perimeter of the purged system.

Following maintenance, purging into service with dry nitrogen prior to startup is also essential. Oxygen shall be removed to avoid the possibility of forming a flammable mixture when hydrogen and hydrocarbons are introduced into the system. Sufficient vent and drain points in a given circuit shall be checked for oxygen, since pressure pumping and purging at low flow and pressure are not always effective in removing pockets of trapped gas. Particular attention shall be given to dead legs and the perimeter of the purged system. Oxygen levels shall be reduced to less than 60% of the minimum oxygen (i.e., limiting oxidant) concentration required to support combustion.

If any portion of the PSA system being purged is located indoors, precautions shall be taken during purging and when checking oxygen or flammable gas levels to prevent flammable gas buildup or oxygen-deficient conditions within the building or enclosure.

Under certain conditions, adsorbent removal and vessel entry is required. While adsorbent is being removed, nitrogen purge is required; once the vessel is empty, the purge can transition to air. Used adsorbents shall be stored in an adequately ventilated and dry area taking into account the hazards associated with desorption of the impurities.

5.2 Impact of adsorbents on purging of vessel

The presence of adsorbents within the PSA system present an additional complication when purging the PSA system prior to maintenance or startup. Adsorbents by nature adsorb the components in the feedgas into the pores of the material. Purging of the PSA system should be conducted at low pressure to maximize the desorption of gas from the adsorbent; however, it takes time to displace the gas in the pores of the adsorbent. It is possible that the atmosphere in a vessel containing adsorbent can test below 25% of LEL at one point in time, and then exceed the limit for LEL at a subsequent time after the gas in the adsorbent pores further desorbs.

If the PSA vessel contains residual pressure when the piping or vessel is opened for maintenance, gas constituents will desorb as the pressure in the vessel drops to atmospheric pressure. This will affect the composition of gas at the line break location, potentially creating a hazardous atmosphere. The composition of gas at the line break location can also vary with time as gas constituents continue to desorb due to mass transfer effects.

Pressure pumping the adsorber vessels with nitrogen is one means to accelerate the cleanup of a PSA system. By alternately pressurizing and depressurizing the vessels with nitrogen, the nitrogen displaces the gases adsorbed within the pores of the adsorbents. Purging the adsorbents at low flow and pressure can result in uneven desorption if there is gas channeling or other maldistribution of flow. The potential for channeling and maldistribution increases with vessel size.

PSA system depressurization and purging procedures shall be developed and maintained. These procedures shall consider and address the specific hazards of all components in the feedgas (i.e., impurities and products), including the adsorption and desorption properties of the compounds in a given PSA system.

5.3 Other maintenance considerations

5.3.1 Noise exposure

During PSA system operation, the pressure in the PSA vessels cycles from high to low. During the depressurization steps of the cycle in particular, the noise level in the area around the PSA can exceed permissible exposure limits established by Title 29 of the U.S. *Code of Federal Regulations* (29 CFR) Part 1910.95, *Occupational Noise Exposure* or equivalent [11]. When conducting online PSA system mechanical integrity inspections, appropriate

hearing protection and/or limiting the exposure of the individuals that work in the proximity of the PSA could be required.

5.3.2 Hazardous area formation

When conducting maintenance or inspections on PSA systems, it may be desirable to install weather protection such as tarpaulins or implement other measures to limit the impact of atmospheric conditions (e.g., wind, rain) on the work being done. Installation of these measures can reduce the ventilation in a given area and can result in the formation of a hazard within the enclosure. During purging operations, either an asphyxiating or a flammable/toxic atmosphere can be formed. If tarpaulins or other weather protection are installed around valves while the PSA system is in operation, the presence of valve packing leaks and the subsequent buildup of flammables (if ventilation is reduced) could alter the electrical classification of the area within any enclosure that is formed. Adequate remediation of the enclosed areas shall be taken (e.g., installation of forced ventilation, continuous monitoring of the atmosphere, etc.).

5.3.3 Acoustic emission testing

Acoustic emission testing (AE) requires pneumatic pressurization at a significant percentage greater than the maximum operating pressure; therefore, there is significant stored energy at a pressure greater than what the vessel has seen in the past. Suitable safety precautions and procedures shall be followed to ensure personnel carrying out the testing are not exposed unnecessarily to the hazards produced by a failure.

6 General mechanical design and fabrication considerations

6.1 Vessel design and fabrication considerations

Pressure vessels used in a hydrogen PSA are subject to fatigue loading by cyclic pressures. Such vessels shall be designed and constructed in accordance with recognized pressure vessel codes and fatigue design rules.

Fatigue design (i.e., cyclic service analysis) is addressed by codes and standards such as the ASME Code, Section VIII, Division 2, EN 13445, or PD 5500 [1, 2, 5]. They contain detailed procedures to calculate the allowable design cycles for a specified operating pressure range.

The number of design cycles for a specified operating pressure range (i.e., $P_{\max} - P_{\min}$) is established during the design phase of the vessel when applying the relevant design codes. The number of cycles chosen for the design should be equal to or greater than the expected cycles for the specified operating duration of the vessel.

The following items should be considered as good engineering design practice for PSAs.

6.1.1 Surface quality

Fabrication should avoid surface defects, which could promote local stress concentration. Examples include rolling imperfections, scratches, grinding marks, notches, dents, or other surface imperfections caused by the manufacturing process or handling. Surface discoloration can indicate localized overheating, which can result in material hardness and should be further investigated.

Removal of surface defects shall only be accepted after assessment and final approval by the purchaser or a competent person.

6.1.2 Welding

Welding can have a significant impact on hydrogen embrittlement behavior. The hardness of the welded area and heat-affected zone shall be controlled within the specified limits.

Weld seams in pressure retaining parts, including attachment welds, should be welded with full penetration and should be free from notches. Fillet welds to pressure retaining walls require special consideration due to the potential to create a local peak stress.

Longitudinal seams on shell courses shall be staggered so they do not line up. Permanent backing strips shall be avoided. Due to the elevated risk of lack of fusion, gas metal arc welding (GMAW) should not be used for