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Piping material for hydrogen service

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With regard to piping material selection for gaseous hydrogen service there are two main considerations, aside from the basic criteria for determining ASME pressure classification and pipe material. Those two considerations are hydrogen attack and the high degree of concern with regard to leak potential.

Carbon steel is acceptable for use in hydrogen service when operating temperatures remain below 500°F. Hydrogen attack occurs when hydrogen is contained under high partial pressure in combination with high temperatures. When the partial pressure of hydrogen is expected to be approximately 200 PSI, at temperatures above approximately 500°F, carbon steel is not recommended.

As you can see by the modified Nelson diagram, Fig. 1, as taken in part from API 941, elevated temperatures have the greatest effect in contributing to hydrogen attack. In selecting carbon steel with operating temperatures below 500°F, the partial pressure of hydrogen can exceed 3000 PSI (not indicated on chart) with little concern for hydrogen attack.

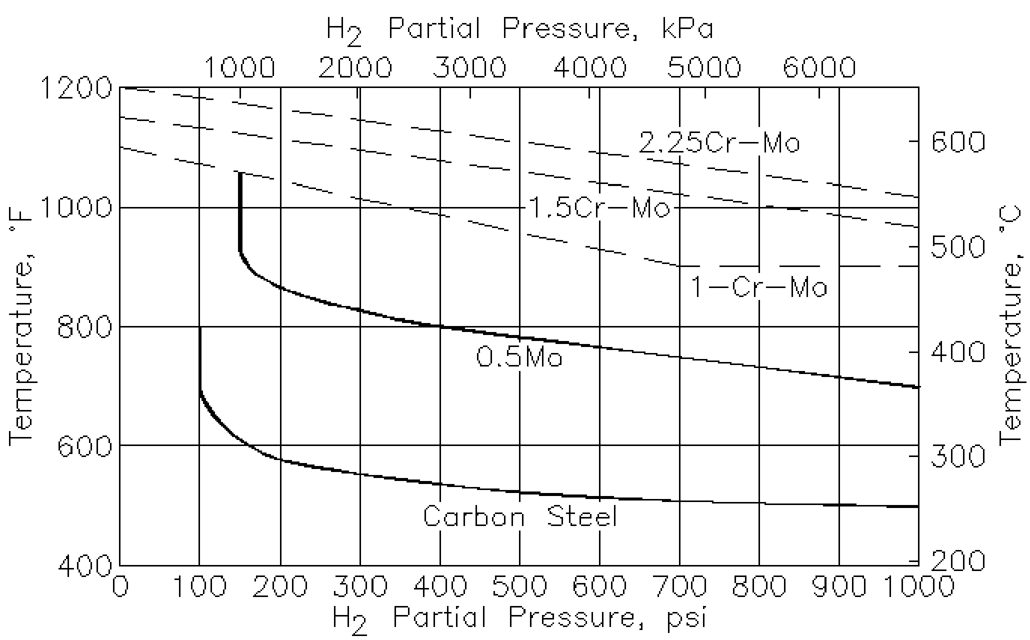

Fig. 1 Nelson diagram – API 941

This diagram indicates the choice of steel warranted to avoid hydrogen attack as a function of operating temperature and partial pressure of hydrogen. Austenitic materials are satisfactory at all temperatures and pressures from hydrogen damage.

Issues and Recommendations

When referring to leak points in a piping system we are referring to mechanical type joints such as a flange joint, threaded joint, valve body seal, and valve stem packing. Since hydrogen, with a molecular weight of 2, has such a high propensity to leak, with potentially devastating results, it is imperative that a piping system be designed to limit those leak points, and to provide a high degree of assurance for those possible leak points that cannot be avoided.

In an effort to limit potential leak points it is suggested that a piping system be entirely welded with the exception of flanged joints at equipment and/or valving. Threaded joints should typically be avoided with pipe to pipe joints buttwelded. Carbon steel should be post-weld heat treated. After welding, pipe within the heat-affected zone (HAZ) becomes susceptible to hydrogen attack, even at ambient temperatures. And while hydrogen attack mainly occurs at elevated temperatures this step will reduce, if not eliminate, that possibility entirely.

The weak point in an all welded system will be the flange joint. In order to provide a high degree of integrity at flanged joints a gasket that consists of a serrated solid metal ring sandwiched between a soft, deformable sealing material as shown in Fig. 2. The serrations concentrate bolt load on a smaller area to provide a tighter seal at lower stress. Its design allows the gasket to compensate for irregularities in the flange surfaces as well as fluctuations in service conditions.

Fig. 2 – Suggested Gasket Design

Another consideration in system integrity is the valving; Leaks around valve stem packing is a real concern. In an effort to prevent this, the selection of bellows seal valves and/or diaphragm valves is recommended.

System Pressure Rating

Using a 1" sch. 80 carbon steel pipe per ASTM A106 Gr B with a corrosion allowance of 0.050", the maximum allowable working pressure can be calculated for temperatures below 400°F using eq. 1:

Eq. 1: $$P_a = \frac{2St}{D_o - 2yt} \div 4$$

Where:

P_a = Maximum allowable internal pressure for straight pipe
S = Maximum allowable stress for the material at design temperature (psi)
D_o = Outside diameter of pipe (inches)
y = Coefficient. 0.4 for ferritic steel in temperatures below 900°F.
t = Specified wall thickness minus mechanical and corrosion allowance and manufacturing tolerance.
4 = Safety Factor

Therefore: $$P_a = \frac{2 \times 20{,}000 \times .107}{1.315 - (2 \times .4 \times .107)} = 3481 \text{ psig (burst pressure)} \div 4 = 870.25 \text{ psig MAWP}$$

For a 1" sch. 40 pipe, using the same criteria, the results would be:

$$P_a = \frac{2 \times 20{,}000 \times .066}{1.315 - (2 \times .4 \times .066)} = 2092 \text{ psig (burst pressure} \div 4 = 523 \text{ psig MAWP}$$

The 870.25 and 523 psig maximum allowable working pressure applies to the pipe only. The flange joints will be the governing factor in determining the allowable pressure for the system.

Based on ASME B16.5, at temperatures from -20°F to 100°F, the Class 150 carbon steel flange joint has a maximum allowable working pressure of 285 psig. Class 300 has a maximum allowable working pressure of 740 psig. This will be the limiting factor for the system as per the following specifications.

Basic Specification

A pipe spec for gaseous hydrogen service operating at ambient temperatures with design pressures below 740 psig might consist of the following material requirements:

Pipe		Sch 80, C.S., ASTM A106 Gr. B
Fittings		Sch. 80, B.W., C.S., ASTM A234 Gr. WPB, ASME B16.9
Flanges		R.F. Welding neck, C.S., ASTM A105, ASME B16.5, 150/300 Class
Bolts		Stud bolts, ASTM A193 Gr B7, with nuts, ASTM A194 Gr 2H
Gaskets		0.125" thk. 316 SS serrated solid metal core, with spiral wound flexible graphite both sides, and integral centering ring.
Valves:		
	Gate	B.W. or flanged, bellows seal gate valve, welded bonnet, stainless steel bellows, test port.
	Globe	B.W. or flanged, bellows seal globe valve, welded bonnet, stainless steel bellows, test port.
	Check	(Not recommended)

Examination, Installation and Testing

Examination should include 100% radiograph of all welds.

Installation should minimize or eliminate the use of breakout flanges. Flange joints should only exist at flanged equipment, including instruments, and flanged valves. Design requirements, both general and specific, and material information can be found in the following referenced Codes and Publications:

American Petroleum Institute		
	API 940	Steel Deterioration In Hydrogen
	API 941	Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and Petrochemical Plants
American Society of Testing and Materials		
	ASTM B-849	Standard Specification for Pre-Treatments of Iron or Steel for Reducing Risk of Hydrogen Embrittlement
	ASTM B-850	Standard Guide For Post-Coating Treatment Of Iron Or Steel For Reducing Risk Of Hydrogen Embrittlement
	ASTM F-1459	Test Method for Determination of the Susceptibility of Metallic Materials to Gaseous Hydrogen Embrittlement
	ASTM F-1624	Standard Test Method for Measurement of Hydrogen Embrittlement Threshold in Steel by the Incremental Step Loading Technique
	ASTM G-142	Standard Test Method for Determination of Susceptibility of Metals to Embrittlement in Hydrogen Containing Environments at High Pressure, High Temperature, or Both
	ASTM STP-962	Hydrogen Embrittlement: Prevention And Control
Code of Federal Regulations		
	Title 29, Chapter XVII, Part 1910.103	
Compressed Gas Association		
	Publication G-5	Hydrogen

Publication G-5.4	Standard for Piping at Consumer Locations
Publication G-5.5	Hydrogen Vent Systems
National Fire Protection Assoc.	
NFPA 50A	Gaseous Hydrogen Systems at Consumer Sites (Superceded ANSI Z292.2)

After installation a pneumatic pressure test at 110% of design pressure should be performed using helium as the test gas. With a mole weight of 4 it is as close to hydrogen replication as you can get with an inert gas.

Preparation for this test shall include temporary piping or hoses to allow pressure release and purge of helium to be vented to the outside. Each branch of the test circuit shall be purged with helium and valved off or blinded in preparation for testing. The pressure shall be gradually increased until a gauge pressure is reached which is the lesser of one-half the test pressure or 25 psig. At this time a preliminary check of all joints should be made. After the piping system is examined for the first time, the pressure is increased gradually, allowing any piping strains to equalize, until the test pressure is reached. The pressure is held momentarily to allow equalization of pipe strains before reducing the pressure back to the circuit's design pressure and maintained while a thorough leak test is done.

Summary

This is a basic overview of piping requirements for a gaseous hydrogen system operating at ambient temperatures and relatively low-end pressures for consumer distribution. At these conditions containment of hydrogen is relatively straightforward. And while containment of hydrogen should always be a concern at any operating condition, it is the higher operating temperatures that pose the real problems.

End of Paper