IMPLEMENTATION OF PEM HYDROGEN GENERATION INTO AN EXISTING UPPER AIR NETWORK

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ABSTRACT

Environment Canada currently uses helium gas to launch balloons at 17 of 31 upper air network sites. The remaining stations use hydrogen gas, generated by an aging alkaline electrolysis system. The rising acquisition and delivery costs of helium gas combined with concerns regarding the reliability of existing hydrogen generation have initiated a project to update Upper Air Network sites with modern hydrogen generators using Proton Exchange Membrane (PEM) technology. The contrasting requirements between the alkaline system and a PEM system present several challenges. Additionally, hydrogen safety standards developed since the original implementation of the alkaline system over 30 years prior require thorough review. This paper illustrates the challenges faced in the process of designing and implementing a modern hydrogen gas generation system that effectively combines safety and reliability into a cost effective solution.

1.0 INTRODUCTION

Environment Canada has recently committed to updating the existing Upper Air Network with modern hydrogen generation equipment - replacing aging alkaline hydrogen generation equipment and costly helium storage and delivery programs.

The replacement generator, provided by Proton Energy Systems (Model HOGEN S40), uses a proton exchange membrane (PEM) cell to produce hydrogen from purified water and electricity. Unlike the network`s existing alkaline units, this modern generator operates autonomously without chemicals and offers advanced features for safety and monitoring system integration. These additional features combined with dissimilar operating requirements make the installation of these generators into the network more complex than simply physically replacing the current generators.

The following paper will explain these complexities beginning by briefly reviewing the hazards associated with hydrogen and the operation/requirements of the HOGEN S40 generator. It will also describe the challenges encountered when developing a specification to implement the HOGEN and discuss the operation of the safety systems used to protect the operator and facility from the inherent dangers associated with gaseous hydrogen.

2.0 HYDROGEN HAZARDS

Despite being 75% of the universe's elemental mass, hydrogen gas is not a commonly found in everyday life in a concentrated form. It is well known for its flammability and low density, the latter making it ideal for filling buoyant vessels such as weather balloons (H_2 is 8% more buoyant than He).

The hazards associated with hydrogen extend beyond its high flammability. Hydrogen burns extremely fast, with a laminar burning velocity 9 times that of gasoline; it is combustible over a very wide range of mixtures in air (4% to 75% by volume); and can be ignited with very little energy - less than you would feel in a static shock. The gas is colourless and odourless making it difficult to detect, and it burns with a nearly invisible flame.

Hydrogen also presents challenges due to its small molecular size. Hydrogen embrittlement is a mechanism where metals exposed to hydrogen can lose ductility due to permeation of hydrogen molecules into their crystal lattice structure; leading to premature failure. Hydrogen's small molecular size also makes it difficult to contain since it is able to escape through passages that larger molecules would not. These are important characteristics to note when selecting components and materials to be used in hydrogen systems.

3.0 THE HOGEN GENERATOR

The HOGEN S40 is a `site ready` enclosed unit that is roughly the size of a household clothes washing appliance (figure 3.1). The unit produces 99.9995% purity H_2 at 13.8bar (200psi) without mechanical compression at a rate of 1.05SCM/hr. To accomplish this, the unit must consume ASTM Type2+ (10MΩ resistivity) quality water at a rate of 1.0L/hr. The water quality represents the first challenge faced when updating to a PEM generator from an alkaline unit. In contrast, the outgoing alkaline generator required water purity of Type4 (0.2MΩ). This increased quality requires a reagent grade water purification system to supply the HOGEN generator. Operating a PEM cell with insufficient water quality will drastically reduce the lifespan of the cell due to damage incurred at the membrane from impurities.

Figure 3.1: The HOGEN S40 Hydrogen Generator

Additionally, the outgoing alkaline generator produced lower purity H_2 at ambient pressure, requiring mechanical compression to increase pressure to the storage and dispensing level of 6.9bar (100psi). The low storage pressure, combined with high moisture content in the H_2 gas, required a large pressure vessel to be located in a non-freezing indoor space, beside the alkaline generator. In contrast, the higher pressure and purity (-65°C dew point) produced by the HOGEN generator allows for a much smaller pressure vessel to be located in a freezing

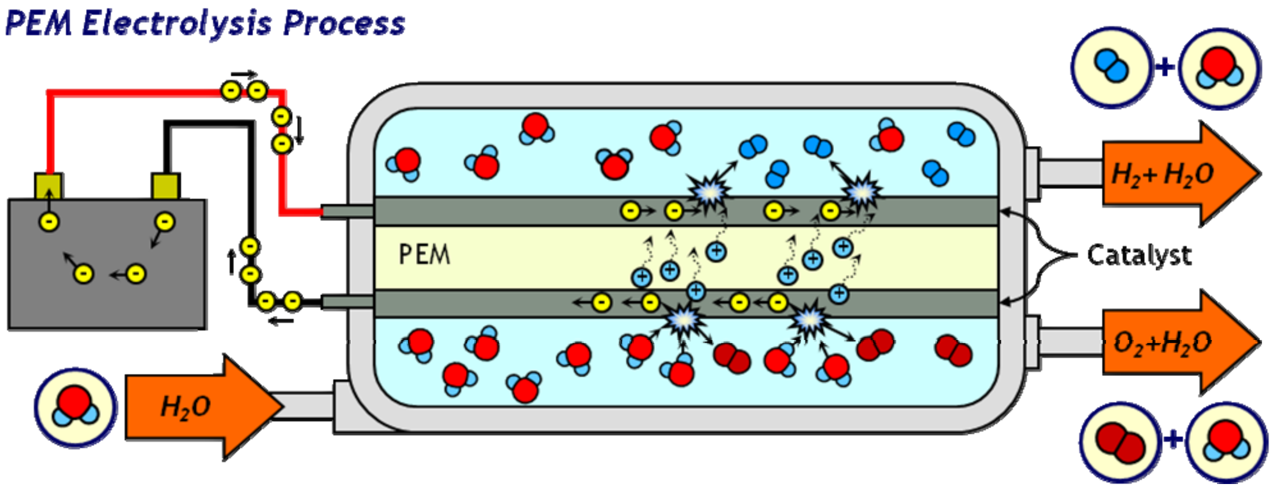

Figure 3.2: The PEM Electrolysis Process

environment away from the generator and associated control systems.

The basic operating principle of the HOGEN generator is essentially a hydrogen fuel cell process in reverse. The PEM cell unit, located centrally in the generator, introduces purified reagent grade water to a catalytic surface which splits H_2O into H^+ protons and O_2. The H^+ is driven through the membrane by electrical current where it combines with electrons on the other side producing H_2 at pressure. It is important to note that both sides of the PEM cell are 'wet', one side containing water saturated with oxygen, the other water saturated with hydrogen (Figure 3.2).

These saturated solutions are separated within the generator and the hydrogen product is sent through a dryer process bringing the purity to 99.9995%. This dryer process creates a 'wet' hydrogen by-product at a rate of 10% of the hydrogen gas generation. The by-product must be safely vented outside the building. Care must be taken if venting to a freezing temperature since the high moisture content can create a frozen ice plug that blocks by-product ventilation.

Oxygen is another by-product of the hydrogen production, produced at 50% the rate of product hydrogen. Due to the difference in pressures within the electrolysis cell, a breach in the proton exchange membrane pushes hydrogen saturated water into the oxygen side of the cell. For this reason, the generator uses a combustible gas sensor to detect hydrogen in the oxygen by-product and will halt production if a hazardous condition exists. Oxygen is typically vented immediately outside the generator since it does not present a hazard nor does it reduce the lower flammability threshold of hydrogen.

It is also worth noting the heat by-product of the generation process. As with a hydrogen fuel cell, the electrolysis process is not 100% efficient. The HOGEN generator produces up to 4200W of heat while generating which requires consideration when planning room temperature controls for the area in which the generator is placed.

One of the greatest advantages of a modern hydrogen generator is the ability to integrate with more comprehensive safety systems. The HOGEN unit offers relay controlled outputs for remote alarms indicating detected faults in the generator as well as relay controlling inputs capable of halting production and powering down the generator remotely via an emergency stop switch, or an output from a monitoring system. Since the HOGEN generator is controlled by a processor, remote telemetry is possible through an internet connection allowing service and maintenance activities to be planned more effectively - especially for remote sites.

4.0 SPECIFICATION DEVELOPMENT

Development of a comprehensive specification document to retrofit the new HOGEN generators into existing Upper Air Network sites began with a thorough analysis of the current applicable codes and standards related to hydrogen systems and explosive atmospheres.

The codes and standards researched involved two main categories; codes regarding area classification, containment, and approved equipment for explosive atmospheres; and standards regarding the generation, transmitting, storage, and dispensing of gaseous hydrogen. The latter often covers aspects of the former and was therefore the logical place to start.

4.1 HYDROGEN CODES AND STANDARDS

Much of the useful information found regarding the criteria that should be given consideration when designing a hydrogen system came from "Basic considerations for the safety of hydrogen systems – ISO 15916". This document provides an excellent consolidation of the information that is scattered throughout many of the other standards available. It is also written with the objective of simplifying the arduous process of regulatory compliance and is specific to hydrogen. Another helpful document examined was the NASA standard "Safety Standard for Hydrogen and Hydrogen Systems – NSS 1740.16" which discussed in more detail the many safety considerations, the types of components/materials recommended, and information on procedures/best practices when working with hydrogen - both in the gaseous liquid forms.

It is important to note that when reviewing standards and codes, their scope should be considered. As the hydrogen alternative energy industry grows, codes and standards shift towards controlling hazards inherit with commercial quantities. For example the "Canadian Hydrogen Installation Code – CAN/BNQ 1784-000" was created to remove the barriers slowing the development of hydrogen technologies and allow for the development of a hydrogen economy. The code is focused on the commercial storage and dispensing of hydrogen, and as such, references quantities at magnitudes greater than what would be used in a meteorological balloon site. Many of the National Fire Protection Agency (NFPA) codes make early reference to threshold quantities of stored hydrogen below which the regulations do not apply.

These threshold quantities, often referred to as the Maximum Allowed Quantity (MAQ) were used to determine the hydrogen storage vessel volume in the specification (750L). This represents enough hydrogen to launch 5 balloons, doubling the network standard of 2.5 balloons reserve lift gas. This is not to say that reviewing the standards that apply to commercial quantities of hydrogen did not provide valuable information and design elements which were relevant to the meteorological application. However, as the duty of navigating the complexities of regulations can be quite tedious, distinguishing features that *must* be applied from those that *can* be applied did save considerable time in specification development.

The second category of applicable regulations examined dealt with the subject of area classification and explosion rated equipment. Several codes exist, the most prevalent ones being the international code IEC-60079, the European code EN-60079, and the National Electrical Code (chapter 5). The Canadian Electrical Code (chapter 18) was used as the authority for sites in the Environment Canada network. Each code was found to vary slightly; however there appeared to be consensus on how to classify atmospheres and what design aspects and equipment are allowed in a classified atmosphere.

4.2 AREA CLASSIFICATION

Establishing area classification was the first step to applying the regulations and selecting powered equipment.

The first layer of the area classification process involved the material state of the combustible fuel. An area that contains a combustible gas or liquid becomes a Class I atmosphere. Three atmosphere classes exist; Class 2 –dusts, and Class 3 –fibres and fillings.

The next layer involved the more subjective process of establishing the probability that an explosive atmosphere may exist. In the zone system, three zones exist:

- **Zone 0** is an atmosphere where an explosive mixture is continuously present, or present for long periods of time.
- **Zone 1** is an atmosphere where an explosive mixture is likely to occur in normal operation.
- **Zone 2** is an atmosphere where an explosive mixture is not likely to occur and if it occurs will exist for a short period of time.

In contrast, the two level division system combines Zone 0 and Zone 1 into a single area referred to as Division 1. Division 2 is equivalent to Zone 2.

The final layer of the area classification process involved specifying the exact combustible material involved by selecting the appropriate group. These groups are created based on the combustion properties such as pressure, temperature, and ignition energy. Hydrogen is classified as a Group B gas by the North American codes, and as a IIC Group by the European and I.E.C. codes. It is second in hazard level only to Acetylene in the North American codes. In the European and I.E.C. codes Hydrogen and Acetylene occupy the same group.

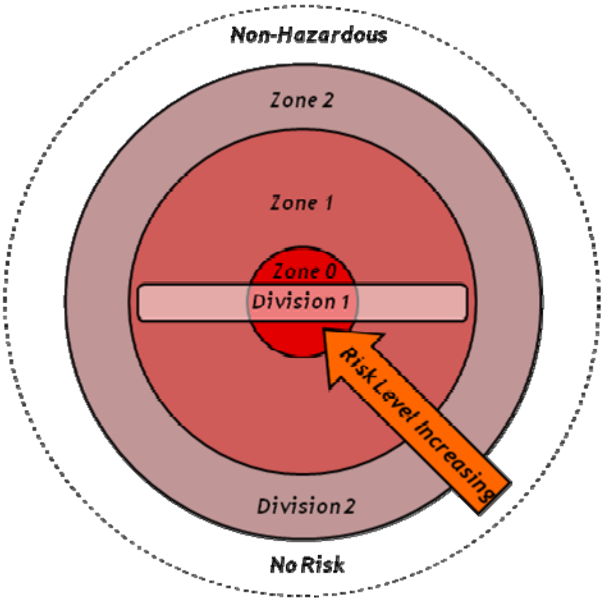

Figure 4.1: Zone and Division Levels

To summarise, the only decision process required in a meteorological application using hydrogen was to establish the applicable zone or division. Hydrogen is by default Class 1, and Group B (IIC). In determining the zone several resources were consulted. The NFPA 497 code dealt specifically with examples of common occurrences where classification is not straight forward. Further research indentified accepted techniques used to 'de-classify' a zone using a purge and pressurize system as described in NFPA 496.

It was noted that the zone assessment process required the evaluation of the probability of an explosive atmosphere existing, and by definition an explosive atmosphere first requires a combustible mixture to be achieved. For example, a very small hydrogen leak will introduce hydrogen to an oxygen rich environment, but will take time to achieve a 4%

by volume mixture with air (the lower flammable limit of hydrogen). If sufficient ventilation is present, it may be impossible to reach an explosive atmosphere. Additionally; if hydrogen detection is employed, a system response such as additional ventilation or the emergency stoppage of the generator can prevent an explosive atmosphere from ever existing.

The HOGEN generator is a good example of this methodology. The unit itself generates and contains pressurized hydrogen, and although under normal conditions it does not leak hydrogen, it does fall into the Zone 2 classification since under abnormal circumstances it is capable of leaking hydrogen. However, the HOGEN unit is not a classified area and is not certified to be installed in an explosive atmosphere. This is achieved by a purge and pressurizes process, whereby the unit pumps air through the cabinet at a rate one thousand times greater than the maximum production rate of hydrogen. The ventilation is interlocked to hydrogen production by a cabinet pressure switch, where if ventilation were to fail hydrogen production would halt. By this method, an explosive atmosphere is not possible and therefore the cabinet is 'de-classified'.

4.3 OPERATIONAL REQUIREMENTS

In developing the implementation specification, a careful examination of the operational requirements of the network sites was completed. This began with several site visits to understand the current operational procedures and how they might be impacted by the introduction of the new generator. It was observed that several areas offered opportunities for improvement to safety. These opportunities were made possible by the additional functionality of the new generator's integration capability. Additional issues were identified that can be attributed to the era from which these original systems were installed over thirty years ago. Many of the design aspects identified in the codes and standards reviewed were applied to provide additional fail-safes in abnormal operating conditions.

4.4 PAST PROBLEM HISTORY

As with any complex project, moving forward without first taking the opportunity to learn from the past can be a critical error. The existing Upper Air Network has been in operation for decades and provides a wealth of knowledge and experience when examined carefully. Records of incidents were reviewed as well as interviews conducted with experienced site operators. Several issues were identified and reflected to the specification development.

Figure 4.2: The aftermath of a hydrogen incident in Baker Lake, Nunavut -1979. No injuries occurred however the building was destroyed.

Additional historical data was researched from outside the meteorological community. The ISO 15916 document included a summary of the common causal factors in hydrogen accidents. Similar information and studies have been performed and are available on the internet with careful searching. One website that was found to have a wealth of incident investigations was www.h2incidents.org.

In examining both internal and external problem history a clear trend was observed. In the majority of hydrogen accidents, human error was attributed as the predominant causal factor. This was followed by errors or omissions in operating procedures. It was noted that in developing the specification for a meteorological application, autonomous fail-safe systems and clear operating procedures must be a priority.

4.5 RESOURCE STATUS

One project objective in the implementation of the new generators was to reuse whatever existing equipment was feasible. A careful assessment of existing resources and their status was conducted. It was found that for the most part sites required no major overhauling activity to accept the new system. In most cases, the sites followed a standard configuration established in the past when the previous alkaline generators were installed. In the case of the alkaline system, the generator was not designed with the same high level of fail-safe as the HOGEN unit, and was therefore classified as a Zone 2 area. This required the generation room to be outfitted with explosion rated lights, heaters, switches, and for all wiring to be installed in sealed conduit tubing. These systems are still viable to be used with the new generator and system layout, since they offer a level of protection well above the minimum required for a non-explosive atmosphere.

Another resource that required careful examination was the site water quality. Because the new generator would require extensive water processing, a baseline needed to be established to ensure any processing equipment specified could handle the quality of incoming water and provide reasonable service intervals.

At many sites in the Canadian network, water must be delivered and stored on site since wells are not feasible in permafrost conditions. At other sites, well water is of questionable quality. For those reasons a survey was conducted to establish water quality and the filtration system was sized on those results.

Electrical power quality was also a concern due to the sensitive nature of the power supplies used in the HOGEN generator. Since many Upper Air Network sites are located in remote northern areas, power is often supplied by a diesel generator. A power line conditioning system was developed to ensure large voltage transients and low voltage situations would not damage the generator.

5.0 SYSTEM DESIGN

The design of the support systems that would be required to retrofit the new generator into existing sites began with a process map (Figure 5.1) and comprehensive schedule.

The design focus was shared between system safety and system reliability, identified as project ‘viewpoints’ from the research performed in the body of knowledge processes discussed above.

A concept configuration was drafted to provide a starting point for iterative analysis with respect to the project viewpoints.

Viewpoints were then subjected to a rigorous Fault Tree Analysis (FTA) process where each potential failure mode of the concept design was broken down to singular causal factors. These factors were then paired with designed systems and fail-safes to ensure that system safety and reliability were maintained. It was necessary to carefully balance the safety and reliability viewpoints, since an extensive and complex safety system may compromise reliability, and vice versa, a robust and reliable system may not have the necessary fail-safes in place to ensure safety.

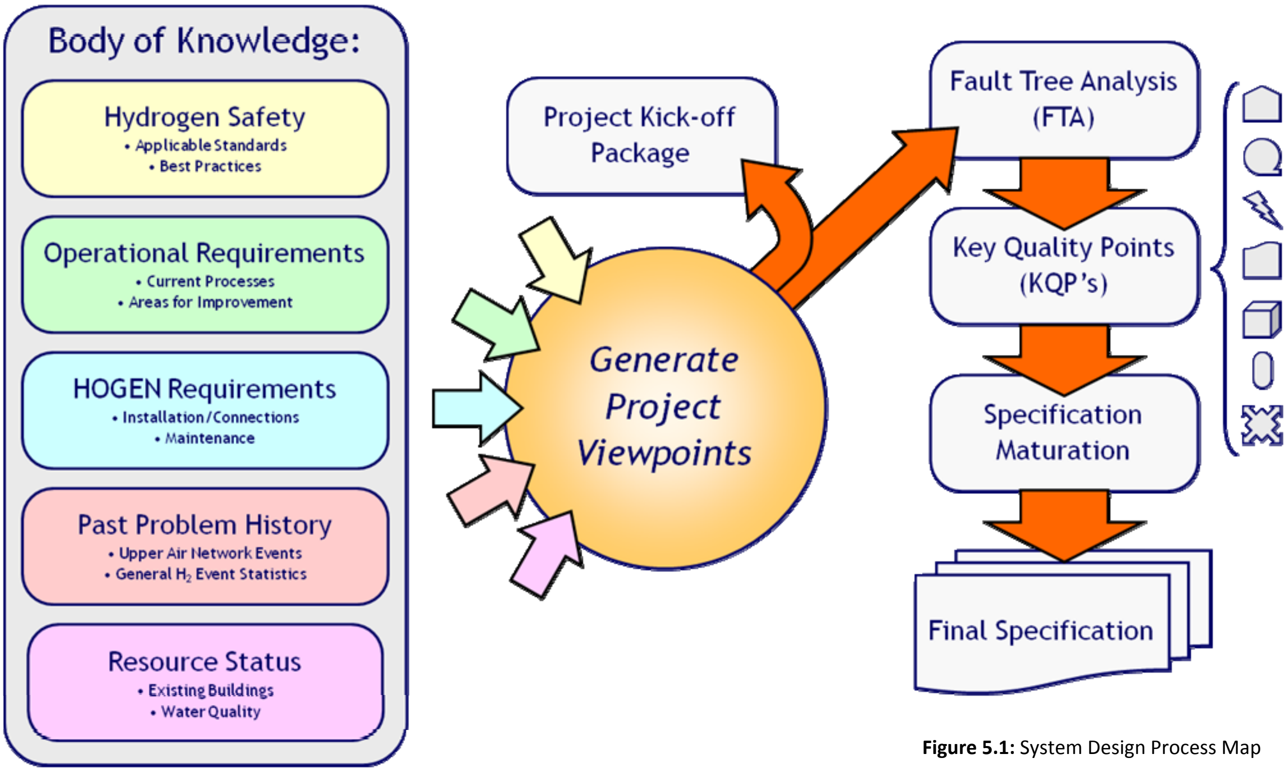

Figure 5.1: System Design Process Map

Each designed system characteristic and failsafe was then made into a Key Quality Point (KQP) where it was grouped by system (ex: ventilation system, safety system, hydrogen plumbing system... etc). From there the KQP's were matured by examining their compatibility, availability, cost, and ultimately feasibility of incorporating them in the system design specification. The following sections briefly describe the key characteristics of each system prefaced by an explanation of the area classification assessment results that provided the foundation of the specification.

5.1 Area Classification Result

The existing inflation building structures located on Upper Air Network sites include two rooms in the standard configuration layout. One room is used to fill the balloon. It includes a fill table and two large roll up doors. It is unheated and uses passive ventilation by means of vents in the lower wall and a peaked roof with vents at the apex. The other room, adjacent to the inflation room, houses the generator and storage tank along with a dispensing valve to fill the balloon. With the alkaline generator system installed, the inflation room was classified as Zone 1 and the generation room was Zone 2. There was a doorway between the two rooms used to enter the inflation room from the generation room once the balloon was filled and ready for attachment of the radiosonde.

In consideration of the requirements of the new generator, the area classification was revised to maintain the Zone 1 classification for the inflation room, but making the generation room a non-explosive atmosphere (unclassified). This was necessary simply because the HOGEN generator was not approved for installation in an explosive atmosphere. The reclassification required the elimination of the doorway between the two rooms. By the area classification code, an area adjacent to a Zone 1 area that is connected by a doorway or passage is by default a Zone 2 area.

The storage tank was also moved from the generation room to the inflation room where it posed a lower risk and allowed the generation room to remain unclassified. This was not possible with the alkaline generation system because the tank required a positive temperature environment.

5.2 Heating and Ventilation

The HOGEN generator requires a minimum room ventilation rate of one hundred times the production rate of hydrogen. Because the HOGEN generator itself uses a purge technique to eliminate the risk of an explosive atmosphere accumulating, the same technique must be applied to the room where it is installed. Failure to do so would only transfer hydrogen from inside the HOGEN cabinet to the room where it could concentrate to the lower flammability limit of 4% by volume.

One challenge identified early in the project was the impact that a high rate of air exchange with the outdoor environment would have on energy consumption, especially in northern climates. The heat output of the generator during generation process somewhat offsets this loss, however ventilation was required during times when generation was not occurring due to the presence of a small amount of hydrogen in the generator and lines exiting the machine.

A Heat Recovery Vent (HRV) unit was specified to provide the necessary efficiency in heating the generation room, however the large potential temperature differential between outdoor and indoor air required special consideration to be given to the frost build up that would occur in the heat exchanger. Most HRV's operate on a timed cycle of ventilation and recirculation to address this frosting issue and can therefore not provide continuous ventilation with outside air. A tandem interlocked pairing of HRV's provided the necessary solution allowing one HRV to defrost while the other maintained the necessary air exchange rate. A flow switch was also specified to interlock the air circulation with hydrogen production, much like the logic employed in the HOGEN generator.

5.3 Water Purification

Proton Energy Systems recommended a water purification unit to accompany the HOGEN generator (Figure 5.2). The water purifier, supplied by AquaSolutions, uses a Reverse Osmosis (RO) and Deionization (DI) process to filter tap water to the necessary level of purity for the PEM cell to operate without risk of damage. Due to the remote location of many of the network's sites, water storage was also necessary. Storage volume specified was based on the water quality survey results and ranged from 1000-2500L, using an agricultural style plastic tank. The tank was placed in the generation room near the HOGEN generator. By placing the tank close to the generator, it also functioned as a thermal mass in the event room heating were to fail. The thermal inertia of a large volume of water provided a small but valuable margin of freezing protection for the costly PEM cell.

Figure 5.2: The AuqaSolutions Water Purifier

The HOGEN generator consumes purified water at a rate of 1.0L/hr; however the water purifier rejects up to four times the water it sends to the generator (depending on the initial water quality), making the total maximum water consumption of the system 5L/hr. The water purifier also requires water to be supplied at pressure, so a pump and accumulator were included in the specification to ensure the necessary input pressure. A pre-filter was also used ahead of the water purifier to guarantee the minimum tap water quality (<1000TDS) was maintained.

The HOGEN generator itself includes an additional internal DI cartridge to 'polish' the incoming water from the water purification unit. The generator also monitors water resistivity and is able to reject water of insufficient quality.

One major source of poor water quality to note is contamination after the purification process. Type 2+ level reagent water is extremely pure, and is therefore very aggressive. It is starved of ions and will draw them from materials it comes in contact with - even absorbing CO_2 if exposed to air. Materials such as copper, PVC, stainless steel, and cast iron were specifically excluded in the specification as they can destroy the water quality and rapidly damage the PEM cell. Further precautions were necessary in the handling of components that would be in contact with the purified water during maintenance per Proton's recommendations.

5.4 HYDROGEN STORAGE AND PLUMBING

In researching acceptable materials for hydrogen service, 316 series stainless-steel (316SS) was the most frequently recommended. This was due to the material's resistance to hydrogen embrittlement, which was far superior to materials such as alloy steels like 4140 or 1042. The resistance is due to the face-centred-cubic (FCC) crystal structure of austenitic stainless-steels, which unlike alloy steels with a body-centred-cubic (BCC) crystal structure; do not allow disassociated hydrogen atoms to permeate as easily.

Additional consideration was necessary for the operating temperature the storage and plumbing components would be subjected to. Since the new generator provided ultra pure hydrogen virtually free from moisture, the tank was specified to be located in the unheated inflation room. A minimum performance temperature requirement of -50°C was specified. In many cases, special order valve seals using ethylene propylene seat material were required to perform at low temperatures.

The hydrogen storage tank was constructed from 316SS and designed for a maximum pressure of 20.7bar (300psi), 50% higher than the maximum output of the generator. Redundant pressure relief devices were specified as per recommendations in many of the standards reviewed. The secondary relief device incorporated a manual override which doubled as a manual purge valve.

One voluntary design aspect extracted from commercial applications was an emergency discharge device (EDD). This was not a regulatory requirement based on the quantity of hydrogen stored; however it did provide an additional layer of safety in the event of a fire where the tank contents could be remotely evacuated to the outdoors. This was accomplished by adding a solenoid valve in parallel with the primary and secondary safety relief valves.

To mitigate the risk of leakage, the dispensing circuit layout was changed from the standard configuration used with the alkaline generators. Previously, hydrogen was dispensed to the balloon table via a quarter turn ball valve located in the generation room, beside the doorway linking the inflation and generation rooms. This provided an opportunity for two main failure modes. First, the valve could fail and leak, allowing hydrogen to escape to the generation room. Second, the valve itself provided no 'dead-man' function. By replacing the valve with a remotely operated solenoid valve located in the inflation room with the tank, the risk to the generation room was eliminated. Additionally, the solenoid valve was remotely actuated from the generation room and a momentary switch was specified requiring the operator to continuously press the switch to maintain hydrogen flow. Another valuable function the remotely actuated valve allowed was the ability to use the safety system to disable dispensing automatically. Two solenoid valves were specified for redundancy with a flow switch used to detect valve failure to close. It is important to note that only normally closed valves were specified, a two position valve would not close in the event of power loss to the system.

Additional manual valves were specified at tank inputs and output to facilitate safe repair to the generation and dispensing circuits. These valves functioned to isolate these circuits in the event of a detected failure, or for necessary repair. No isolation valves were used on the primary safety relief circuits and EDD as this would bring the risk of the isolation valve accidentally being shut disabling the safety relief.

Check valves were used extensively as safety devices to control flow direction. The most critical check valve was installed in the storage tank inlet where hydrogen entered via the generator in the generation room. By installing a check valve, any leak that may occur in the generation room circuits would only spill the contents of those circuits, which was minimal, and what the generator was producing - at a very slow rate. Conversely, without the check valve, a leak in the generator room could drain the entire 750L tank into the room, rapidly achieving the lower flammability limit. Other check valves functioned to prevent the complete drainage of the storage tank. Check valves block flow in one direction, while allowing it in the other. A cracking pressure was specified for the allowed flow direction that essentially functioned as a low pressure switch whereby if the tank were to be drained below the cracking pressure of the check valve, flow would be stopped. It was important to ensure that the atmosphere inside the storage tank remained pure hydrogen. By draining the tank to empty, oxygen may be allowed to enter, creating a potentially combustible mixture at the upper flammability limit of 75% and requiring the tank to be purged.

The storage tank included both an analogue pressure gauge and a pressure transducer. The latter served as a remote pressure monitor so that no analogue gauge was required in the generation room. This followed the same logic as the solenoid operated dispensing valves. No hydrogen circuits would be allowed in the generation room that weren't absolutely necessary.

5.5 SAFETY SYSTEM

The safety system represents the highest work load of the specification planning since it lays the foundation for all the mechanical and electrical systems that must support it.

The primary objective in developing a safety system was to include both redundancy and autonomy to ensure the same level of safety regardless of operator experience level.

Specification design began with a hazard assessment based on the decided classification of each room. Items identified in FTA activity were incorporated into the system logic. Each room was to be outfitted with both hydrogen and flame detection units. Despite the generation room being unclassified, gas and fire detection was specified as an additional layer of safety and in most cases already existed due to their necessity with the alkaline generation system

The gas detector specified was an explosion rated device using a catalyst bead detection method calibrated for hydrogen gas (Figure 5.3). The unit provided both digital communication outputs and analogue relay outputs. Two detection levels were specified, one at 20% of the lower flammability limit (1% hydrogen in air overall), a second threshold at 40% of the lower flammability limit. The response for the first limit involved a warning in the form of an audible alarm and light and shut down of all non-essential powered systems. The second triggered an immediate shut down of all electrical systems that were not rated for an explosive atmosphere as well as additional alarms. Each gas detector was outfitted with a 'scoop' which was recommended by the manufacturer when trying to detect lighter than air gases. The scoop captured rapidly rising hydrogen to improve detector sensitivity and accuracy. Detectors were installed directly above the highest risk area with previsions for calibration –required every ninety days.

Figure 5.3: An Explosion Proof Combustible Gas Detector

The fire detection unit offered the same outputs and operated on a three spectrum (UV-Visible-IR) optical scanning principle. The unit required line-of-sight, making placement critical to realizing the full benefit. The visual detection method was chosen over the more common room temperature monitoring for its faster response and performance, especially in the inflation room which is unheated.

Both the gas and flame detection sensors included fault detection, alerting the safety system when they became disabled.

A central control unit was mounted in a partitioned area of the generation room to allow the detection circuits to maintain operation in the event gas or fire was detected in the generation room.

Additional sensors monitored gas flow in the dispensing circuit, air flow in the ventilation circuit, and temperature in the generation room. Due to the damage that would occur if the generator were exposed to freezing temperatures, an alarm was also specified to alert operators of a problem with the heating system.

The safety system was also tied to the HOGEN generator to allow the system to disable the generator in the event of a gas leak or fire, and to allow the HOGEN generator to alert the safety system of a internal fault.

Both the HOGEN generator and safety system were outfitted with provisions to be connected to a network allowing remote monitoring of all controlled parameters. This provided technicians with the opportunity to assess issues before traveling to remote sites making maintenance and repairs more timely and efficient.

Provisions were specified in the safety system for a backup analogue logic system in the event the more complex digital system was to become disabled. Relay outputs from the detectors were connected to contactors in the main building breaker panel to disable priority systems at the programmed set points. This was not the preferred mode of operation since it did not incorporate the remote network monitoring function, however in the interest of maintaining reliability in a network where a technician may be as many as three days away, a backup 'simple' system offered additional robustness at little cost.

5.6 ELECTRICAL SYSTEM

Many of the aspects of the electrical system specification were extracted directly from the Canadian Electrical Code. As with all codes examined that include provisions and equipment for explosive atmospheres, specific methods and materials are approved for the fabrication of electrical circuits.

Conduit was required for all electrical connections in the inflation room, and for the detection circuits in the generation room.

Circuits and equipment that were not rated for an explosive atmosphere were mounted close to the floor, to provide additional safety in case of a gas leak. Although they would be disabled in the event of gas detection, mounting low to the floor in an environment where the combustible gas is known to rise was considered good practice.

Explosion rated lighting and electric heaters were previously installed with the alkaline generation system and did not need replacement.

All metal surfaces in the building were bonded and confirmed using ground validation equipment. A grounded metal surface was also provided for the operator to ground themselves upon entering the building.

5.7 BUILDING PREPARATION

Many of the structures that are to be retrofit require some level of repair. Along with these repairs, additional insulation was specified to increase the thermal efficiency and work in conjunction with the HRV's to reduce overall operating costs of the site.

As mentioned, the doorway between the inflation and generation rooms was removed and replaced with a window to allow the operator to fill the balloon from the safety of the generation room. Operators would be required to exit the generation room to the outdoors and then re-enter the inflation room from outside.

No passages were allowed between the inflation and generation rooms. All hydrogen and electrical connections were sealed, along with the wall at the floor and ceiling. Latex paint was specified for generous application to the walls and ceiling of the generation room.

A passive ceiling vent was incorporated into the generation room at its highest point to allow hydrogen to escape in the unlikely event a leak occurs and the mixture reaches a flammable level shutting down the powered ventilation. The vent was minimally sized to prevent heat loss.

6.0 SUMMARY

Implementation of a PEM hydrogen generation system into an existing network of Upper Air sites requires a thorough understanding of the hazards involved in hydrogen systems. Many aspects of the specification developed for Environment Canada's project were extracted from the wealth of knowledge and experience that is available in the many codes and standards available for hydrogen and explosive atmospheres. Additional information on problem history and lessons learned was given by a careful review of both internal and external hydrogen accidents and near-misses.

In developing project viewpoints, used to focus development towards critical objectives, the risk of human error and incomplete procedures were identified as the greatest source of hazard. Multiple redundancy, safety system autonomy, and fail-safe devices are design features that are paramount in reducing these hazards, as well as teamwork between those providing training to operators and those who layout the system specification.

Component selection was made easier by first understanding the unique requirement of hydrogen systems and the mechanical failure modes these systems are susceptible to. More and more manufacturers are offering components that are designed for use with hydrogen as the world's hydrogen economy grows, making it easier to select the right materials for the operating conditions.

Ultimately, the task of developing a specification is heavily influenced by national codes which vary slightly in detail by region. A meteorological application is difficult to compare to a commercial or industrial hydrogen system, but a careful selection of system size and storage volume can separate a meteorological application from the regulations that were developed for large scale hydrogen systems.

Included with this paper is a system schematic representing the layout of the described hydrogen plumbing and storage system. Additional information is available on request.

REFERENCES:

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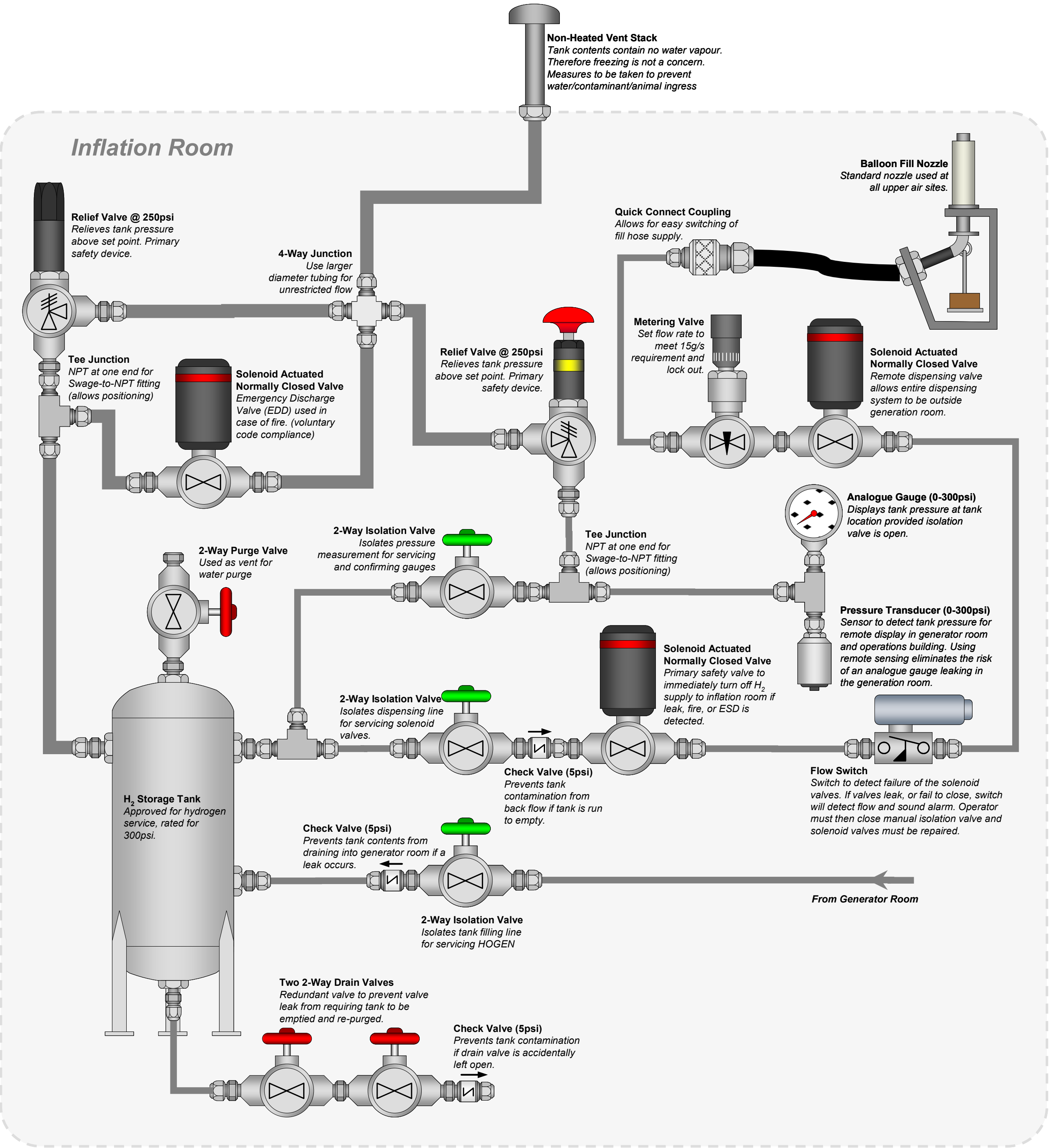
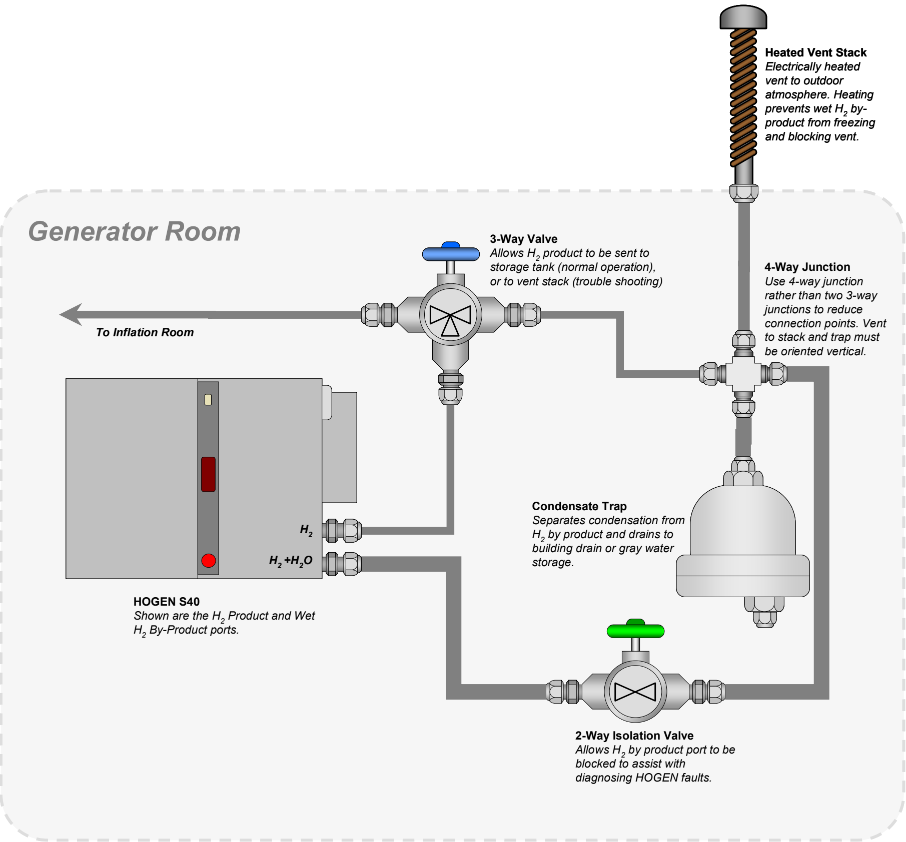


Figure 6.1: Illustrated Schematic of the Storage and Dispensing Circuits



Heated Vent Stack
Electrically heated vent to outdoor atmosphere. Heating prevents wet H_2 by-product from freezing and blocking vent.

3-Way Valve
Allows H_2 product to be sent to storage tank (normal operation), or to vent stack (trouble shooting).

4-Way Junction
Use 4-way junction rather than two 3-way junctions to reduce connection points. Vent to stack and trap must be oriented vertical.

Condensate Trap
Separates condensation from H_2 by product and drains to building drain or gray water storage.

HOGEN S40
Shown are the H_2 Product and Wet H_2 By-Product ports.

2-Way Isolation Valve
Allows H_2 by product port to be blocked to assist with diagnosing HOGEN faults.

Figure 6.2: Illustrated Schematic of Generation Circuit