



21, rue d'Artois, F-75008 PARIS
<http://www.cigre.org>

CIGRE US National Committee 2023 Grid of the Future Symposium

Pipeline Considerations for New and Repurposed Pipelines: Conversion for Pure H₂ Pipelines and Blended NG/H₂ Pipelines

Andrew S. LÓPEZ
Burns & McDonnell
USA

SUMMARY

This paper provides guidance to owners of pipeline assets in natural gas and other non-hydrogen services who would like to introduce blended or pure hydrogen into their steel transmission and distribution systems or who would like to install new pipeline assets to transport pure hydrogen. The use of both ASME B31.12-2019 and ASME B31.8-2022 for blended and pure hydrogen systems are discussed, plus when the use of each is appropriate. Required inspection and testing is discussed along with the anomalies that can be detrimental to a hydrogen system, even if they may be acceptable for a natural gas pipeline system. Finally, methodology and examples are provided for determining the required wall thickness for a pipeline, or conversely how to determine the maximum allowable operating pressure (MAOP) for an existing pipeline to be converted to hydrogen service.

KEYWORDS

Hydrogen Pipelines, Blended Natural Gas, Net Zero Carbon Economy

1.0 INTRODUCTION

This paper provides guidance to owners of pipeline assets in natural gas and other non-hydrogen services who would like to introduce blended or pure hydrogen into their steel transmission and distribution systems. This paper does not address plastic piping within distribution systems, but these plastic products have shown favorable behavior to hydrogen service with the greatest concern being permeability through plastic [6] [7].

2.0 DISCUSSION

2.1 Relevant Code

The Owner must consult the relevant code to confirm the required wall thickness once a candidate pipeline has been selected. The code for pure hydrogen systems is *Hydrogen Piping and Pipelines* (ASME B31.12-2019) [4]. Although ASME B31.8 is incorporated by reference in 49 CFR Part 192 [1], the scope section of B31.8 (802.1 (b) (14)) specifically excludes hydrogen piping systems from the application of B31.8 [3]. For hydrogen systems within a mixture of hydrocarbon vapors B31.8 is the applicable code. However, ASME has only clarified that “ASME B31.8 may be used for gas mixtures with hydrogen compositions that are below what is covered by ASME B31.12. See the definition of gas in para. 803.1.” [2] without providing an upper limit for hydrogen content. ASME B31.12 does mention blends of hydrogen once in PL-3.1.2 and PL-1.3 excludes pipelines with hydrogen content below 10% by volume. PL-1.3, the EXCLUSIONS section also limits pipelines to 3,000 psig, while hydrogen piping systems (facility piping) may operate up to 6,000 psig.

It should be noted that B31.12 has a separate section for hydrogen pipelines (PL) and hydrogen piping systems (IP). According to IP-1.1 hydrogen piping refers to systems within “petroleum refineries, refueling stations, chemical plants, power generation plants, semiconductor plants, cryogenic plants, hydrogen fuel appliances, and related facilities.”

The definition of gas in B31.8 does not define any upper limits to the hydrocarbon percent in B31.8 and the author has made interpretation requests 23-1683 and 23-1684, for ASME B31.8 and B31.12, respectively, to clarify the scope of each code.

2.1 Conversion of Existing Pipelines

There is industry consensus that natural gas pipelines with hydrogen blended at less than 25% by volume behave similarly to pipelines with only natural gas. Therefore, when blended hydrogen systems are discussed here it means a system with less than 25% by volume hydrogen in an otherwise natural gas system. Specifically, it should be noted that the partial pressure of hydrogen has been shown to be the best predictor for hydrogen attack of steel and it is the combination of increasing hydrogen concentration and system pressure that leads to increased hydrogen-induced damage. Several studies have been performed to understand the action and it is understood that hydrogen embrittlement occurs when hydrogen adsorbs onto a steel surface, atomizes to single hydrogen atoms which act as highly reactive protons, and permeate through the steel’s 3D lattice structure resulting in reduced ductility and tensile strength [9] [11]. A visualization of the steps of how hydrogen is adsorbed onto the surface and then permeates through the steel appears in Figure 1 - Hydrogen Embrittlement Visualization.

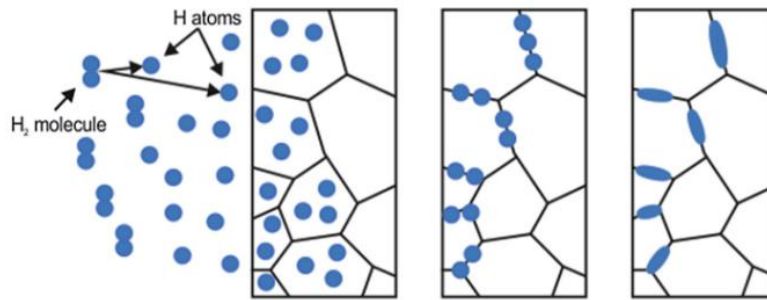


Figure 6.6 Absorbed hydrogen atoms by carbon steel alloys.

Figure 1 - Hydrogen Embrittlement Visualization

2.1.1 Blended Hydrogen Systems

There are decades of evidence of the safety associated with having hydrogen in gas systems for industrial and commercial use, with Hawai'i Gas providing its customers up to 15% hydrogen gas for nearly 50 years with no reported safety incidents related to the presence of hydrogen and no special appliance market for Oahu [5]. Existing pipelines with a specified minimum yield strength (SMYS) of 52 ksi (i.e., API 5L X52), are believed to be acceptable for blended hydrogen service. There is evidence that grades as high as X70 and X80 can safely contain blended hydrogen. Regardless of the grade of the pipe, the pipe should be examined internally through means like smart pigging to identify anomalies. If we take the example of European utilities, destructive testing of randomly selected pipeline segments, especially for higher-grade pipe, where pipe is subjected to pressure cycles similar to the pipe's expected service life can provide hydrogen service support [7].

2.1.2 Pure Hydrogen Systems

Any pipeline must meet the calculated fracture and fatigue minimums from B31.12. However, as the partial pressure of H₂ increases, the likelihood of hydrogen embrittlement/attack on existing anomalies increases and surface cracks which are acceptable in natural gas service may not be acceptable in hydrogen service, see Figure 1 for an example. Note that this picture is used to help explain that tolerable defects may be smaller with H₂ service. While it illustrates the concept, the actual tolerable defect sizes in real pipeline applications will likely be smaller.

Any candidate pipeline must be inspected with one or more smart pigs or other means to identify anomalies within the pipe's structure. The Owner must have well-established records of the integrity of their pipeline system including the absence of internal or external damage events.

- All threaded and flanged connections should be inspected for potential leaks.
- Existing or historic pipeline defects that can be embrittled by H₂
 - Axial cracks
 - Circumferential cracks
 - Internal surface-breaking defects
 - Pipe seam defects, e.g., hook cracks and lack of weld seam fusion
 - Hard spots
 - Welds with defects or high hardness

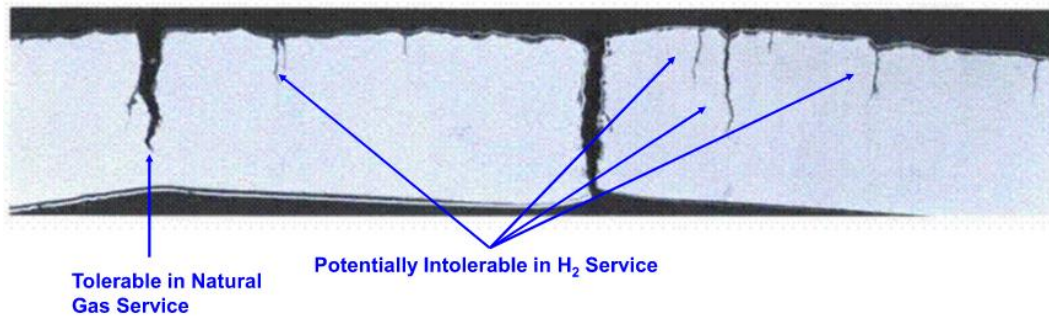


Figure 2 - Example of ID pipe wall cracks
*courtesy of Ken Lee from DNV GL

Once a suitable pipeline has been selected the wall thickness and grade must be applied to the equation in ASME B31.12 IP-3.2.1, equation 3a (IP systems), or the unlabeled equation from PL-3.7.1 (PL systems). Because of the derating in Table IX-5A and Table IX-5B (ASME B31.12), the new MAOP will be lower than the MAOP for natural gas service and all compression and safety devices must be adjusted accordingly.

Equation 1 - equation 3a from ASME B31.12 from IP-3.2.1

$$t = \frac{PD}{2(SEMf + PY)}$$

Equation 2 – Steel Pipeline Design Formula from ASME B31.12 from PL-3.7.1

$$P = \frac{2St}{D} FETHf$$

Equation 3 - equation 2 rewritten to calculate wall thickness

$$t = \frac{PD}{2SFETHf}$$

2.2 Material Specifications & Selection for New Pipelines

A hydrogen pipeline requires additional consideration of metallurgical reactions between pipe materials and the proposed medium. ASME B31.12 refers to the various grades of carbon steel pipe having a hydrogen embrittlement range, which implies that under ideal conditions hydrogen embrittlement is negligible. Academic literature has covered the effects of hydrogen on the material properties of ASTM A53, A106, and API pipe grades extensively including a recent meta-analysis prepared by Raju, et al. for the CPUC that continues to point toward the use of lower-grade materials with a maximum SMYS of 52 ksi (i.e., X52 pipe) to prevent or at least reduce hydrogen embrittlement [8]. As shown in the following figures and tables, the use of material grades with a yield strength greater than 52 ksi shows little benefit, with X56 pipe having a slightly thinner required wall thickness for, but with an added cost per weight of steel that renders the benefits inconsequential.

B31.12 has additional derating factors when calculating the required wall thickness for straight pipe (IP) called the piping material performance factor (M_f) and another for pipelines (PL) called the pipeline material performance factor (H_f). M_f and H_f are related to the effect of H_2 on steels of different grades and as the partial pressure of H_2 increases which is shown here in Figure 3 and Figure 4.

Table IX-5A Carbon Steel Pipeline Materials Performance Factor, H_f

Specified Min. Strength, ksi		System Design Pressure, psig						
Tensile	Yield	≤1,000	2,000	2,200	2,400	2,600	2,800	3,000
66 and under	≤52	1.0	1.0	0.954	0.910	0.880	0.840	0.780
Over 66 through 75	≤60	0.874	0.874	0.834	0.796	0.770	0.734	0.682
Over 75 through 82	≤70	0.776	0.776	0.742	0.706	0.684	0.652	0.606
Over 82 through 90	≤80	0.694	0.694	0.662	0.632	0.610	0.584	0.542

Figure 3 - Table IX-5A from ASME B31.12 (PL)

Table IX-5B Carbon Steel Piping Materials Performance Factor, M_f

Specified Min. Strength, ksi		System Design Pressure, psig						
Tensile	Yield	≤1,000	2,000	3,000	4,000	5,000	6,000	
70 and under	≤52	1.0	0.948	0.912	0.884	0.860	0.839	
Over 70 through 75	≤56	0.930	0.881	0.848	0.824	0.800	0.778	
Over 75 through 80	≤65	0.839	0.796	0.766	0.745	0.724	0.706	
Over 80 through 90	≤80	0.715	0.678	0.645	0.633	0.618	0.600	

Figure 4 - Table IX-5B from ASME B31.12 (IP)

To help the Owner with an example to understand the required wall thickness an existing pipe would need Table 1 – B31.12 Wall Thickness for 42" Piping @ 1400 psig up to 300 °F

Grade	Wall Thickness
X42	1.535"
X52	1.399"
X56	1.397"
X60	1.456"
X65	1.426"
X70	1.571"
X80	1.434"

Table 2 - B31.12 Wall Thickness for 30" Piping @ 1400 psig up to 300 °F

Grade	Wall Thickness
X42	1.096"
X52	0.999"
X56	0.998"
X60	1.046"
X65	1.019"
X70	1.122"
X80	1.024"

Table 3 and Table 4 to provide the calculated minimum wall thickness for 42" and 30" pipe, respectively, assuming a weld efficiency (E) of 0.95, using ASME B31.12. Table 3 and Table 4 provide the calculated minimum wall thickness for 42" and 30" pipe, respectively, assuming a Location Class 1 and Division 2 (F = 0.72), using ASME B31.8.

2.3 Example Calculations using ASME B31.12 and ASME B31.8

Table 1 – B31.12 Wall Thickness for 42" Piping @ 1400 psig up to 300 °F

Grade	Wall Thickness
X42	1.535"

X52	1.399"
X56	1.397"
X60	1.456"
X65	1.426"
X70	1.571"
X80	1.434"

Table 2 - B31.12 Wall Thickness for 30" Piping @ 1400 psig up to 300 °F

Grade	Wall Thickness
X42	1.096"
X52	0.999"
X56	0.998"
X60	1.046"
X65	1.019"
X70	1.122"
X80	1.024"

Table 3 - B31.12 Wall Thickness for 42" Pipeline @ 1400 psig up to 300 °F

Grade	Wall Thickness
X42	2.195"
X52	2.014"
X56	2.127"
X60	2.027"
X65	2.200"
X70	2.084"
X80	2.117"

Table 4 - B31.12 Wall Thickness for 30" Pipeline @ 1400 psig up to 300 °F

Grade	Wall Thickness
X42	1.568"
X52	1.439"
X56	1.519"
X60	1.448"
X65	1.572"
X70	1.489"
X80	1.512"

Table 5 - B31.8 Wall Thickness for 42" Pipe @ 1400 psig up to 300 °F

Grade	Wall Thickness
X42	1.167"
X52	0.9423"
X56	0.875"
X60	0.817"
X65	0.754"
X70	0.700"
X80	0.613"

Table 6 - B31.8 Wall Thickness for 30" Pipe @ 1400 psig up to 300 °F

Grade	Wall Thickness
X42	0.834"
X52	0.674"
X56	0.625"
X60	0.584"
X65	0.539"
X70	0.500"
X80	0.438"

2.4 Example Calculations for converting an existing line to B31.12

If we take the example wall thickness calculated in B31.8 for a pipeline designed to carry natural gas at 1,400 psig assuming a pipe grade of X52, a 30" and 42" pipeline require a wall thickness of 0.674" and 0.9423", respectively. Applying Equation 2, the calculated design pressure is reduced from 1,400 psig to 430 psig for both cases. The combination of the reduced operating pressure and lower energy content by volume must both be weighed when converting a pipeline to hydrogen service.

2.5 Conclusion

Hydrogen can safely be blended into existing pipelines at levels up to 25% with normal monitoring and maintenance and the pipeline can remain under B31.8 service, following 49 CFR 192. Asset Owners must still inspect and understand their systems before making such a change, but evidence shows positive outcomes for such systems.

For the conversion of pipelines to pure hydrogen service, the Owner must individually analyze any pipeline candidate, but the most likely candidates will be X52 or X56 pipelines with a good service and maintenance history. Once a pipeline is identified, the allowable maximum pressure must be calculated using ASME B31.12. The maximum pressure will be based on actual pipeline conditions like wall thickness and the decided corrosion/erosion allowances and will be greatly reduced from the 1,400 psig used in this paper to 430 psig.

For new pipelines in hydrogen service, Asset Owners must consider the costs and advantages of different line sizes, pressure ratings, the required wall thickness, and the possible implementation of multiple pipelines.

BIBLIOGRAPHY

- [1] US CFR, 06/09/2006, “§ 192.7 What documents are incorporated by reference partly or wholly in this part?” Accessed on 2023/07/27 <https://www.ecfr.gov/current/title-49/subtitle-B/chapter-I/subchapter-D/part-192/subpart-A/section-192.7>
- [2] ASME “Interpretation Detail: Hydrogen Blending” Interpretation Number: B31.8-22-08; Published on 09/06/2022, Accessed on 2023/08/03 <https://cstools.asme.org/Interpretation/InterpretationDetail.cfm?TrackingNumber=22077>
- [3] ASME, 2022, “Gas Transmission and Distribution Piping Systems; B31.8 - 2022” <https://www.asme.org/codes-standards/find-codes-standards/b31-8-gas-transmission-distribution-piping-systems>
- [4] ASME, 2020, “Hydrogen Piping and Pipelines; B31.12 - 2019” <https://www.asme.org/codes-standards/find-codes-standards/b31-8-gas-transmission-distribution-piping-systems>
- [5] Hawai’i Gas, 04/06/2023, “Hawai’i Gas Issues Request for Proposals for Renewable Natural Gas and Renewable Hydrogen” Accessed on 07/28/2023 <https://www.hawaiigas.com/posts/hawai-i-gas-issues-request-for-proposals-for-renewable-natural-gas-and-renewable-hydrogen>
- [6] Smith, B., Frame, B., Eberle, C., Anovitz, A., Blencoe, J., Armstrong, A., Mays, J. (2005). New Materials for Hydrogen Pipelines [pdf]. Presented at Hydrogen Pipeline Working Group Meeting, Augusta, Georgia. Retrieved from <https://forcetechnology.com/en/cases/hydrogen-transport-danish-gas-pipelines-ideal#:~:text=The%20plastic%20pipe%20tests%20found,use%20in%20environments%20containing%20hydrogen.>
- [7] FORSE Technology, “Danish gas pipelines are ideal for transporting hydrogen” <https://www.energy.gov/eere/fuelcells/articles/new-materials-hydrogen-pipelines-0>
- [8] Raju, A., Martinez-Morales, A., Lever, O., 07/18/2022. “The California Public Utilities Commission, Final Report: Hydrogen Blending Impacts Study”, Retrieved from <https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M493/K760/493760600.PDF>, accessed on 08/22/2022.
- [9] Murakami, Y., 2019. Academic Press, Metal Fatigue (Second Edition), Pages 567-607, Hydrogen embrittlement, <https://doi.org/10.1016/B978-0-12-813876-2.00021-2>
- [10] Parfomak, P W., March 2, 2021. Congressional Research Service “Pipeline Transportation of Hydrogen: Regulation, Research, and Policy”
- [11] Del-Pozo, A., Villalobos, J.C., Serna, S., 2020. Elsevier, Current Trends and Future Developments on (Bio-) Membranes, “A general overview of hydrogen embrittlement”, <https://doi.org/10.1016/B978-0-12-818332-8.00006-5>