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TABLES

1. INTRODUCTION

This document consists of the Standard applicable to the Hydrogen Systems within Eskom.

2. SUPPORTING CLAUSES

2.1 SCOPE

2.1.1 Purpose

Hydrogen is used at the power station as a cooling medium for large two-pole and four-pole generators. A need has been identified for a document which contains general and specific information relating to the Hydrogen production plant, bulk storage, Hydrogen reticulation system and generator Hydrogen cooling system. This document defines the minimum requirements for selection of equipment and materials to meet the need, purpose, functions and safety requirements of these Hydrogen systems.

2.1.2 Applicability

This document shall apply throughout Eskom Holdings Limited Divisions.

a. This Standard addresses Eskom's requirements for Hydrogen production plant installations, associated controls, measuring equipment, storage vessels, reticulation system, generator Hydrogen cooling system and related plant safety requirements.
b. This standard is applicable to the inert gas purging system required as an integrated part of the Hydrogen production plant.
c. This standard is applicable to the generator gas cooling system and includes the inert gas purging system of the generator.
d. Compliance is required for safety critical items to ensure safe plant operation, noncompliance to the required safety critical items requires a risk assessment with mitigating actions implemented.
e. Within one year of the authorisation of a new revision of this standard, compliance of all existing plant shall be evaluated and future upgrades and/or refurbishment planned accordingly.
f. Within three years there shall be compliance to the latest revision of this standard, or alternatives as authorised by the SCOT, Technical Committee.
g. The requirements in this standard will be applicable to all new and refurbishments.

2.2 NORMATIVE/INFORMATIVE REFERENCES

Parties using this document shall apply the most recent edition of the documents listed in the following paragraphs.

2.2.1 Normative

[1] ANSI/AIAA G-095-2017, American Institute of Aeronautics and Astronauts, Guide to Safety of Hydrogen and Hydrogen Systems, American National Standard Institute, Reston, VA, USA, 2005.
[2] ISO 22734, Hydrogen generators using water electrolysis — Industrial, commercial and residential.
[3] CGA G-5.3, Commodity Specification for Hydrogen.
[4] CGA G-5.4, Standard for Hydrogen Piping Systems at Consumer Locations.
[5] CGA G-5.6, Hydrogen Pipeline systems
[6] ANSI/ISEA Z358.1, American National Standard for Emergency Eyewash and Shower Equipment
[7] EN 13445, Unfired pressure vessels (All Parts)

[8] EN 13480, Metallic industrial piping (All parts)
[9] EN 15154, Emergency safety showers (All Parts)
[10] 240-56227443: Requirements for Control and Power Cables for Power Stations Standard
[11] 240-106365693, Standard for the External Corrosion Protection of Plant, Equipment and Associated Piping with Coatings
[12] NFPA 55, Compressed Gases and Cryogenic Fluids Code
[13] ASME B31.3, Process piping
[14] PD 5500 Specification for unified fusion welded pressure vessels
[15] 240-56536505 Hazardous Locations Standard
[16] SANS 10119, Reduction of Explosion Hazards Presented by Electrical Equipment Segregation. Ventilation and Pressurization.
[17] SANS 1507, Electric cables with extruded solid dielectric insulation for fixed installations (300/5000V to 1900/3300V).
[18] SANS 1574, Electrical cables — Flexible cords.
[19] 32-303, Requirements for the Safe Processing, Handling, Storage, Disposal and Phase-out of Asbestos
[20] 240-145581571, Standard for the Identification of the Contents of Pipelines and Vessels
[21] 240-101712128, Standard for the Internal Corrosion Protection of Water Systems, Chemical Tanks and Vessels and Associated Piping with Linings.
[22] 240-150642762, Generation Plant Safety Regulations.
[23] IEC 61000-2-2:2002, Electromagnetic Compatibility (EMC) - Part 2-2: Environment - Compatibility Levels for Low-Frequency Conducted Disturbances and Signalling in Public Low-Voltage Power Supply Systems
[24] SANS 1652 Battery chargers — Industrial type
[25] 240-56364545, Structural Design and Engineering Standard
[26] Occupational Health and Safety Act 85 of 1993,
[27] 240-54937439 Fire Protection/Detection Assessment Standard
[28] 240-54937450 Fire Protection and Life Safety Design Standard
[29] 240-56737448 Fire Detection and Life Safety Design Standard
[30] ISO 1114, Transportable gas cylinders- Compatibility of cylinder and valve material with gas contents.
[31] 240 -106628253, Standard for Welding Requirements on Eskom Plant
[32] ASME B16.5, Pipe Flanges and Flanged Fittings
[33] IEC 60071, Insulation Coordination Standard
[34] 240-56356396, Earthing and Lightning Protection Standard
[35] 240-50237155, MV motor procurement standard
[36] IEC 60529, Degrees of Protection provided by enclosures
[37] SANS 60947-7-1, specifies requirements for terminal blocks with screw-type or screwless-type clamping units primarily intended for industrial or similar use.
[38] SANS 60947-7-2. specifies requirements for protective conductor terminal blocks with PE function up to 120 mm2 (250 kcmil)
[39] IEC 60751, Industrial platinum resistance thermometers and platinum temperature sensors
[40] IEC 60585, Extension and compensating cables - Tolerances and identification system

2.2.2 Informative

None

2.3 DEFINITIONS

Definition	Description
AC Ripple	The Alternating Current component of a Direct Current (DC) supply. This is possible in cases where the DC is obtained from a rectified AC supply. It is easiest measured using a multi-meter set for AC voltage measurement.
Arrested Flame	Combustion process which is stopped or flame which is put out
Atmospheric Dew Point	The dew point of a gas that is at atmospheric pressure, normally regarded as 1bar or 101 kPa. Generally, plant dew point measurements are at higher pressures and will need to be adjusted, through calculations, to provide an atmospheric dew point value.
Authorised Inspection Authority (AIA)	Person responsible for the plant (normally the Government Ticket Holder) refer to definition in vessels under pressure regulations.
Code	Regulations, requirements or standards that have been made binding and mandatory by a local or national government or design standard organisation.
Component	Any discrete part of a complete item or system.
Confined Space	Space not normally occupied by personnel NOTE 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.
Confinement	Physical restriction, sufficient to influence the combustion process.
Desiccant	
Deluge System	Water spray system that is used to keep equipment, especially Hydrogen storage vessels, cool in the event of a fire and fire extinguishing in high risk areas in which Hydrogen is used. Definition as per the Eskom Fire Protection Standards [28]: Networks of piping similar to a sprinkler system, except that it utilizes open-head spray nozzles. NFPA 15 provides guidance on these systems.
Detonation	Exothermic chemical reaction coupled to a shock wave that propagates through a detonable mixture or medium. Note 1 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. Note 2 the detonation process is characterised by a propagation speed that is greater than the speed of sound in the unburned mixture.
Detonation Limits	Explosion limit maximum and minimum concentrations of a gas, vapour, mist, spray or dust, in air or Oxygen, for stable detonation to occur. Note the limits are controlled by the size and geometry of the environment, the concentration of the fuel, as well as the means by which ignition occurs.
Dewpoint	The temperature, for a given pressure, at which a relative humidity of 100% will be reached. At this point the water vapour- and partial-pressures are equal and condensation will take place if the temperature is further reduced or the pressure increased.
Diluent	Inert component within a gas mixture that reduces the concentration of the remaining (active) materials

Entrainment	Process in which the flow of a gas pulls or draws liquid droplets along with the gas flow. Note: this is of special concern in the vent system for a liquid Hydrogen storage vessel and is most likely to occur with rapid vent rates. It is undesirable because of the considerable volume expansion of the liquid, which would have an effect on the vent rate, including the vent capability of relief devices, and the loss of the liquid product that occurs.
Explosion	Rapid equilibrium of pressure between the region of energy release (system) and its surroundings. Note: explosions can occur through mechanical failure of vessels containing high-pressure fluids (which includes a gas) or through rapid chemical reactions producing large volumes of hot gases (see detonation limits).
Facility	Group of buildings or equipment used for specific operations at one geographic location.
Fail-Safe	Ability to sustain a failure without causing loss of equipment, injury to personnel, or loss of operating time.
Fire	Rapid chemical reaction that produces heat and light; sustained burning as manifested by any or all of the following: light, flame, heat, and smoke; stationary flame with the flammable mixture fed into the reaction zone. Note Hydrogen flames are nearly invisible in daylight and are without smoke, unless other materials are entrained in the flames.
Flammability	Degree to which a material is easily ignited in an oxidising atmosphere; concentration of a fuel in an oxidiser below which a burning reaction cannot be sustained.
Flammability Limits	Lower (LFL) and upper (UFL) vapour concentrations of fuel in a flammable mixture that will ignite and propagate a flame. NOTE 1: These limits are functions of temperature, pressure, diluents and ignition energy. NOTE 2: These limits are usually expressed as percent (volume fraction).
Hydrogen Embrittlement	Deleterious changes in the physical properties of a metal that exposure to Hydrogen can produce.
Ignite	Cause to burn or to catch fire Note: the process involves the raising of a substance to its ignition point (the minimum temperature at which a substance will continue to burn without additional application of external heat).
Ignition Energy	Energy required to initiate flame propagation through a flammable mixture.
Maximum Allowable Working Pressure (MAWP)	Maximum gauge pressure permissible in a storage vessel (at its top) or piping system for a designated temperature. Note 1: the MAWP is the basis for the pressure setting of the pressure-relief devices protecting the vessel or piping system. Note 2: the MAWP may also be the maximum allowable operating pressure rating of pressure vessels manufactured in accordance with national pressure vessel codes.
Normal Temperature and Pressure (NTP)	Temperature of 273,15 K and absolute pressure of 101,325 kPa
Non Return Valve	Valve that operates on differential pressure and allows flow in one direction only
Overpressure	In a blast wave pressure above atmospheric pressure
Overpressure	Within a containment structure pressure that exceeds the maximum allowable working pressure of the containment structure
Pressure Regulator	Device that is used in a system to regulate the pressure to a set value

	Note: the regulator limits a variable high-pressure input to a constant lower-pressure output.
Pressure-Relief Device	Basic safety device used to prevent the pressure within a system from exceeding the MAWP NOTE 1: This device is installed so that excessive pressure within the containment structure can be relieved before damage to the containment structure occurs. NOTE 2: A pressure-relief device is typically a spring-loaded valve that will open at a set pressure or Temperature or a rupture disk that contains a membrane designed to rupture at a set pressure.
Purge	Process used to remove or displace gases. Note for example, before admitting Hydrogen to a system, the air in the system is removed to avoid the formation of a combustible mixture within the system.
Q-D Quantity Distance	Relationship between quantity of flammable or explosive material and distance separation from the exposed object(s) that provide(s) a defined type of protection. Note 1: these relationships are based on levels of risk considered acceptable for the stipulated exposures and are tabulated in appropriate q-d tables. Note 2: relationships include separation distances for safe operations between facilities, roadways, etc. And total quantities of energetic materials that can interact in a given location. Note 3: this approach to safety is commonly used for Hydrogen in aerospace and military applications.
Quench	Terminate a chemical reaction or the propagation of a flame.
Quenching Distance	Gap dimension required to prevent the propagation of an open flame through a flammable fuel/air mixture.
Quenching Gap	Between electrodes spark gap between two flat parallel-plate electrodes at which ignition of a combustible fuel/air mixture is suppressed NOTE: Smaller gaps totally suppress spark ignition.
Quenching Gap	The passage gap dimension required to prevent propagation of an open flame through a flammable fuel/air mixture that fills the passage
Redundancy	Use of more than one independent means to accomplish a given function
Risk	Exposure to the possibility of injury or loss as applies to safety. Note: risk is a function of the possible frequency of occurrence of an undesired event, of the potential severity of resulting consequences, and of the uncertainties associated with the frequency and severity.
Soft Goods	Non-metallic material Note: for example polymers, coatings or lubricants. In a valve, the term soft goods would refer to items such as the seals, possibly the seat, and the 0-rings.
Standard	Generally agreed-upon set of criteria specifically designed to define a safe product, practice, mechanism, arrangement, process or environment based on currently available scientific and experimental knowledge concerning the relevant subject or scope.
Stoichiometric Mixture	Mixture of reactants in a chemical reaction that optimises production of the reaction products.
System	Assembly of components in which Hydrogen is delivered, stored or used. Note 1: a system can include components such as storage vessels, piping, valves, pressure-relief devices, pumps, expansion joints and gauges.

	Note 2: a system can refer to a new site, a new facility at a site, or a new installation at a facility.

2.3.1 Classification

Controlled Disclosure: Controlled Disclosure to External Parties (either enforced by law, or discretionary).

2.4 ABBREVIATIONS

Abbreviation	Description
°C	Degree Celsius
A	Ampere
AC	Alternating current
Ah	Ampere per hour
ANSI	American National Standards Institute
ARC	Automatic reclosing
ASD	Adjustable speed drive
AVR	Automatic voltage regulator
BIL	Basic insulation level
C	Current
CPU	Central processing unit
CSU	Control and supervisory unit
CVT	Constant voltage transformer
DC	Direct current
DCS	Distributed control system
DOL	Direct online
DPI	Dip proof inverter
Dx	Distribution division
EMC	Electromagnetic compatibility
EUT	Equipment under test
FTS	Fast transfer scheme
GCR	Grid code requirement
HV	High voltage
Hz	Hertz
IEC	International Electrotechnical Commission
IED	Intelligent electronic device
IEV	International Electrotechnical Vocabulary
IGBT	Insulated-gate bipolar transistor
I_n	Nominal current

Abbreviation	Description
IPS	Integrated power system
kV	Kilovolt
kVA	Kilovolt ampere
LA	Lead acid
LC	Inductor capacitor
LV	Low voltage
MCB	Miniature circuit breaker
mm	Millimetre
ms	Millisecond
mV	Millivolt
MV	Medium voltage
MVA	Megavolt ampere
MW	Megawatt
OFAF	Oil forced air forced
ONAN	Oil natural air natural
p.u.	Per unit
pf	Power factor
PIT	Process immunity time
PLC	Programmable logic controller
RAL	Reichs-Ausschuss für Lieferbedingungen
Rev	Revision
RGB	Red-green-blue (colour model based on additive colour primaries)
RMS or rams	Root mean square
s	Second
SANS	South African National Standards
THD	Total harmonic distortion
UPS	Uninterruptable power system
V	Volt
var	Volt-ampere reactive
V_{nom}	Nominal voltage
VSD	Variable speed drive
μs	Microsecond

2.5 ROLES AND RESPONSIBILITIES

Engineering Managers are responsible for ensuring that this standard is implemented by a competent person, as per Eskom Governance and Competency requirements.

The competent person is responsible for ensuring that the design, the operation, and the maintenance of the Hydrogen plant complies to this standard.

2.6 RELATED/SUPPORTING DOCUMENTS

- Annexure A — Material Data Specification
- Annexure B — Hydrogen Generating Plant Factory Acceptance Testing

3. REQUIREMENTS FOR HYDROGEN SYSTEMS

3.1 OPERATING CONDITIONS

3.1.1 Site conditions

The equipment covered by this specification shall be suitable for operation under the following conditions:

- Altitude : 2 000 metres maximum
- Relative humidity : 20% to 90% non-condensing
- Lightning : high lightning area

Outdoor air temperatures:

- Maximum : 50 °C
- Daily average : 30 °C
- Minimum : -15 °C

3.1.2 Equipment room and substation air temperature

- Maximum : 50 °C
- Daily average : 35 °C
- Minimum : -5 °C

3.1.3 Electrical input supply

- The nominal three phase input voltage is 400V ±25%.
- The nominal input frequency is 50Hz ±5%.
- The nominal single phase to neutral voltage is 230V ±25%.
- The equipment shall be tested to tolerate an input voltage deviation from the specified maximum to minimum within one to ten cycles.
- The input voltage frequency can fluctuate between the minimum and maximum value within one to ten cycles.
- Unbalance between phase voltages of not more than 3% negative phase sequence and/or the magnitude of one phase not lower than 5% than any of the other two for 6 hours.
- Input voltage total distortion factor <8% with the following maximum level of individual harmonic voltages according to table 1 of IEC 61000-2-2 [23] for public low-voltage supplies, up to the 40th harmonic.

3.2 INHERENT SAFETY FEATURES

3.2.1 Hazard Management

Hazard management must be exercised for all Hydrogen systems and operations:

- All applications which involve Hydrogen regardless of quantity, volume or pressure.
- All methods must be applied as part of the management of Hazards i.e. ventilation, designing and operating systems to prevent leakage, and eliminating potential ignition sources, potential hazard monitoring and defences.

3.2.2 Safe Plant Operation Assurance

Safe plant operation needs to be ensured as a minimum and not limited to:

- Warning systems to be installed to detect abnormal and unsafe conditions, monitor malfunctions, and indicate incipient failures.
- Implement safe plant operation controls i.e. de-pressurisation, inert gas purging, prevent air entrainment, limiting Hydrogen leaks, prevent flammable or explosive mixtures from occurring, limit ignition sources, prevent equipment failure, exposure to flame temperatures, single failure may not result in an unsafe condition.
- Incorporate barriers or safeguards to minimize risks and control failures.
- Warning system data transmissions with visible and audible signals with sufficient redundancy to prevent any single-point failure from disabling the system to detect and respond.
- Safety valving and flow regulation to be installed to safeguard personnel and equipment during Hydrogen storage, handling, and use.
- System and equipment safety features to be installed to automatically control the equipment and process required to reduce the hazards or prevent a hazard from occurring.
- Manual controls within the systems should be constrained by automatic limiting devices to prevent over-ranging.
- The equipment, instrumentation, power, and all other system services shall be verified for safe performance in the design and normal and transient operational regimes through certification.
- Any failure from which potentially hazardous conditions may result is required to revert to conditions that will be safe for personnel and, prevent and limit damage to plant and property.

The conditions of the Occupational Health and Safety Act [26] in its entirety shall apply. This document shall not be interpreted in any way which contravenes the requirements of the OHS Act [26]. Should any inconsistencies arise, these should be brought to the attention of the Generation Engineering Department.

All Hydrogen systems shall comply with [15], Management of Hazardous Locations.

The following are considered to be critical to the safe operation of Hydrogen plant and no plant shall operate without meeting these requirements:

- Oxygen content measurement of produced Hydrogen after the cells on atmospheric electrolysers
- Hydrogen purity after the dryers including Oxygen content (before bulk storage).
- Minimum flow through analysers is ensured.

- Hydrogen leak detection.
- Generator Hydrogen leakage/consumption must be monitored. When the leakage exceeds the maximum value as indicated by the original manufacturer a risk assessment needs to be conducted. Only if the risk can be mitigated to a level of no risk of injury or risk to life, may the generator remain on load.
- Water seals and/or flashback arrestors on all vents excluding safety valve vents.
- Hazardous area classification.
- Hydrogen fire detection.
- Hydrogen in Oxygen measurement on the Oxygen stream.
- Minimum quantity of inert gas connected and monitoring to perform emergency purge on Hydrogen production plants and generators.
- Emergency depressurisation system on Hydrogen production plants and generators.
- The plant design for the production of Hydrogen through water electrolysis must be such that the Oxygen and Hydrogen production process must be segregated to avoid cross contamination. On pressurized electrolysers the contamination limits in this standard during operation, transients or plant failures may not exceed the limits stipulated in this standard.
- The Hydrogen purity in the generator must always be maintained above the high flammability limit of Hydrogen and Oxygen mixture of ≥ 96 % Hydrogen purity and ≤1% Oxygen. Running the generator at Hydrogen purity levels lower than 96 % is allowed only if the Oxygen content of the gas is measured with an on-line Oxygen analyser and the Oxygen measured is less than 1 %.
- Consideration should be given to the response time and the accuracy of the analysers being utilised.
- As part of gas purity, analysing the minimum and maximum flow through the analysers, must be monitored and interlocked with the gas analysers to provide a true reading of the gas inside the generator.
- The delivery gas purity for bulk storage shall be > 99%. The contamination of Hydrogen in Oxygen and vice versa measured directly after the cell stack should less than 1,6% during the transient state and less than 1% during the steady state.
- In the event of Hydrogen purity below 99% and provided Oxygen is less than 1 %, one of the following two actions is required:
  - Old production plants without an automated vent facility a normally open solenoid valve on the user line will be de-energised and the entire plant be tripped with an alarm to the control room (not applicable to new installations) A normally closed solenoid valve on the user line will be de-energised and the normally open solenoid valve will be de-energised to allow venting, of the out of specification produced gas.
  - The production of gas be reduced to the minimum production levels or 50% maximum production. The condition shall be alarmed, and the Hydrogen vented until the quality returns to specification for a period not exceeding 8 hours after which the plant should be tripped

Hydrogen Plant meets the classification of "Level 1" as per the Engineering Change Classification. Should the site be declared as Major Hazard Installation in accordance with the OHS Act [26] by the Approved Inspection Authority, inter alias, the following shall be noted:

- A Risk Assessment shall be carried out at intervals not exceeding five years on all hazardous installations by an Approved Inspection Authority.

- The Risk Assessment shall be reviewed "forthwith if there is any reason to suspect that the preceding assessment is no longer valid".
- "Temporary Installations" are to be considered "installations" at their points of departure and arrival. Consequently, tube-trailers shall be considered "installations" and the above mentioned Risk Assessments shall specifically address the tube trailer supplies.
- There shall be a readily available emergency plan, reviewed not less than every three years and formally tested at least once per year. This plan shall be submitted to local relevant government department for approval.
- Any activation of the emergency plan shall be reported to Chief Inspector (Department of Labour) and all near misses shall be recorded in a register that is available for inspection.
- All certificates required by the OHS Act [26] shall be available on site.
- All equipment supplied for permanent installation, as well as any portable equipment used from time to time, shall be suitable for operating in the Hydrogen plant. Specification for all equipment used shall make specific reference to the use in Hydrogen containing areas.
- The Generation Division's Plant Safety Regulations shall apply.
- All equipment utilised in the classified area, shall conform to meet the level of classification e.g. tools, clothing, shoes etc. shall be non-static.
- Hot work procedures shall be compiled for all maintenance and testing conducted in the Hydrogen plant. This shall be incorporated into the power station permit to work system.
- Asbestos used shall be managed in accordance with [19], Requirements for the Safe Processing, Handling, Storage, Disposal and Phase-out of Asbestos

3.3 GENERAL REQUIREMENTS

As Hydrogen production plants incorporate elements of the Mechanical, Civil, Chemical, Electrical and Control & Instrumentation Engineering, sound engineering practices from these disciplines shall be applied.

At all times the original requirements of the manufacturer with respect to operating and maintenance of the plant shall be adhered to subsequent to compliance to this standard.

The response, through design and operating procedures, to a failure should be such that a single failure does not lead to a series of failures or a chain reaction of failures. Any failure should be restricted to a local event, otherwise the hazard and probability for damage is greatly enhanced.

The design of the Hydrogen production plant must ensure that a single component or equipment failure may not result in an unsafe condition.

Local procedures shall be compiled, and approved by the Power Station Manager, addressing the following:

- General plant safety requirements.
- Plant start-ups.
- Plant shutdowns.
- Emergency conditions, including management of explosive mixtures.
- Preventative maintenance requirements.

- Corrective maintenance.
- Test and inspection requirements.
- Purging and safe isolation requirements.
- Alarm response procedures.

3.3.2 Hydrogen Production Quality

a. Hydrogen purity shall be a minimum of 99,5 % by volume during the steady state measured after the electrolyser of production and the contamination limits stipulated shall not be exceeded during transient states. These limits are applicable through the production and pressure range minimum to maximum.
b. The dew point of produced gas must be measured before bulk storage and shall be better than -50°C. The Hydrogen production plant shall be designed to produce Hydrogen with this dew point and a deviation from this quality due to a plant irregularity must be addressed. The production plant can be kept in service until the dew point reaches -10°C when it is expected to stop production.
c. Measurement points, and measurement requirements, are provided in Section 3.17 of this standard.
d. All measurement lines that are vented to atmosphere shall be fitted with flash-back protection and flow monitoring.
e. The Hydrogen production plant shall be designed to produce Hydrogen that is free of ammonia, hydrazine and any other impurities, which could be harmful to the materials used in the construction of the electrical generators and their cooling systems. Specifications for raw materials required to achieve this requirement shall be included in the relevant maintenance instruction document.
f. The moisture content of the Hydrogen fed to the generator shall ensure that the dew point at the generator operating pressure shall be at least 20°C below the lowest temperature to which the generator can be exposed.

3.3.3 Production Capacity and Hydrogen Gas Storage Capacity

Hydrogen Gas storage capacity shall be based on the greater of the design versus the actual consumption figures. Hydrogen Gas storage capacity shall be determined on the following basis:

a. A quantity of two fills of Hydrogen for the largest generator with the turning gear in operation; and a sufficient quantity for seven (7) days of normal consumption of all generators,
b. Where there is insufficient surplus storage capacity to allow for statutory inspections of or maintenance on, storage vessel without contravening the requirements above, there shall be a sufficient alternative backup supply on site.
c. To give added security against the consequences of a breakdown of the Hydrogen production plant or the reticulated Hydrogen system, a seven (7) days' supplementary supply of Hydrogen, based on normal consumption for all generators, shall be safely stored on site in cylinders.
d. Contingency plans shall be implemented with a gas supply company to ensure rapid delivery of replacement cylinders.
e. Hydrogen production rate shall be sufficient to enable the minimum storage capacity to be achieved within 7 days, with all generators in service and allowing for a single generator fill within this 7 day period.
f. The Hydrogen production plant shall be able to increase production to 100 % of design capacity within 8 hours.

g. The operating philosophy of each Hydrogen production plant shall ensure that operation at levels below the minimum level recommended by the manufacturer is not possible.
h. An explosion proof wall shall be built around each receiver and shall be designed to withstand the explosion pressure from the receivers.
i. When network black start requirement is specified for a power station it will be required that the power station be equipped with a second Hydrogen production plant 2 x 100% production capacity as specified above and additional 25% bulk storage.

3.3.4 Hydrogen Production System Efficiency

The fully compliant Hydrogen production system efficiency shall be ≥60%. The system efficiency is measured in percent (%) and describes the energy content of the Hydrogen as the lower heating value (LHV) compared to the electricity which is consumed to produce the Hydrogen under nominal/nameplate capacity.

3.3.5 Hydrogen Production Facilities

The production of Hydrogen in Eskom is currently by water electrolysis and the Hydrogen production plant shall comply to Hydrogen production through water electrolysis — Industrial, commercial and residential applications [2] with the additional requirements stipulated in this standard superseding the ISO 22734 standard. However, Hydrogen can be produced by any alternative means provided it meets the quality, quantity and operational safety requirement specified in this document. Use of alternative methods shall be subject to approval by the Generation Engineering Department.

3.4 BUILDINGS

3.4.1 Building Design or Bulk Storage Walls or Weather Shelter

a. A weatherproof shelter or canopy in an outdoor location shall be a structure enclosed by not more than two walls set at right angles and shall have vent space provided between the walls and vented roof or canopy. Such walls shall be constructed of non-combustible materials
b. A weatherproof shelter or canopy shall be installed over any containerised plant. Buildings or special rooms in which Hydrogen is stored and used (monopropellant) as allowed by the OSHACT [26] shall be constructed according to the construction regulations. Buildings shall be constructed of non-combustible materials on a substantial frame. Windowpanes shall be shatterproof plastic or glass. To limit the generation and accumulation of static electricity the floors, walls and ceilings should be designed accordingly, a fire resistance rating of at least two hours is acceptable.
c. The Seismic design of the building shall be in accordance with Structural design Standard [25].
d. Structural design of the building shall be in accordance with Structural design Standard [25]
e. Sun shields shall be installed as part of the bulk storage vessels with adequate ventilation and prevention of Hydrogen entrapment.
f. All Hydrogen-containing vessels, piping, and other equipment should be protected from potential sources of shrapnel end explosion walls shall be installed around each bulk storage vessel.
g. All Hydrogen-containing vessels, piping, and other equipment being a source of Hydrogen release should be protected from potential sources of shrapnel.
h. Explosion venting must be designed to relieve at a maximum internal pressure of 1, 2 kPa. Doors must be hinged to swing outwards in an explosion and doors must be easily accessible to employees.

Partitions shall be continuous from floor to ceiling and securely anchored. At least one wall shall be an exterior wall, and the room shall not be open to other parts of the building. Any heating in rooms containing Hydrogen shall be limited to steam, hot water, or other indirect means.

i. Explosion venting shall be provided in exterior wall or the roof only. According to the OHSACT[26] above regarding room volume the venting area shall not be less than 0, 11 m^2/ m^3. Vents may consist of one or a combination of the following:
   - Walls of light material, lightly fastened outward — opening swinging doors in exterior walls
   - Lightly fastened walls or roofs
   - Lightly fastened hatch cover

3.4.2 Location and QD (Quantity Distance) Guidelines

a. For new Hydrogen production plants, risk assessment shall be done that considers the location of the plant relative to the unit and generator transformers and routine traffic, limiting the impact of an explosion to power generating plant and personnel. The hazards analyses should identify the primary hazards involved with the installation, such as:1) Hydrogen release and burning of a Hydrogen/air mixture, and 2) explosion and fragment projectiles.
b. The AIA must handle the determination of the QD on an individual basis for quantities of Hydrogen less than the minimum specified in the standard of guidelines. Each situation should be evaluated based on the hazard presented by the specific quantity of Hydrogen being considered.
c. The installation and location of Hydrogen storage facilities shall conform to OHSACT[26] above and NFPA 55[12] above. Hydrogen systems of 84,9 m^3 or less, located inside building, shall be situated in the building so the following criteria are met:
   - Adequately ventilated area
   - 6,1 m from stored flammable materials
   - 7,6 m from open flames, electrical equipment, or other sources of ignition
   - 15,2m from ventilation intakes and air conditioning equipment
   - 15,2 m from other flammable gas storage
   - 7,6 m from concentrations of people
   - More than one system of 84.9 m^3 or less may be installed in the same room provided the system is separated by at least 15.2 m. Each shall meet all the above requirements.

3.4.3 Access

a. Access to the Hydrogen plant and bulk storage shall be controlled and the requirements of the Generation Division's Plant Safety Regulations 240-150642762 shall apply.
b. An employee accessing a Hydrogen system must consider it as a potentially hazardous. An employee entering the Hydrogen plant shall be provided and utilise the necessary personal protective clothing, equipment and detection devices as required OHSACT.
c. Access shall be limited to authorised personnel (OHSACT [26]; NFPA 55[12] above) on the Hydrogen system.
d. Sufficient personnel must be available to perform a hazardous operation safely and in the event of accident, to obtain help and aid the injured.
e. Facilities in which combustible mixtures exist shall not be entered under any conditions
f. Personnel shall be warned of the presence of combustible mixtures or low Oxygen concentrations OHSACT [26]. Warning systems such as approved vapour detectors sensors, and continuous

sampling devices shall be employed to ensure that the plant environment is safe. The warning and detection devices shall operate audible and visible alarms. These systems shall be designed and installed to allow for the operation of equipment needed to reduce possible hazards.

3.4.4 Signage, Posting and Labelling

a. Each Hydrogen system and control areas must have signage, placards, postings, and labels displayed, so employees shall be aware of the potential hazards in the area. The location of Hydrogen systems shall be permanently placard as follows:
   - HYDROGEN-FLAMMABLE GAS-NO SMOKING- NO OPEN FLAMES
   - Each portable container shall be legibly marked with the name "HYDROGEN". Each manifold Hydrogen supply unit shall be marked with the name "HYDROGEN" such as: "This unit contains Hydrogen" (OHSACT[26]; NFPA55 [12]). Placards must be of sufficient size and colour that they are readily visible to employees entering the work area.

b. All plant to be fitted with AKZ or the KKS labelling consistent with the power station plant codification standards for unique identification.
c. Coding shall be used on all drawings, isometrics, schedules, documents and operating/ maintenance manuals.
d. The identification of contents of pipelines shall be in accordance with [20]
e. Identification shall include colour banding, code by stencilling or labelling and flow direction arrows.
f. All pipework shall be provided with markings, labels or colour coding indicating the contents thereof.

3.4.5 Layout

a. Separating the components into individual rooms may result in less stringent requirements as per the Structural Design Standard [25]. Therefore, new plant design shall include physical separation of the Hydrogen production from the control and switchgear i.e. rooms or individual panels or segregated compartments in a container. The Hydrogen production areas shall be designed to prevent a confined explosion.
b. Building design shall take into account of separate compartments suitably laid out for the safe clean storage and handling of potash. The design and layout shall take into account the safe mixing, pumping and loading operations of electrolyte. (Storage may be separate from the Hydrogen plant if preferred by individual stations.)
c. Doors and other openings shall have the required ingress protection.
d. All emergency exit doors shall open towards the outside and shall be lockable. Emergency exit door "handles" shall be fitted on the inside of the doors fitted to open towards the outside for exiting from the inside.

3.4.6 Safety Showers and Eye Washers

a. Safety shower and an eye washer shall be provided in the vicinity of the caustic-handling equipment. An eye washer shall also be provided in the vicinity of an alkaline electrolyser. Further safety showers and eye washers may be installed if required by power station specific requirements or designer recommendations.
b. Safety showers and eye washers complies to ANSI/ISEA Z358.1[6] or EN 15154[9].

3.4.7 Ventilation

a. Ventilation shall be provided as per the requirements of Hazardous Location Standard [15]. The standard allows for area classification to be downgraded (from Zone 0 to Zone 2 for example) through the implementation of ventilation systems.
b. For new production containerised plant with protection based on the loss of vacuum in the container, the allowable pressure rise (vacuum loss) shall be calculated such that a maximum Hydrogen concentration of 0,8 % is not exceeded. This is consistent with the principles contained in the standard and is 20 % of the flammable limit of Oxygen in Hydrogen.

3.4.8 Drains

Drain lines and pipes (e.g. condensate, oil and electrolyte) shall be provided. As these are likely to feed to the common station drains, this will require an Environmental Impact Assessment.

3.5 FIRE SYSTEMS

Preventive measures against fire shall include automatic or manual process shutdown systems.

The fire systems approach for Hydrogen Plants shall following the Eskom Fire Standard requirements:

a. A Fire Protection / Detection Assessment shall be done in accordance with the Eskom Standard [27] as early in the design process as possible with due consideration to the exposure risks, plant layout and general arrangement.
b. Fire Protection (passive, active and manual) shall be provided as per the Eskom Standard [28].
c. Fire Detection (including Hydrogen detection) shall be provided as per the Eskom Standard [29].

Fire protection may be achieved by passive or active means. Passive being elements of layout and construction that affords a level of inherent protection against fire or exposure to fire (physical barriers, walls, spatial separation). Active protection defined as a fixed fire protection, engineered system usually water based to provide cooling to areas of exposed plant and equipment.

Standard practice for active fire protection on receivers and cylinders is an automatically activated deluge water spray system with medium velocity spray nozzles with a density requirement of 10.2 L/min/m2. The system should be designed as indicated in Eskom Standard [28] to NFPA 15. All pipes and valves within 2m of the storage vessel should be protected.

The deluge control valve shall be located in a safe area to ensure manual activation of the system is possible in a fire event.

3.6 PURGING

All piping equipment that was filled with Hydrogen must be purged with an inert gas before work can commence or before the Hydrogen system is returned to service. The design of the plant must provide for a purging facility and the double block and bleed principle must be applied. Points for administering an inert gas and venting to atmosphere must be provided.

Depending on the application carbon dioxide is the most effective gas medium to reduce the flammability limit. Following carbon dioxide is nitrogen and is recommended to be used in applications where moisture is present. Helium is a good alternative to nitrogen. The use of argon should be avoided due to it being the least effective in reducing the flammable range.

All Hydrogen production plants shall be fitted with automated nitrogen purging systems. Nitrogen purging shall be done following any safety trip and start-up prior to Hydrogen production. The availability of the nitrogen purging system to perform an emergency purge must be monitored and alarmed and a facility to replenish the nitrogen without interrupting the connected nitrogen supply must be provided.

3.6.1 Carbon Dioxide Purging and Cylinders

Carbon dioxide purging is required to degas the generator before maintenance activities or in the case of an emergency. Carbon dioxide is used for generator purging as 60% carbon dioxide diluent of the generator volume is required in order to dilute an equal concentration Hydrogen air mixture out of the flammability region.

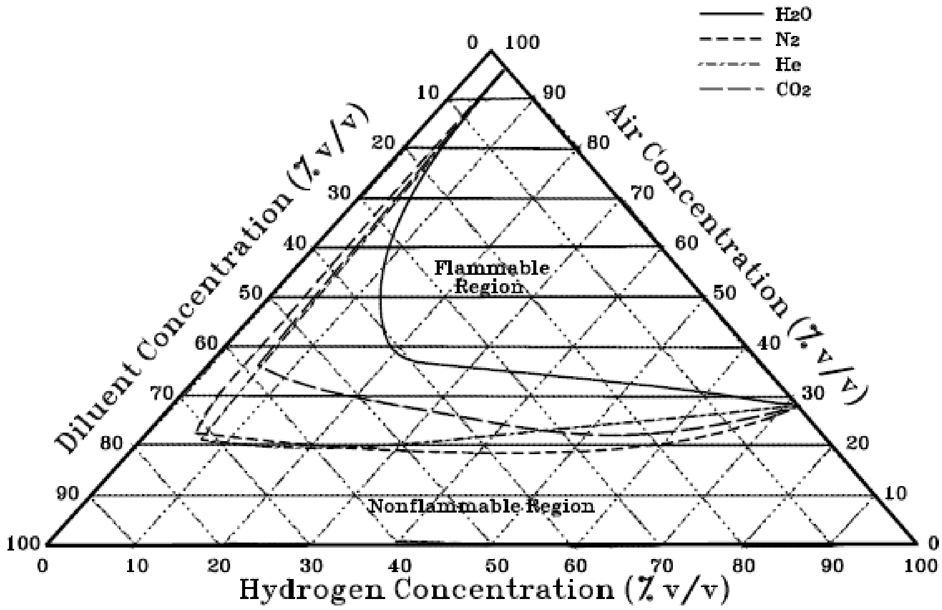

Figure 8 — Effects of N_2, He, and CO_2 diluents at 298 K (77 °F), and H_2O diluent at 422 K (300 °F) on flammability limits of hydrogen in air at 101.3 kPa (14.7 psia) (Coley and Field, 1973; Coward and Jones, 1952; Jones and Perrott, 1927).

Figure 1: Hydrogen Concentration

The following are the purging requirements:

a. Sufficient carbon dioxide cylinder supply must be connected to each generator to replace the entire volume of Hydrogen inside the generator twice. Each carbon dioxide cylinder holds 22,6kg of gas in liquid form, equivalent to 11,4m^3 at NTP, and is used for purging Hydrogen and air from the generator.
b. Carbon dioxide admission to the generator must be from the bottom of the generator and displacement of Hydrogen and air from the generator casing at the highest point on the generator casing.
c. During displacement of carbon dioxide in the generator the Hydrogen admission must be from the highest point on the generator casing and venting of carbon dioxide from the lowest point on the generator casing.
d. On-line gas analysing of Hydrogen, carbon dioxide and Oxygen.
e. Purging of the entire generator within 30 minutes.

f. Carbon dioxide purging station must be accessible and operable in the case of an emergency or fire. As an alternative remote operation of vent valves and initiation of the carbon dioxide purge via a control system.
g. All pipework, valve and fittings must be rated 1,5 times the MAWP.
h. Venting of all gasses must be through a water seal or flashback arrestor.
i. Siphon tube fitted carbon dioxide cylinder must be used and an evaporator must be utilised to prevent freezing of the cylinder valves and piping, to ensure adequate purging rates with carbon dioxide in an emergency. The evaporator shall ensure a minimum of 30 minutes of purging without availability of power supply.

3.6.2 Nitrogen Purging

a. Nitrogen is an effective medium to purge pipelines and systems and does not create carbonic acid in a moisture environment.
b. A nitrogen purging facility must be provided as an integral part of the Hydrogen production plant and the control system must identify the requirement for a purge and monitored that such a critical safety activity was done before the plant can start Hydrogen production. It is required that this be fully automated. The nitrogen used for purging must have a purity better than 99, 5% with the Oxygen content less than 0,5%. The dew-point of the nitrogen gas must be better than -50 °C at NTP. This is essential for the start-up of the Hydrogen production plant from an inert gas purged state.
c. Nitrogen may be used as an alternative purging medium, provided it is approved by the generator original manufacturer. The generator casing must be purged to 70 % dilution within 30 minutes and an analyser to monitor 70 % diluent must be provided.

3.6.3 Air Purging

a. Quality of air being used for purging the inert gas from the generator must be ensured and monitored at the point of admission to the generator.
b. The quality of air that is introduced for purging of the generator must have a dew point of -20°C at normal pressure (700 kPa).

3.7 HYDROGEN AND HYDROGEN FIRE DETECTION

3.7.1 Hydrogen Detection

The system design must ensure that detection occurs instantaneously and operating personnel are notified immediately, if Hydrogen leaks into the atmosphere or a Hydrogen fire occurs. A Hydrogen detection system must be compatible with other systems such as those for fire detection and fire suppression. The detection units must be suitably rated, to prevent ignition of flammable mixtures. The detection signal must actuate warning alarms and automatically effect shutdown whenever practicable.

3.7.2 Hydrogen Detection Specifications

a. Detection and alarm at 1 % by volume Hydrogen concentrations in air, equivalent to 25 % of the low flammable limit (LFL), is required for enclosed areas in which Hydrogen build-up is possible.
b. Detection and alarm at 0,4 % by volume Hydrogen concentrations in air (equivalent to 10 % of the LFL) is required for permit-required confined spaces OHSACT [26].
c. A 1 % by volume Hydrogen concentration at any point 1 m from the Hydrogen equipment should generate an alarm in areas around Hydrogen facilities.

d. Specification for Hydrogen sensors should include requirements for the following:
   - Minimum gas concentration detection requirements;
   - A scale range of the detector system based on the application;
   - Level of concentration for which alarm detection is required;
   - Response time of the detector system;
   - Accuracy of sensors;
   - Drift of the analyser;
   - Reliability and recalibration frequency;
   - Interface to facility safety and shutdown systems;
   - Analyser principle of operation adequate for the application as indicated in the Commodity Specification for Hydrogen [3],

3.7.3 Hydrogen Fire Detection Systems

a. A fire detection system must be capable of detecting, at a minimum distance of 4,6 m the flame from the combustion of 5,0 l/min of Hydrogen at NTP flowing through a 1,6 mm orifice to produce a 20 cm high flame. For a potential release of a large volume of Hydrogen, sensors with the ability to detect flames at distances greater than 4,6m must be used to provide coverage over a large area.
b. The fire detection should not be susceptible to false alarms from the sun, lightning, welding, lighting sources and background flare stacks.
c. The fire detection systems response time should meet the requirements for the specific application for prevention of loss of facility, equipment and protection of personnel.
d. Fixed systems are required for continuous monitoring of remote operations, and portable systems are required for field operations.
e. Special imaging systems are required for determining the size and location of a flame for assessment of the hazard because Hydrogen is not visible during daylight conditions. Use thermal protect-o-wire, temperature sensors, and UV-only optical fire detectors for transfer systems.

3.8 PROTECTIVE MEASURES FOR SLIPRINGS AND COUPLED EXCITERS

a. If the exciter or slip rings are situated in a housing into which Hydrogen may leak, the accumulation of an explosive Hydrogen-air mixture must be prevented, e.g. by maintaining a flow of air through the enclosure.
b. The flow can usually be produced while the shaft rotates at normal speed, but additional means may be needed when the machine contains Hydrogen and the shaft is stationary or rotating slowly or if an exhaust duct is not provided to vent Hydrogen leakage through natural convection and buoyancy. If local fans are used to ensure ventilation, their motors shall have a type of protection for flammable gas atmospheres in accordance with IEC Publication 79.
c. Hydrogen leak and fire detection must be installed in the enclosure.

3.9 HYDROGEN PRODUCTION PLANT DESIGN REQUIREMENTS

a. Key design requirements for the Hydrogen production plants are:
   - Safe operation shall be assured at all times.
   - Simplicity and reliability.
   - Measuring equipment and analysers must be installed to identify the production of a potentially explosive mixture and prevent it from being stored.

- Automatic, unattended operation, insensitive to power interruptions. In the event of a power interruption, the plant shall revert to a safe condition, Hydrogen vented and a nitrogen purge executed through a control and instrumentation back-up power system, providing plant status and alarms for a period of 1 hour after power interruption.
- A back-up power facility must be provided to perform venting, inert gas purging and data capturing.
- All components suitable for use with Hydrogen and classified accordingly.

b. The gas production facility shall preclude the possibility of the Oxygen and Hydrogen forming an explosive mixture through firstly segregation, secondly monitoring and control in design

c. For electrolysers operating at atmospheric pressures, a water safety seal shall be provided and installed between Hydrogen production (electrolyser) and reticulation gas holder storage.

d. All vents shall be routed to the outside of the building and positioned such that free dispersion of Hydrogen is ensured.

e. All gas vent lines to atmosphere shall flow through a water seal or be fitted with a flashback arrestor normally low pressure rated to maximum 500 kPa Hydrogen gas.

f. All water seals shall be designed for the maximum flow possible, ensuring that a sudden release of gas does not break the seal.

g. Any equipment installed, that introduces a risk of air entrainment, must be fitted with on-line monitoring equipment that will automatically react if an unsafe condition occurs.

h. Oil, condensate, moisture off-loading will not be done directly to atmosphere. The block-and-bleed principle shall be applicable to these systems. The accumulating vessel to be fitted with level monitoring. When the high level is reached the inlet line must be isolated an outlet solenoid valve opened and level drained to the minimum level. A liquid seal must be maintained and monitored with a low-low level sensor that will initiate an emergency/safety trip.

i. If a gas holder is used:

- The gas holder's water seal shall be designed to fulfil the requirements of the output of the plant.
- Precautions shall be taken to prevent corrosion of the gasholder.
- The gas holder shall be designed for unrestricted movement.
- The gas holder shall be fitted with low pressure monitoring.
- At least one low-level proximity switch shall be provided on the gasholder as a backup to the fixed limit switches. The preferred proximity switches are the type where a magnet is fitted to the gas holder bell and reed type switches for high-high, high, low and low-low are fitted to fixed positions adjacent to the bell.
- The gas holder water safety seal shall be fitted with a low-level monitor that initiates a rectifier trip or ensures that a safe plant condition is reverted to.

3.10 WATER TREATMENT

In order to ensure Hydrogen production plant health and safe plant operation all water electrolysis Hydrogen production plants shall be supplied with a water treatment process for the removal of ionic mineral contaminants of the station demineralized water supply.

The conductivity of the demineralized water supply must be monitored before the buffer tank, incorporated in the Hydrogen production process. The buffer tank that was exposed to atmosphere must be flushed before demineralized water is introduced into the electrolyser for any plant stoppage period longer than 24 hours. The flushing needs to occur automatically.

Recycled water or condensate which was exposed to any potential form of contaminants i.e. drying agents, exposed to atmosphere etc. must pass through the water treatment process before it is introduced into the cell stacks or drained off. The conductivity must be monitored after the water treatment process.

3.11 HYDROGEN STORAGE

3.11.1 Bulk Storage

3.11.1.1 Vessels and Valve Panels

a. Bulk storage vessels shall be provided for the specified capacity.
b. Pressure reduction, downstream of the storage vessels, shall be provided to reduce the pressure to the required reticulation pressure.
c. The minimum flow rate that is required as part of reticulation to the Generators is 200Nm^3/hr.
d. The vessels shall be arranged and inter-connected in such a way that they may be taken out of service individually for periodic statutory inspection and put back into service, with minimum loss of Hydrogen from the rest of the system. For pressure tests, vessels shall be completely isolated (disconnected) from the rest of the system. The facility for purging the vessel prior to and following pressure tests shall be provided.
e. Vessels shall be individually filled and individually used.
f. Isolating valves and non-return valves shall be fitted to the inlet and outlet of each vessel to ensure individual vessel isolation and prevent pressure equalisation between vessels.
g. Each bulk storage inlet and outlet valve panel must be fitted with block and bleed valve arrangements to allow for isolation and purging of the valve panel.
h. Valves shall allow for isolation without interfering with adjacent equipment and to prevent the inadvertent cross contamination of Hydrogen and air-filled vessels by operators and maintenance personnel.
i. Pressure regulators at the station main and at each generator shall be provided. Each pressure regulator shall be followed by dual independent pressure relief devices.
j. Excess flow shut-off valves shall be provided at each bulk storage outlet that is required to protect against the consequences of any possible pipe fracture or major leak. The excess flow shut-off valves and system design as a whole shall be designed to allow the normal demand of gas flow without shutting off the supply but shall shut off the gas flow when demand exceeds the normal flow by 20% or the excess flow shut off valve must be set at the dumping rate of the generator safety valve.
k. Facilities for Nitrogen or Carbon-dioxide purging shall be incorporated. Use of drain and vent valves shall be acceptable for purging when no alternatives are in place.
l. Provision for the purging of bulk vessels shall be as follows:
    - Where there is a single inlet/outlet, purging shall be by means of evacuation and filling with an inert gas.
    - Where separate inlet and outlets are installed, purging shall be by means of positive displacement.
m. The vessels shall be in accordance with EN 13445 [7] or PD 5500 [14]. The design temperature range is -10 °C to 50 °C.
n. Piping between vessels shall be provided with manifolds and non-return valves so arranged that cross-vessel transfer of Hydrogen, including equalisation of receivers, cannot be achieved.

o. All manually operated valves that can lead to air contamination of Hydrogen or Hydrogen venting directly into atmosphere shall have lockable handles and be fitted with locks under the control of the "permit to work" system.
p. It is preferred that all new storage vessels shall be horizontally installed.
q. Hydrogen shall not be supplied to the bottom of the bulk storage vessels and nor shall Hydrogen be delivered to generators from the bottom of the bulk storage vessels. This is to prevent corrosion particles and other impurities such as moisture accumulated over a long period of time from being fed into the reticulation system.
r. Filling of the storage vessels will be automated, based on a filling philosophy to optimise cell stack life and meeting the requirements of minimum Hydrogen availability. The receiver filling and Hydrogen production philosophy must be based on the volume of Hydrogen calculated from the known volume of storage vessels and pressure measured.
s. A manual by-pass shall be provided for the outlet solenoid valve. Two in series isolation valves mechanically linked with a second double in series valve arrangement in parallel with mechanical interlock shall be provided on each bulk storage vessel to allow the installation of a spare safety valve for the removal of the in-service safety valve for maintenance purposes and ensuring that a safety valve remains in-service. A double isolation valve vent shall be provided before the safety valve for depressurisation. The removal and installation of the safety valve is only allowed when the pressure in the vessel is at approximately 500kPa.
t. A metering station after bulk storage must be fitted to reduce pressure to reticulation pressure and measure pressure, dew point and mass flow into the reticulation system. The mass flow, pressure and dew-point must be trended and data stored as a minimum for a moving 30 day period at a sampling rate of at least once every minute.
u. The ambient temperature for the design of the bulk storage vessels, valves and equipment is -20ºC to +50ºC.
v. All bulk storage vessels shall be fitted with a sunshield. The sunshield design must be such that a fire spray system can cool down the surface of the vessel.
w. The manufacturing material for new Hydrogen bulk storage vessel shall be the correct grade of stainless steel.
x. The bulk storage vessel inlet and outlet solenoid valve shall be a spring-loaded pilot forced closed valve that does not require a delta pressure across the valve to ensure the valve is and remains closed.
y. Service life expectancy of 50 years for bulk storage vessels.
z. All valves of new Hydrogen generating plant installations or refurbishments shall be of a suitable grade of stainless steel.

3.11.2 Hydrogen Cylinder Supply

a. A Hydrogen bottle bank of eight cylinders with a weight of 0,75kg each will be installed inside the power plant for topping up the generator when the bulk supply system is unavailable. A maximum number of two cylinders can be opened simultaneously to limit the Hydrogen that can leak into the vicinity. Connecting fittings shall be configured so that it is physically impossible to cross-connect incompatible systems without malicious intent to do so.
b. The high-pressure line from the cylinder feed must be protected with an automatic emergency isolating valve, which is required to protect against the consequences of any possible pipe fracture or major leak.

c. An inert gas purging and venting facility (block-and-bleed valve arrangement) must be provided between two isolation points. This includes the connection between each cylinder to the reticulation system. An isolation facility between each cylinder and the reticulation system must be provided to ensure that each cylinder can be individually isolated and replaced.
d. The high-pressure reticulation line must be protected with a non-return valve as well as each cylinder connected to the reticulation system.
e. Line pressure indication must be provided on all lines between two isolation points.
f. The low-pressure side, after pressure reduction, must be protected by a safety valve rated to dump the maximum amount of Hydrogen from the source, without allowing the generator casing pressure to increase above the maximum allowable working pressure.
g. As a minimum all Hydrogen cylinders must comply with this ISO standard [30].

3.11.3 Hydrogen Multi Cylinder Pallets

a. Unless fully compliant to the above for Hydrogen cylinder supply, a Hydrogen multi cylinder pallet cannot be utilised inside the power generating plant.
b. The high-pressure line from the Hydrogen cylinder pallet feed must be protected with an automatic emergency shut-off valve, which is required to protect against the consequences of any possible pipe fracture or major leak.
c. An inert gas purging and venting facility must be provided between two isolation points. This includes the connection between each Hydrogen cylinder pallet to the reticulation system.
d. The high-pressure reticulation line must be protected with a non-return valve as well as each cylinder connected to the reticulation system.
e. Line pressure indication must be provided on all lines between two isolation points.
f. The low-pressure side, after pressure reducing, must be protected by a safety valve rated to dump the maximum amount of Hydrogen from the source, without allowing pressure to increase above the maximum allowable working pressure.
g. A mechanical supply shut-off or controlled solenoid valve at 500kPa shall be provided for each Hydrogen cylinder supply connection.
h. Five Hydrogen cylinder supply connections shall be provided after the metering station with a common pressure reduction station.
i. A pressure transmitter with signal to the DCS for each Hydrogen cylinder connection must be provided.
j. Flexible hose connections with the required depressurization and purging facility shall be provided between each multi cylinder pack and valve panel.

3.11.4 Mobile Hydrogen Supply

a. Mobile Hydrogen supply units shall be electrically bonded to the system before discharging Hydrogen.
b. All off loading facilities shall provide easily accessible grounding connections and be located outside the immediate transfer area. Facility grounding connections should be less than 10 ohm resistance.
c. Transfer subsystem components should be grounded before subsystems are connected.
d. Electrical wiring and equipment located within 0,9 m of point at which connection is regularly made and disconnected shall be in accordance with Zone 2 classified location.
e. Flexible hose connections with the required depressurization and purging facility shall be provided between the mobile Hydrogen supply vessel and valve panel.

3.12 PIPING SYSTEMS

3.12.1 Piping Systems

a. Piping systems shall be in accordance with EN 13480 [8] or ASME B31.3[13].
b. Piping systems for Hydrogen use shall be designed based on the most severe condition of coincident pressure, temperature, and loading. Special consideration shall be given for the unique properties of Hydrogen, such as Hydrogen embrittlement. The most severe condition shall be the requirement that results in the greatest required pipe thickness and highest flange range rating. These include:
   - pressure relief valves
   - valves
   - filters
   - fittings
   - gaskets
   - Hydrogen pipelines

   It also includes hangers and supports and other equipment items necessary to prevent overstressing and vibration of pressure-containing components. Safety reviews of piping systems designs shall be in accordance with those detailed in ANSI/AIAA standard [1]. Piping and pressure-containing components shall be pressure tested.
c. Facility and transfer piping systems shall include safeguards in according with ASME B31.3 [13] for protection from accidental damage and for the protection of people and property against harmful consequences of vessel, piping and equipment failures. Within a process area, Hydrogen transport piping shall be treated similar to Hydrogen storage in that all such piping shall be isolated by an exclusion zone in which access is restricted and certain types of operations are prohibited while Hydrogen is present in the piping system.
d. Materials for Hydrogen piping systems and components must be suitable for the stress, temperature, pressure and exposure conditions. Conditions considered to characterise Hydrogen embrittlement failures include temperature, pressure and Hydrogen purity as described in GCA [5].
e. High-pressure gas manifolds shall be constructed of suitable and of welded construction wherever possible. Expansion or contraction should be looked at and adequate supports shall be provided.
f. New piping for Hydrogen shall not be buried. Piping shall be placed in open trenches with removable grating if placed below ground. All piping shall be periodically pressure tested and recertified. The piping and components shall be tagged and coded as described in section 4.10 of ANSI/AIAA [1].
g. Hydrogen piping that is installed in cable tunnels etc. must be monitored for Hydrogen leakage and fire detection. Alternatively, be protected by an inert gas "blanket" at higher pressure than the Hydrogen.
h. Sufficient grounding connections should be provided to prevent any measurable static charge from accumulating on any component. Each flange should have bonding straps in addition to metal fasteners, which are primarily structural.
i. Joints in piping should be made by welding. Mechanical joints such as flanges should only be used for ease of installation and maintenance. Provisions shall be made for the expansion and contraction of piping connected to limit forces by providing substantial anchorage at suitable points, so there shall be no undue strain to the piping.
j. All pipework, valve and fittings must be rated 1,5 times the maximum operating pressure.
k. Special consideration shall be given for the Joule-Thompson effect when the carbon dioxide expands to prevent freezing of valves and piping.

l. All piping of new installations on the Hydrogen generating plant and reticulation system to the Generators shall be of a suitable grade of stainless steel. The minimum diameter of piping from the bulk storage vessels to the generator connection shall be 20 NB. The minimum diameter of piping used as part of the Hydrogen Generating plant from the cell stack manifold to the bulk storage vessel inlet connection shall be 15mm NB for plants with a production capacity of 5 Nm3/h to 20Nm3/hr with plants with higher production capacity larger diameter piping. All impulse lines need to meet the C&I instrumentation requirements.

3.12.2 Supports

The design of piping support members shall account for all concurrently acting loads transmitted into such supports. All supports and restraints shall be fabricated from materials suitable for the service conditions. Any attachments welded to the piping shall be compatible with the piping material and service conditions.

3.12.3 Bending and Forming Piping

a. Pipe may be bent to any radius that will result in arc surfaces free of cracks and substantially free of buckles. Flattening of a bend, as measured by the difference between the maximum and minimum diameters at any cross section, shall not exceed 8% of the normal outside diameter for internal pressure and 3% for external pressure.
b. Piping components may be formed by any suitable hot or cold working method, provided such processes result in formed surfaces that are uniformed and free of cracks or other defects. The various piping components should conform to the specified requirements of the engineering design.

3.12.4 Double Block-and-Bleed Valve Arrangement

A double block-and-bleed arrangement to isolate supplies from other parts of the system must be implemented, including on inert gas purging and venting facility. A doubleblock-and-bleed arrangement as shown in Figure 1 below is a positive way to ensure that Hydrogen leaking through a shutoff valve does not enter other parts of a system where it is not desired.

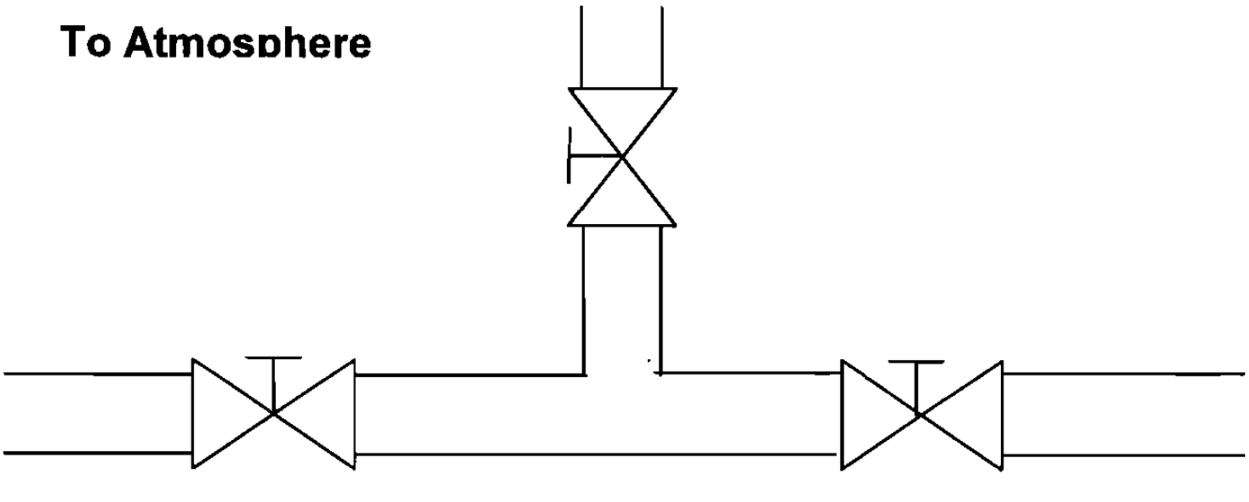

Figure 2: Double Block-and-Bleed Arrangement

3.13 COMPONENTS

3.13.1 Joints in piping and tubing

a. Welding is the first preference for all Hydrogen systems and it shall be in accordance with the Standard for Welding Requirements on Eskom Plant [31].
b. Joints in piping and tubing may be made for H_2 by welding or brazing or using flanged, threaded, socket or compression fittings. Brazing materials shall have a melting point above 538 °C. The fused joint is recommended in Hydrogen systems because of its simplicity and high reliability. Hard soldering and welding often can meet the bonding requirements, but the welded joint takes preference for safety OHSACT [26].
c. Tube fitting of flared or compression type may be used for tube sizes not exceeding 5.1 cm outside diameter within the limitations of applicable standards.

3.13.2 Threaded joints

National pipe thread (NPT) and similar threaded joints with a suitable thread seal are acceptable for use in Hydrogen systems. Consideration should be given to back-welding threaded joints for Hydrogen systems inside buildings.

3.13.3 Flanged joints

a. In cases where welded joints are not desirable it can be replaced with flange connections. Flanged joints with radially compressed seals, such as Grayloc, Reflange R-Con or E-Con type flanges and seal rings are acceptable. Flanges with dual seals and inter-seal vent ports are recommended in applications where leakage may be induced by system thermal expansions.
b. Flanges should be designed and manufactured in accordance with ASME B16.5. [32]. Flanges using a soft gasket should use a raised-face flange with a concentrically serrated face.
c. An earth loop connection of minimum $6mm^2$ must be fitted across the flanged connection.

3.13.4 Silver braze joints

The choice of braze composition is determined by ease of application to the material to be joined; however, cadmium containing silver brazes shall not be used. Silver brazes are recommended for joining copper-base materials and dissimilar metals such as copper and stainless steel. The melting point must be greater than 538 °C.

3.13.5 Soft solder joints

Soft solder joints are not permissible in Hydrogen systems.

3.13.6 Pipe connections

a. The designer shall determine that the type and the material of the fitting selected is adequate and safe for the design conditions in the absence of standards, specifications or allowable values for the material used to manufacture the fitting.

b. Greater flexibility should be provided in designs of small branches out of large and heavy runs, to accommodate thermal expansion and other movements of the larger line. Branch connections should be made in piping systems as followings:

- Fittings (tees, laterals and crosses) should be made in accordance with standards procedures.
- Outlet fittings should be welded.
- The branch pipe may be welded directly to the run pipe or without reinforcement.
- Extruded outlets in the run pipe, at the attachment of the branch pipe, should be butt-welded.

3.13.7 Flexible hoses

a. Flexible hoses pressurised to greater than 1,14 MPa should be restrained at intervals not to exceed 1,83 m and should have an approved restraint device such as the Kellems hose containment grips attached across each union or hose splice and at each end of the hose. The restraint devices should be secured to an object of adequate strength to restrain the hose if it breaks.
b. Hose containment methods and devices that differ from standard devices should be approved by the AIA.
c. Only crimped clamps may be used on any hoses.
d. ISO standard gas cylinder connections must be fitted to the end of the flexible hose.
e. Flexible hoses shall have electrical continuity to earth through the length of the hose from both end connections and shall have a bonding strap along the length of the hose.

3.13.8 Expansion joints

a. Bellows expansion joints used in Hydrogen piping systems may be convoluted or toroidal and may or may not be reinforced. Lap-welded tubing should not be used.
b. A fatigue life able to withstand the full thermal motion cycles is a design requirement, but the life of the bellows should not be less than 1000 full thermal movement and pressure cycles in any case ASME B31.3 [13].
c. Expansions joints shall be marked to show the direction of flow. Flow liners should be provided when flow velocities exceed the following values:
    - Expansion joint diameter less than or equal to 15,2 cm: gas flow velocity of 48 m/s per m of tube diameter
    - Expansion joint diameter greater than 15,2 cm: gas flow velocity of 300 m/s per m tube diameter
d. An expansion joint must be installed in a location that is accessible for scheduled inspection and maintenance.
e. Pressure test of piping systems shall be performed with the bellows expansion joint installed in the line with no additional restraints, so the expansion joint cross connections or external main anchors carry the full pressure load. Test should not be performed until all anchors and guides are securely in place.

3.13.9 Valves

a. Valves for gas service in a Hydrogen environment shall comply with the requirements of the Compressed Gas Association (CGA) of America [4] or equivalent such as
    - European Industrial Gas Association; and
    - British Company Gas Association.
    - South African National Standards
b. Valves shall have factory certification of hydrostatic pressure tests and details of leak tests carried out using Hydrogen or helium as the leak test medium.
c. Test certificates stating compliance with the specification, for all valves, shall be available on site.

d. All valve and fittings must be rated 1,5 times the maximum operating pressure.
e. Valves identified by Eskom to form part of the permit to work system shall be lockable valves to accommodate an 8mm padlock.

3.13.9.1 Excess Flow Valves (EFVs)

a. EFVs for gaseous Hydrogen service must be self-actuated devices that shut-off flow when the built-in sensing mechanism detects that the flow exceeds the pre-set flow value.
b. The normally actuated valve to open the Hydrogen supply feed should not cause an operation of the EFV and must be designed or selected as a gradually opening valve. EFV installed to provide an immediate Hydrogen supply shutoff in the event of gas line or component failure, must have a manual reset facility.
d. EFV installed in-line with pressure gauges on Hydrogen lines must have an automatic reset facility. This is normally achieved via a small leakage that equalise pressure across the EFV.

3.13.9.2 Emergency Isolation Valves (EIVs)

a. Emergency isolation valves capable of full closure without leakage must be provided that are readily accessible to stop Hydrogen flow.

b. EIVs should be installed before branch or multiple distribution lines feed different facilities or to isolate all Hydrogen feeds to the generator. EIVs must have a metal-to-metal seat or a metal to metal backup of a soft-seated valve for positive shut-off.

c. A block-and-bleed valve arrangement is acceptable as an emergency isolation point.

d. All EIVs shall have a fail-close operation and may be operated remotely or locally.

3.13.9.3 Isolating Valves

a. To allow for maintenance activities and emergency response, isolation valves are required. An isolation valve shall be installed at an accessible location in the gas line so that flow can be shut off when necessary.

b. The high pressure line from the cylinder feed must be protected with an automatic emergency isolating valve, which is required to protect against the consequences of any possible pipe fracture or major leak. A double-block-and-bleed arrangement is a positive way to ensure that Hydrogen/carbon dioxide leaking through a shutoff valve does not enter other parts of a system where it is not desired.

3.13.9.4 Gas Cylinder Valves

a) The valves fitted to the individual gas cylinders must be of a screw down complying with ISO standard [30].

b) The valve material must also comply with the ISO standard [30].

c) Carbon dioxide cylinder valves shall be fitted with siphon tubes to facilitate rapid gas discharge.

3.13.9.5 Non Return Valves (NRVs)

a. The high pressure reticulation line must be protected with a non-return valve as well as each cylinder connected to the reticulation system.

b. Each individual Hydrogen cylinder connection to the manifold must be protected with a non-return valve.

c. Swing-type and lift type NRVs are recommended for 2.54cm nominal and larger sizes. Poppet-type NRVs are recommended for 2.22cm and smaller.

3.13.10 Gauges

a. The pressure gauges shall be the Bourdon type or intrinsically safe pressure transmitters for a Hydrogen environment application.
b. The gauge graduation shall be 50 kPa minimum for the storage vessels and 0,5 kPa minimum for the atmospheric electrolyser.
c. The gauge pressure rating shall be 150 % to 200 % of the anticipated maximum allowable working pressure (MAWP).
d. The gauge face shall be a minimum of 100 mm diameter for gauges not more than 2, 5 m above ground and 150 mm diameter for gauges more than 2,5 m above ground level.
e. Each gauge shall be clearly marked on the face with a red line which indicates the relevant system section maximum allowable working pressure level.
f. All gauges shall have blow-out protection and excess flow shut-off to minimise the release of Hydrogen should there be a rupture of the gauge. Gauges shall have pulsation compensators where required.
g. All gauges will be fitted with safety glass.

3.13.11 Hydrogen venting

a. All vents shall be routed to the outside of the building at the highest point and positioned such that free dispersion of Hydrogen is ensured away from any possible ignition sources. The Hydrogen and the Oxygen vent lines shall be at least 2m apart. All gas vent lines to atmosphere shall flow through a water seal or be fitted with a flashback arrestor, normally low pressure rated to maximum 500 kPa Hydrogen gas.
b. The vent line must have a minimum diameter equal to the critical tube diameter. Critical tube diameter (Dcrit): The maximum tube diameter, for a specific pressure, that will prevent Hydrogen flame propagation within the tube. Dcrit = 13 A, where A is the cell size and has a value of 1cm at atmospheric pressure (i.e. Dcrit = 13 cm for atmospheric vent pipes).
c. All water seals shall be designed for the maximum flow possible, ensuring that a sudden release of gas does not break the seal. Hydrogen venting from the generator casing down to 80kPa gauge, must be achieved within 10 minutes when inert gas purging is initiated. The generator seal oil minimum pressure requirements must be considered when this test is conducted.

3.13.12 Transfer connections

Interlocking between purging the generator with Hydrogen or air must be incorporated in order to prevent air being introduced to the generator while filled with Hydrogen or vice versa.

3.13.13 Compressor machines

Where high pressure compression is required for bulk storage of the produced Hydrogen gas:

a. Duplicate compressors shall be installed, with controls to select either one for operating or as standby. Each compressor shall be rated to continuously handle the full capacity of the plant and specifically designed to handle wet Hydrogen containing traces of lye. (Note: when ordering spares for compressor plant, it is essential to specify that the components are for Hydrogen plant compressors as they may be susceptible to degradation by wet Hydrogen containing lye).

b. Compressors shall be single or multistage with inter-stage cooling, and after-cooling provided after the final stage of compression.
c. Compressors shall be fitted with condensate blow down mechanisms between each stage to prevent inter-stage build-up of condensate and damage to compressors. In all cases, this blow-down shall be vented through a water seal. It is preferred that a condensate trap be installed and draining of accumulated condensate will be done with level control, avoiding venting of Hydrogen due to over-draining. For automated blow-down, the condensate trap must be fitted with low-low level monitoring which will disable compressor starting. For manual blow down, an appropriate works-instruction shall be in place to avoid release of Hydrogen.
d. Compressors shall be supplied with safety valves at each stage and on the final outlet which will be piped to the outside of the building and away from Oxygen vents. Safety valve settings shall be in accordance with OHS Act requirements.
e. A condensate/oil drain line shall be fitted to the compressors leading to a recovery sump in an accessible location in accordance with the power station's policy on effluent recovery and treatment.
f. The suction lines to the compressors shall be designed to avoid the pressure on the suction side of the compressor to decrease below atmospheric pressure. It will be permitted for the design of the suction line to incorporate a condensate trap to prevent pressure swings. If the volume of the supply line is higher than the volume of gas that the compressor is able to take in during suction stoke this will not occur.
g. An interlock must be installed to ensure that the selected compressor will not start if the appropriate suction valve is closed so as to prevent any Oxygen ingress to the receivers or storage facility.

3.13.14 Hydrogen dryers

a. A dryer system (redundant dryer system applicable for atmospheric electrolysers) shall be installed immediately after compression and before storage. These dryer systems should be common for any one of the compressors.
b. Dryers shall be able to handle the quantity and quality of gas being produced and ensure safe plant operation.
c. All valves to control the dryer cycles shall be electrical actuated valves and only NRV valves are not accepted.
d. Desiccant dryers shall be acceptable subject to the requirements below.
    - Dryers shall be fitted with filters to remove particles and oil.
    - Oil and condensate off-loading will not be done directly to atmosphere. The block-and-bleed principle shall be applicable to these systems. The drain outlet shall be fitted with liquid level detectors.
    - The liquid level shall be monitored and alarmed.
    - The installed dryers are capable of continuous drying without the need to halt production for regeneration of the drying medium and are compatible with the operating philosophy of the compressors.
    - Automated condensate off-loading systems shall be closed off from the main supply before the condensate/oil is drained. Monitoring of a passing valve shall be provided.
    - The installed dryers are capable of continuous drying without the need to halt production for regeneration of the drying medium.

- Hydrogen velocity through the desiccant bed does not cause fluidization of the bed.
- The contact time between Hydrogen and desiccant is sufficient to dry 100 % saturated inlet Hydrogen to the specified dew point.
- Sufficient desiccant is provided so as to negate the effects of desiccant ageing (normally a 30 % loss of effectiveness).
- The desiccant must be compatible with the elements in the process for example KOH and oil, or the process specifically designed to protect the desiccant from oil or KOH contamination.
- Dryer regen condensate must be drained into the drainage system and may not be recycled back into the cell stack or production process.
- Ceramic or metallic cartridge type filters are installed to filter out impurities down to 1ppm or better in the Hydrogen.
- All dryer chambers must be fitted with a heating element, temperature control system and flow monitoring.
- In the case of regeneration, the heating cycle must be interlocked with minimum flow through the chamber. The temperature of the heating element must not exceed 300 °C.
- A de-oxidiser must be fitted to remove Oxygen as part of the gas drying unit. The gas must be heated to a value which will ensure optimum operation of the catalyst. The catalyst must be protected from moisture contamination. Sufficient catalyst must be provided to absorb 1% Oxygen continuously for a minimum of one year at full production of the Hydrogen production plant. Gas cooling and liquid separation must be provided after deoxidizer before gas drying. Gas temperature at the inlet and outlet of the deoxidizer must be provided with alarming facility to unit control desk.
- The dryer vessel design must be such that the desiccant and catalyst can be changed without requiring replacement of the vessel or mechanical intervention that will require recertification thereof. A specific access must be provided to remove and replace the desiccant or catalyst.

3.13.15 Generator Hydrogen dryers

a. The gas dryer must be dimensioned for a test pressure of 1000 kPa gauge. Valves shall be interlocked, so that the gas dryer is associated either with the generator for drying operation, or with the blower and the blow-offline for regeneration purposes. Dryer status indication must be provided.
b. All dryer chambers must be fitted with a heating element and a blower.
c. A blower failure may not disable the operation of the dryer. In the case of a blower failure the dryer needs to continue operation as a pressure swing dryer.
d. In the case of regeneration, the heating cycle must be interlocked that heating cannot be operated without flow. The temperature of the heating element must not exceed 300 °C and also be hardwired protected.
e. Hydrogen Dryers shall be able to handle the quantity and quality of gas to ensure that the Hydrogen dew point is improved with 5 °C at NTP over a 24 hour cycle, taking into consideration Hydrogen contamination from the seal oil system to a value of -30 °C at NTP.
f. Dryers shall be fitted with filters to remove particles and oil down to 1ppm or better.
g. Block-and-bleed isolation arrangement must be supplied before and after Hydrogen dryer, without isolating gas quality measurement while generator is on load.
h. A de-oxidiser can be fitted to remove Oxygen as part of the gas drying unit. The gas must be heated to a value which will ensure optimum operation of the catalyst. The catalyst must be protected from moisture contamination. Sufficient catalyst must be provided to absorb 1% Oxygen continuously for a

minimum of one year at full production of the Hydrogen generating plant. Gas cooling and liquid separation must be provided after deoxidizer before gas drying. Gas temperature at the inlet and outlet of the deoxidizer must be provided with alarming facility to unit control desk.

i. Oil and liquid off-loading shall not be done directly to atmosphere. The block-and-bleed principle shall be applicable to these systems.
j. The liquid level shall be monitored and alarmed.
k. The dryer vessel design must be such that the desiccant and catalyst can be changed without requiring replacement of the vessel or mechanical intervention that will require recertification thereof. A specific access must be provided to remove and replace the desiccant or catalyst.

3.13.16 Condensate traps

a. In addition to condensate off-loading on the compressors, condensate traps shall be installed on the suction line of compressor.
b. Volume of condensate should not exceed the capacity of the trap. If necessary multiple traps should be installed. The condensate trap needs to act as a buffer and remove condensate from gas.
c. Discharging of condensate traps shall be as described in the section of condensate traps.
d. All traps and bypasses shall be piped to the respective power station drainage sumps via the local pipeline.

3.13.17 Cooling water systems

a. Materials making up the cooling water system shall be suitable for the power station water quality. Materials shall be corrosion-resistant and of low carbon content. The use of aluminium is not permitted.
b. The cooling system on all electrolysers shall be a closed loop system preferably demineralised system. A common sump accumulating electrolyte overflow, water-seal overflow and/or gasholder overflow is not permitted as potassium hydroxide is introduced.
c. The cooling water piping to Hydrogen production plant will be part of a large, closed loop system and shall be designed to avoid electrolyte contamination at all times.

3.14 OVERPRESSURE PROTECTION OF STORAGE VESSELS AND PIPING SYSTEMS

3.14.1 Safety Valves

a. The relief or safety valves shall be set to limit the maximum pressure to not exceed the MAWP. The low pressure side, after pressure reducing, must be protected by a safety valve rated to dump the maximum amount of Hydrogen from the source, without allowing the pressure to increase above the maximum allowable pressure.
b. Safety and relief valves should be direct spring or deadweight loaded. Pilot valve control or other indirect operation of safety valves is allowed if the design is such that the main unloading valve automatically opens at the set pressure or less and is capable of discharge at its full rate capacity if the pilot or auxiliary device should fail.
c. All safety valves must be fitted upright with the high pressure entry from the bottom.

3.14.2 Pressure Regulator

- Cylinders should have a regulator and pressure gauge. Regulators should be non-venting or have the vents piped to atmosphere through a flashback arrestor to a safe location. All regulators shall be fitted adequate in-line filters.
- Mechanical shielding should be provided for regulators to protect them from mechanical damage.
- The regulators shall be designed for the specific application.
- The regulator delivery gauge range should be approximately 2 times the operating pressure and at least 1.5 times the MAWP.
- Following the installation of a pressure regulator the downstream system shall be protected with a pressure safety valve as per the Hydrogen Pipeline Systems [5].

3.14.3 Supplemental pressure relief

Supplemental pressure-relief devices must be installed to protect against excessive pressure created by exposure to fire or other unexpected sources of external heat. Relief devices installed in any section of the vessel and piping systems limit the allowable working pressure. The supplemental relief device should be capable of limiting the pressure to 121 % of the MAWP.

3.14.4 Failure modes

Failure modes that must be considered in the design and operation of protective pressure-relief systems include the following:

a. The minimum capacity of the primary protective device should be determined by the heat leak rate. The device should be located as near as possible to the highest point in the line section.
b. The overpressure potential associated with connection to a high-pressure source of any type — pump, pressure-relief valve or direct connection through a flow-limiting orifice requires the existence of a pressure switch to cut off the source of high pressure but does not eliminate the need for the primary protective device. The primary protective device should be located as close as practical to the high-pressure source.
c. Capacity consideration for the jacket should be based on a catastrophic failure.

3.15 ELECTRICAL CONSIDERATIONS

3.15.1 Electrical installation

a. All electrical equipment within the risk envelope of normally operated Hydrogen equipment shall be suitable for the approved classification in accordance with Eskom standard [15].
b. Stuffing boxes shall be used for electrical wiring taken from one explosion-proof enclosure to another. All outdoor controls shall be weatherproof with at least an IP 65 rating.
c. Where equipment is pressurised, the air for the equipment shall be taken from an outside source free of Hydrogen contamination. Alternatively an inert gas may be used.

3.15.2 Bonding and grounding

a. Exposed metal shall be earthed.
b. All metallic services and structures around Hydrogen containing plant shall be earthed and electrically unified to preclude the existence of discrete electrical bodies and potential differences between services and structures.
c. All components in contact with Hydrogen shall be bonded to electrically unify them with one another and the unified system shall be bonded to earth. Components requiring unification and bonding shall not be limited to the obvious items of equipment. Items for earthing and bonding include valve handles, rubber corrosion protected cooling elements in heat exchangers and internal parts of equipment such as the balls and gates of valves and other elements capable of forming distinct electrical entities.
d. All grounding connections should be less than 10 ohm resistance.

3.15.3 Electric motors

a. All main and ancillary drive motors shall conform to Eskom Standard [35]. All motors shall be arranged so that they can be removed and maintained without disturbing the driven machine, piping or electrical items.

3.15.4 Transformer

a. The transformer shall be designed for indoor operation and be rated for continuous operation at maximum rectifier output. Cable boxes shall be fitted with removable gland plates.
b. Over-current protection shall be installed.
c. Equipment shall be designed for the quality of supply provided by the power station.

3.15.5 Electrical controls

a. The operation of the plant shall be fully automatic and preferably arranged with step-less voltage control to vary the Hydrogen output between the manufacturers minimum recommended production capacity and 100 % of capacity.
b. If liable to damage by short breaks in the electrical power supply, the plant shall be provided with an automatic protection facility and an alarm initiating contact.

3.15.6 Electrical connections and cabling

a. All connections shall be rated to the full current rating of the associated equipment i.e. fused-switch, contactor, circuit-breaker, etc. and not to the design current or fuse-link rating.
b. Neutral connections shall have the same rating as the phase connections.
c. Insulated wire shall comply with SANS 1507 [17] [17]and SANS 1574 [18]. Stranded conductor only shall be used unless the solid type is approved by Eskom for the particular application.
d. Wiring at 50 V and below shall withstand a 500 V test voltage to earth for 1 min and wiring above 50 V shall withstand 1000 V to earth, for 1 min when installed.
e. Wiring shall be neatly fixed to avoid vibration and shall not obscure access to components. Wiring across door hinges shall be subjected to torsion rather than bending when opening the door.
f. All leads shall be marked at both ends, using interlocking white ferrules with impressed black characters. Not more than two leads shall be connected to one terminal.
g. An un-drilled, removable gland plate shall be provided at least 300 mm above floor level for each cable entering the equipment. For cables of 185 mm^2 and above, the gland plate shall be at least 6 mm thick

and drilled to suit the gland. For gland plate to terminal distances greater than 400 mm for control cables, or 500 mm for power cables, a means of fixing or bracing cable tails shall be provided.

h. Power supply and control cabling shall not share cable trays. Where control and instrument cables have to cross other cables only right angle crossing will be allowed. The minimum spacing between control and instrument cables and the nearest power cables shall be 1 m.
i. The insulation of all the electrical equipment shall be in accordance with the specification IEC 60071 [33].
j. Power conditioning equipment shall be designed for reliability and ease of maintenance and shall incorporate adequate redundancy to allow for fault repairs and routine maintenance without reducing the plant availability.
k. Individual harmonic currents shall not exceed the following: (these are measured at the electrical supply boards):
   - rms amplitude of 100/n percent, where n is the harmonic number.
   - Sub-harmonic currents shall not exceed the RMS amplitude of 100n percent, where n is the Fraction given by the sub-harmonic frequency divided by the fundamental frequency.
l. All lighting and small power shall be designed and supplied in accordance with the Eskom Standard [34].The Occupational Health and Safety Act [26] specifies minimum illumination levels for safety. At no time shall the illumination level fall below these recommendations, hence the lighting installation of the construction phase lighting must be regularly maintained to ensure conformance to the said act.
m. Any termination cubicle, junction box or distribution box utilized outdoors shall be IP65 rated and IP55 for indoor in accordance with IEC 60529 [36]. Finishing colour of 230/400 V cubicles shall be light grey G29 to Eskom Standard [20].

3.16 CONTROLS AND INSTRUMENTATION

3.16.1 Plant operation and instrumentation

a. The operation of the plant shall be fully automatic, at the manually set Hydrogen production rate, to maintain the rated pressure in the storage vessels.
b. The control system supply must be from an uninterruptable power source with sufficient back-up to allow the safe shutdown of the plant, including data capturing and alarming to the main DCS to indicate that Hydrogen venting, and nitrogen purging was completed to a safe state.
c. The Hydrogen production plant control system needs to include all the process for Hydrogen production including automatic Nitrogen purge venting and gas analysing. The metering panel and bulk storage control system needs to be a separate control system.
d. Indicating, recording and out-of-limits detecting instrumentation shall be provided as necessary for all parameters affecting safe operation of the plant (e.g. purities, temperatures and cell levels).
e. Remote data monitoring for the plant is required so that the plant can be supported by the OEM.
f. The control system for controlling the automated receiver filling and the control of the Hydrogen Production Plant will be integrated to ensure safe plant operation. The control system for the automatic Nitrogen purging and gas purity monitoring must be integrated with the Hydrogen production plant and will not be external system interfacing with the Hydrogen production plant. The control philosophy will revert to plant to the safest state when an unsafe condition is detected.
g. The best operating philosophy for the integrated system i.e. Hydrogen production and storage will be implemented to optimise cell stack life and needs to be approved by Generation Engineering Department.

h. All new installations for generator Hydrogen cooling system, carbon dioxide purging will be fully automated supplied with a full human machine interface that can be operated from a local and remote station, with the remote station located in the control room.
i. All manual operated display valves, monitoring and plant status indication will be mounted in a two dimensional plane at a minimum height of 1 m and a maximum height of 1,8 m.
j. The source code for all programmable logic controllers must be supplied with no access limitation to Eskom. Version control must be implemented.
k. A data recording, trending and data view facility shall be provided with the plant.
l. The PLC and the UPS shall comply IEC 61000 [23] and the battery charger standard [24].
m. All instrumentation and C&I equipment shall have an IP rating of IP66. The Junction Box location shall be outside the hazardous zone location.
n. The terminal block for the marshalling cabinet and junction box terminations shall comply with the SANS 60947-7-1 [37]and 60947-7-2 [38].
o. Transmitters shall be analogue transmitters with software levels. Binary transmitters and/or level switches will be accepted in areas where they are required for statutory requirements or for protection and hardwired interlocking.
p. For level measurement and/or switch where differential pressure transducers are used, all low-pressure instrument tapping points and isolation valve connections shall be ½ inch BSP tapered.
q. For level measurement and/or switch where an ultrasonic or radar transmitter is used, all low pressure instrument tapping points and isolation valve connections shall be 2 inch BSP tapered.
r. All temperature pockets/wells shall be fitted with a cap and chain. All pockets/wells shall have ½ inch BSP parallel female thread for the instrument connection and ¾ inch BSP tapered male process connection, if not welded. The tapping points for the process connection shall have ¾ inch BSP tapered female connection. All other low pressure instrument tapping points and isolation valve connections shall be ½ inch BSP tapered.
s. All temperature pockets/wells shall be fitted with a cap and chain. All pockets/wells shall have ½ inch BSP parallel female thread for the instrument connection and ¾ inch BSP tapered male process connection, if not welded. The tapping points for the process connection shall have ¾ inch BSP tapered female connection. All other low pressure instrument tapping points and isolation valve connections shall be ½ inch BSP tapered.
t. All transmitters shall be HART devices and shall provide measurements that are repeatable and have no drift for a minimum of 10 years with an accuracy of 0.1 % of full scale or better. Each transmitter shall have its own tapping point. Transmitters provided shall be mounted in suitable transmitter racks, equipment cabinets or field panels and be supplied as complete.
u. Temperature transmitters shall either use 4 wire Pt 100 RTDs, or 6 mm type K thermocouples, with calibration characteristics that comply with the Thermocouples standards[39] and [40].
v. All instrumentation pipe work shall be inclusive of supports, valves, fittings, condensing chambers for closed vessel level transmitters, transition pieces to primary isolating valves and drains to provide complete impulse and blow-down lines for all instruments.
w. All cable racking, cable trays and conduits required for the installation of the equipment. All cables provided must be secured with suitable cable glands, straps or clamps on racks, in cubicles and equipment rooms.
x. Where transmitters cannot be mounted in transmitter racks, equipment cabinets or field panels, these shall be mounted firmly on stands or brackets as close as possible to tapping point. The location shall allow safe and easy access for maintenance and calibration.

3.16.2 Mass flow meter

a. A flow/mass meter, with a minimum accuracy of 5 %, shall be installed after the storage vessels and at each generator supply point and must measure the volume of Hydrogen gas into the generator from all sources of Hydrogen.
b. The meters shall be of the positive displacement type fitted with a suitable orifice plate to prevent damage to the meter in the event of a sudden in-rush of Hydrogen during commissioning.
c. A mass flow meter shall be installed at the Hydrogen generating plant and arranged to meter the total quantity of Hydrogen drawn off by the station. The measurement will provide a reading of volume in cubic meters NTP.

3.16.3 Analysing Apparatus

a. Gas analysing equipment shall be provided for testing the purity of the Hydrogen on-line. It shall be the continuously indicating and recording type, essential for the safe operation and control of the plant fitted with an alarm contact arranged to operate between adjustable pre-set limits in the event of a drop in Hydrogen purity. The response time of the equipment shall be catered for in the operating philosophy with periods within the instrument's "dead band" assumed to be unsafe.
b. Only gas analysing equipment that has a fail-safe failure mode shall be installed in the plant that is not indicating purity better than actual and is failing in a slow response time mode. The operating philosophy of the plant must cater for potential equipment failure modes.
c. Metering equipment shall cope with the high flows when filling the generators and with the low make-up rate in normal operation.
d. All gas analysing equipment must be fitted with a minimum gas flow interlock, gas readings can only be accepted when minimum gas flow through the analyser is ensured.
e. Conductivity type sensing equipment shall be installed for gas purity monitoring at the outlet of the desiccant dryers as well as at the analogue dew point sensing equipment.
f. Catalytic Oxygen sensors shall be installed on the line supplying the gas holder on atmospheric electrolysers to provide protection against Oxygen entrainment and must be fail safe.
g. Where instruments used make use of a "de-oxidiser", these must also be backed up with an additional purity measurement using an inert gas, such as nitrogen, as a reference. "De-oxidiser" instruments require Oxygen and Hydrogen in order to function and therefore will not provide a reliable reading in the absence of Hydrogen. Plant operating philosophies must cater for this to avoid the possibility of plant safety being assumed on the basis of an erroneous reading.
h. Hydrogen specific analysers capable of tolerating wet Hydrogen shall be installed where this condition is possible.
i. Critical instrumentation to ensure safe plant operation must be installed with broken wire monitoring or supply failure and the Hydrogen production operation reverted to a safe state when such a condition is detected.
j. Hydrogen purity, Oxygen content and quality must be measured before being administered to the generator casing.
k. All analysers shall have a local display and they shall have the following parameters for configuration
    - High and low measuring range
    - High and low display range
    - Engineering units
    - Temperature at measurement cell (where applicable)
    - Offset adjustment on temperature measurement (where applicable)

- Offset adjustment on measured value
- Indication of measurement device health

l. All analysers shall provide measurements that are repeatable and have an acceptable <1% drift over the range for a minimum of 2 years. The output signal of all the analysers shall be load independent direct current 4 to 20 mA signal or by bus interface. The output signal is also a rising linear and falling linear signal. All gas analysing equipment with a drift worse than specified must be accompanied with a risk assessment proving that no unacceptable safety risk will arise from utilising the specific analyser in the application.

m. The size of the controller cubicles shall be minimum (0.9m x 1m x 2.2m), they shall conform to the following:
   - Floor mounted with suitable dust and vermin proofing
   - Bottom cabling access
   - Earthing
   - Front and rear access
   - Temperature monitoring per cubicle
   - Powder coated RAL 7035

n. All cabling shall be of blue-stripe type i.e. consist of flame-retardant, halogen-free PVC outer sheath

3.16.4 Alarms and trips

a. Visual alarms shall be provided to indicate any abnormal or dangerous conditions which might develop on the plant.

b. Each alarm channel shall be provided with potential free alarm repeat contacts wired to external terminals to initiate a remote alarm system. The number of alarms installed shall be determined in line with the requirements of the safe operating philosophy.

c. Control Device monitoring and controlling of the critical processes. Where reliable controls already exist, the controller can be configured to monitor those controls with alarm and delayed override facilities to trip the plant for critical processes. For example, the controller would monitor the actions of the mechanical switches on the gas holder but override the plant if the compressors were not tripped on a low-low signal by existing controls or if the new proximity switches provided a signal not provided by the mechanical switches.

d. Regular plant operator tests shall be carried out to test system monitoring and safety equipment by simulating failure modes. These test facilities shall be incorporated at design stage if possible.

3.17 PRODUCTIONS QUALITY AND QUANTITY MANAGEMENT

The principle of continuous Hydrogen quality and quantity measurement shall be such that:

a. Purity is measured as soon after the electrolytic cells as possible and before compression and drying. Removal of moisture (free water) may be done before this point.

b. Hydrogen purity, Oxygen content must be measured before bulk storage and reticulation to generators.

c. Hydrogen purity must be measured when the Hydrogen supply was not from the Hydrogen production plant before reticulation to generators. This is achieved with a Hydrogen purity analyser installed in the metering panel. Hydrogen supply purity must be done for each new supply i.e. cylinder, multi pack cylinder or bulk supply. Continuous measurement must be avoided to limit Hydrogen wastage.

d. Dew point after storage and before reticulation to the generators.

e. Hydrogen contamination in the Oxygen stream must be measured.
f. Continuous on-line pressure measurement of pressure in Hydrogen system.
g. Hydrogen purity and Oxygen content is measured before administered to the generators.
h. Continuous on-line generator Hydrogen purity and quality measurement.

3.17.1 Electrolytic cell-stack

a. Each cell-stack shall be fitted with points for manual gas sampling. Proof shall be provided that adequate flow of gas, electrolyte and cooling medium is achieved through-out the cell stack. A maximum of 5ºC between the minimum and maximum measured temperatures shall be accepted though the cell stack
b. Means to ensure adequate electrolyte and cooling water flow through the cell stack shall be provided.
c. The life expectancy of the cell stack should be minimum 10 years at full production.
d. The degradation of the electrolytic cell shall be less than 1% per year measured at the specified maximum production capacity and relevant current densities and continuous operating. The degradation type test report indicating the influencing factors and limits needs to be indicated in the report including catalyst coated membrane thickness etc.

3.17.2 Before storage

a. Continuous Hydrogen purity, Oxygen content and dew point measurement shall be in place on the downstream side of the dryers before delivery to the bulk storage vessels and shall be periodically confirmed by an independent measurement (not necessarily on-line) so as to ensure the integrity and accuracy of the measuring devices.
b. A dew point not meeting requirements shall cause an alarm. Atmospheric dew point shall be better than -50 °C NTP.
c. Measurement of Hydrogen purity (minimum 99,5 %) and also Oxygen contamination (maximum 0,5 %) shall be done. If Oxygen is not measured, any impurity detected by the Hydrogen analysers shall be assumed to be Oxygen.
d. The plant shall be tripped when the Oxygen contamination reaches the limit of 1 %.
e. When Hydrogen purity is less than 99,5 % one of the following two actions is required:
    - Where there is not automated vent facility, the entire plant shall be tripped with an alarm to the control room. OR
    - Where there is an automated vent facility, the out of specification condition shall be alarmed the Hydrogen vented through a water seal, and compressors disabled from starting, until the quality returns to specification.

3.17.3 After storage

a. After storage and pressure reduction, a maximum dew point of -30 °C below the minimum system temperature, and for the generator working pressure, shall be allowed.
b. Instrument specific gas flow through the analyser must be ensured and monitored to ensure that the purity of the gas that is being produced is monitored.
c. The mass flow, pressure and dew-point must be trended and data stored as a minimum for a moving 30 day period at a sampling rate of once every minute.

3.17.4 At the generator

a. Continuous Hydrogen purity, Oxygen content and dew point measurement.
b. Hydrogen purity is measured before being administered to the generators.
c. Continuous on-line generator Hydrogen purity measurement.
d. Measurement of Hydrogen purity (minimum 96 %) and preferably also Oxygen contamination (maximum 1 %) shall be done.

Note: If Oxygen is not measured, any impurity detected by the Hydrogen analysers shall be assumed to be Oxygen and the generator must be tripped if the Hydrogen purity is than less than 96 %.

e. The plant shall be tripped when the Oxygen contamination reaches the limit of 1 %.

3.17.5 Additional plant monitoring requirements

Additional parameters shall be monitored for the purposes of verifying correct operation of plant and/or ensuring plant health.

a. An on-line Hydrogen leak detection system shall be installed in the production plant linked to a plant trip and alarm. These shall be fitted above equipment where leaks are most likely to occur (e.g. water seals, compressors, gas holder, dryers). OR Leak detection by monitoring the pressure rise within containerized Hydrogen production plant set to detect a pressure rise that indicates the presence of 0.8% Hydrogen.
b. Storage vessel pressure and reticulation monitoring, which shall be maintained at a minimum pressure of 500 kPa gauge or 100 kPa above Generator pressure, whichever is the greater, at all times.
c. The supply lines between the Hydrogen production plant and the generators shall be fitted with on-line monitoring and an alarm facility.
d. Correct operation of the ventilation fans, where installed.
e. Concentration of base electrolyte, routine manual measurement is acceptable.
f. Individual cell voltages (anode/cathode, anode/tank, cathode/tank), routine manual measurement is acceptable.
g. Individual cell temperatures. (On-line).
h. Individual cell electrolyte levels. (On-line).
i. Rectifier voltage and current. (On-line).
j. AC Ripple, manual measurement is acceptable.
k. Rectifier temperature. (On-line).
l. Mass flow after storage. (On-line).
m. Compressor running hours, indication.
n. Compressor motor currents, indication.

3.18 CORROSION PROTECTION

a. All piping and steelwork, manufactured from low-carbon or mild-steel, including the pressure vessels shall be coated to prevent corrosion and comply with the requirements of:
   - Standard for the Identification of the Contents of Pipelines and Vessels [20],
   - Standard for the Internal Corrosion Protection of Water Systems, Chemical Tanks and Vessels and Associated Piping with Linings [21].
   - Standard for the External Corrosion Protection of Plant, Equipment and Associated Piping with Coatings [11]

b. As available coatings change with time, outdated specifications shall not be used.

3.19 MAINTAINABILITY

Access to all parts of the plant for normal operating and maintenance requirements without removing panels.

3.20 MATERIALS FOR HYDROGEN SERVICE

The appropriate data must be available for the selection of a material for particular use, see Annexure A for material selection. The following must be considered when selecting suitable material for Hydrogen applications:

a. Properties suitable for design and operating conditions;
b. Compatibility with the operating environment;
c. Availability of selected material and appropriate test data for it;
d. Corrosion resistance;
e. Ease of fabrication, assembly and inspection;
f. Consequences of a material failure;
g. Toxicity;
h. Hydrogen embrittlement;
i. Potential for exposure to high temperature from a Hydrogen fire;
j. Thermal contraction.

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5. REVISIONS

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Hydrogen Forum/Care group

APPENDIX A: MATERIAL DATA SPECIFICATION

A.1 MATERIAL SELECTION CRITERIA

Hydrogen components and Hydrogen systems commonly involve a wide variety of material, both metals and non-metals (such as polymers). Each material that is involved (for example, seats, seals, adhesives, lubricants, electrical insulation, springs, bolts and piping) should be carefully evaluated for its use in the design, operating, and emergency conditions to which it will be exposed.

The selection of a material that is suitable for use in a Hydrogen system involves several factors. Some considerations involved in the choice of a material to be used in a Hydrogen system include the following:

a. Compatibility with Hydrogen (with concerns such as Hydrogen embrittlement, Hydrogen attack, hydriding, porosity, permeation and diffusion);
b. Compatibility with adjoining materials (matching properties under changes in temperature and pressure, for example, and the effect of such changes on the material's shape and dimensions);
c. Compatibility with the conditions of use (effects of temperature and pressure, for example, on ductility, and expansion/contraction; property changes associated with changes in operating conditions);
d. Compatibility with the surrounding environment or exposure (for example, a corrosive environment or high temperature from a Hydrogen fire or fire from nearby materials);
e. Toxicity (the use of a material that is toxic in any way, such as during fabrication, should be considered only when absolutely necessary);
f. Failure mode (for example, brittle rapid rupture versus ductile slow separation);
g. Ability to fabricate into the desired form (for example, machining, welding and bending);
h. Economics;
i. Availability

Most of these considerations are common for the selection of a material for any purpose. However, the first one is unique to Hydrogen, and the next two are important for liquid Hydrogen applications, because of the low temperature involved (20 K). A brief discussion of these first three considerations is given below.

A.2 HYDROGEN EMBRITTLEMENT

Hydrogen embrittlement is a serious concern for metals exposed to Hydrogen. Hydrogen embrittlement can cause a significant deterioration in the mechanical properties of metals. Hydrogen embrittlement involves a large number of variables such as the temperature and pressure of the environment; the purity, concentration and exposure time of the Hydrogen; and the stress state, physical and mechanical properties, microstructure, surface conditions, and the nature of any crack front in the material. The susceptibility to Hydrogen embrittlement of some commonly used metals is summarized in Table A.1.

Table 1: Hydrogen embrittlement susceptibility of some commonly used metals

Metal	Extremely embrittled	Severely embrittled	Slightly embrittled	Negligibly embrittled
Aluminum alloys				
1100				X
6061-T6				X
7075-T73				X
Be-Cu alloy 25			X	
Copper, OFHC				X
Nickel 270		X		
Steel				
Alloy steel, 4140	X			
Carbon steel				
1020		X		
1042 (normalized)		X		
1042 (quenched & tempered)	X			
MaragIng steel, 18Ni-250	X			
Stainless steel				
A286				X
17-7PH	X			
304 ELC			X	
305			X	
310				X
316				X
410	X			
440C	X			
Inconel 718	X			
Titanium and titanium alloys				
Titanium			X	
Ti-5AI-2.5SN (ELI)		X		
Ti-6AI-4V (annealed)		X		
Ti-6AI-4V (STA)		X		

A.2.1 Low Temperature Effects

A.2.1.1 General

The selection of a structural material for use in liquid Hydrogen service is based primarily on the mechanical properties of the material, such as yield and tensile strengths, ductility, impact strength and notch insensitivity. The material should have certain minimum values for these properties over the entire temperature range of operation, with appropriate consideration for emergency conditions such as a Hydrogen fire. The material should be metallurgically stable, so that phase changes in the crystalline structure do not occur with time or repeated thermal cycling. The choice of a material for use at liquid Hydrogen temperature of 20 K involves material behaviour considerations such as the following:

a. Transition from ductile to brittle behaviour as a function of temperature;
b. Modes of plastic deformation, particularly certain unconventional modes encountered at very low temperatures;
c. Effects of metallurgical instability and phase transformations in the crystalline structure on mechanical and elastic properties.

Two of the primary considerations in the selection of a material for liquid Hydrogen service are low temperature ductility (low-temperature embrittlement) and thermal contraction.

A.2.2 Low-Temperature Embrittlement

Many materials change from ductile to brittle behaviour as their temperature is lowered. This change in behaviour can occur at temperatures much higher than cryogenic temperatures.

The results of the Charpy impact test as a function of temperature can be used as an indication of the ductile-to-brittle transition behaviour of a material. Another indication of the ductile-to-brittle behaviour of a material can be obtained by the relationship of the yield and tensile strengths of a material as a function of temperature. If the yield strength of a material approaches the tensile strength of the material as the temperature decreases, then the material will become increasingly brittle.

Generally, a material that has a ductile-to-brittle transition temperature above 20 K should not be used with liquid Hydrogen, unless its use is given careful consideration and thorough analysis. Most polymers become brittle at temperatures much higher than liquid Hydrogen temperature, and consequently, their use in liquid Hydrogen systems is generally avoided.

A.2.3 Thermal contraction

Materials generally have a positive expansion coefficient, that is, the material will expand as its temperature rises (however there are a few exceptions to this). The temperature span from ambient to liquid Hydrogen temperature is about 280 K. Such a large temperature decrease can result in significant thermal contraction in most materials. It is necessary to account for this contraction in the use of a material at liquid Hydrogen temperature. The thermal expansion coefficient itself is a function of temperature.

Typical values for thermal contraction for a temperature change from an ambient to a cryogenic temperature are as follows:

a. About 0,3 % in iron-based alloys;
b. Slightly over 0,4 % in aluminium;

c. Well over 1 % in many plastics.

The use of a plastics material between two metal surfaces (for example, seals) would have to accommodate the approximately 0, 6 % more contraction that the plastic would experience compared to the metal.

A.2.4 Material Suitability for Hydrogen Service

A material should be evaluated carefully before it is used for Hydrogen service. A material should not be used for Hydrogen service unless data are available to show that the material is suitable for the intended service conditions. Materials that have been used successfully with Hydrogen should be preferred over materials with little or no history of use with Hydrogen. The suitability of some commonly used materials for use with Hydrogen is shown in Table A.2, which is provided as a guideline and for informative purposes only.

Table 2: Suitability of some selected materials for Hydrogen service

Material	Gaseous Hydrogen (GH_2) service	Liquid Hydrogen (LH_2) service	Remarks
METALS			
Aluminium and its alloys	S	S	Negligibly susceptible to Hydrogen embrittlement.
Copper and its alloys (such as brass, bronze and copper-nickel)	S	S	Negligibly susceptible to Hydrogen embrittlement.
Iron, cast, grey, ductile	NS	NS	Not permitted by relevant codes and standards.
Nickel and its alloys (such as Inconel and Monel)	E	E	Evaluation needed. Susceptible to Hydrogen embrittlement.
Steel. austenitic stainless with > 7 % nickel (such as 304, 3041_ 308, 316, 321, 347)	S	S stressed above yield	May make martensitic conversion if temperature.
Steel, carbon (such as 1020 and 1042)	E	NS	Evaluation needed. Susceptible to Hydrogen embrittlement. Too brittle for cryogenic service.
Steel, low alloy (such as 4140)	E	NS	Evaluation needed. Susceptible to Hydrogen embrittlement. Too brittle for cryogenic service.
Steel. martensitic stainless (such as 410 and440C)	E	E	Evaluation needed. Susceptible to Hydrogen embrittlement.
Steel, nickel (such as 2,25; 3,5: 5 and 9 % Ni)	E	NS	Ductility lost at liquid Hydrogen temperature
Titanium and its alloys	E	E	Evaluation needed. Susceptible to Hydrogen embrittlement.

Table 3: (Continued): Suitability of some selected materials for Hydrogen service

NONMETALS			
Asbestos impregnated with Teflon a	S	S	Avoid use because of carcinogenic hazard.
Chloroprene rubber (Neoprene a)	S	NS	Too brittle for cryogenic service.
Polyester fibre (Dacron)	S	NS	Too brittle for cryogenic service.
Fluorocarbon rubber (Viton a)	E	NS	Too brittle for cryogenic service.
Polyester film (Mylar) a	S	NS	Too brittle for cryogenic service.
Nitrile (Buna-N a)	S	NS	Too brittle for cryogenic service.
Polyamides (nylon)	S	NS	Too brittle for cryogenic service.
Polychlorotrifluoroethylene (Kel-F a)	S	S	
Polytetrafluoroethylene (Teflon a)	S	S	

NOTE 1 S: Suitable for use.
NOTE 2 NS: Not suitable for use.
NOTE 3 E: Evaluation needed to determine if the material is suitable for the use conditions.

A Teflon, Neoprene, Dacron, Mylar, Viton, Buna-N and Kel-F are examples of suitable products available commercially. This information is given for the convenience of users of this Technical Report and does not constitute an endorsement by ISO of these product(s).

APPENDIX B: HYDROGEN PRODUCTION PLANT FACTORY ACCEPTANCE TESTING GUIDELINE

Factory acceptance testing must be done on all Hydrogen plants unless it is a plant and design that was previously witnessed and approved by GTD.

As a minimum the following must be checked and verified during factory acceptance testing from an Eskom perspective:

a. Factory acceptance testing must be done on all Hydrogen plants unless it is a plant and design that was previously witnessed and approved by GTD.
b. As a minimum the following must be checked and verified during factory acceptance testing from an Eskom perspective:
c. The Hydrogen plant must be in a basic operating state without external devices connected to the control system. If the control system is password protected the unit must be in the lowest level status.
d. The Hydrogen purity and Oxygen content must be monitored on the Hydrogen production stream. The Hydrogen content of the Oxygen gas stream must also be monitored. The analysers for conducting this test must be able to measure PPM.
e. The unit must be cycled through varying the pressure and creating a maximum delta pressure across the Hydrogen and the Oxygen within the cell stack and the current through the cell stack must be taken from minimum to maximum and vice versa. At all times the gas contamination must be maintained below 4%. For the execution of this test the gas analysing tripping values must be altered.
f. During operation the power supply from all the safety devices individually must be removed and the unit should revert to the safest state.
g. The design must be approved and accepted by Eskom prior to FAT.
h. All safety trips must be tested.
i. All safety devices must be calibrated prior to FAT and witnessed by Eskom.
j. The unit must be fully assembled and fully compliant to the requirements of this standard.
k. A leakage test must be conducted prior to FAT with the unit being pressurised to operating pressure all outlets isolated and zero percent leakage over a 24hour cycle. Temperature compensation must be done.
l. The Hydrogen production plant must run continuously uninterrupted for 7 days at full capacity without tripping. The average production must be more than the specified output.
m. All inputs and outputs to and from the control system must be checked and verified.
n. All final drawings, set points and operating instruction documentation must be available.
o. Detailed control and safe plant operating philosophy must be submitted prior to FAT.
p. The source code of all programmable logic controllers will be made available to Eskom prior to FAT with no limitation on access.
q. The source code will be reloaded from the copy supplied to Eskom prior to FAT.
r. For the warrantee period no alterations to the source code will be done without the consent of the OEM.
s. At minimum product rate maximum pressure after the Hydrogen in Oxygen and Oxygen in Hydrogen directly after the cell stack has stabilized, the Hydrogen vent valve and alternately the Oxygen vent file will be forced open. The system needs to trip and maintain the contamination levels within the levels stipulated in ISO 22734 [2], Hydrogen generators using water electrolysis – Industrial, commercial and residential applications.