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Pipeline Considerations for New and Repurposed Pipelines: Conversion for Pure H_2 Pipelines and Blended NG/H_2 Pipelines

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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 for 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

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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] and ASME B31.12 does not discuss blended systems and only refers to hydrogen. 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 which leads to increased hydrogen-induced damage.

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 and there is evidence that grades as high as X70 and X80 are capable of safely containing 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 expected service life of the pipe can provide support for hydrogen service [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 H_2 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 H_2 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 for 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 H_2
    - 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

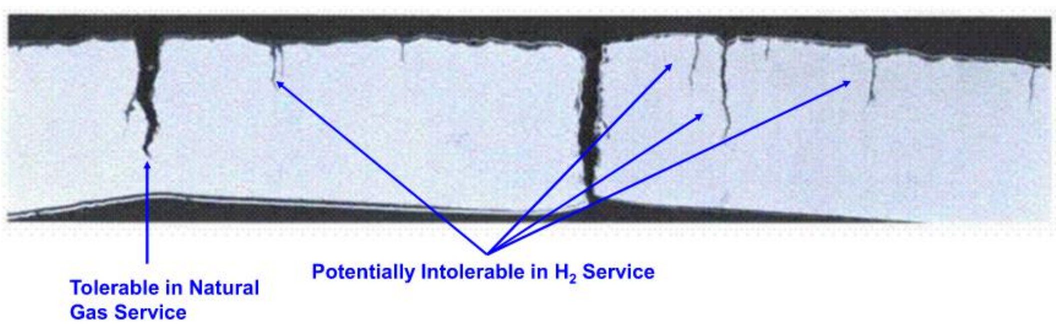

Figure 1 - Example of ID pipe wall cracks
*courtesy of Ken Lee from DNV GL

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 or 3b. Because of the derating in , 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

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

2.2 Material Specifications & Selection for new pipelines

A hydrogen pipeline requires additional consideration of metallurgical reactions between pipe materials and the proposed medium. 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 hydrogen embrittlement [8]. As shown in the following figure and tables, the use of material grades with a yield strength greater than 52 ksi shows very little benefit, with X56 pipe having a slightly thinner required wall thickness, but with an added cost per weight of steel that renders the benefits inconsequential.

B31.12 has an additional derating factor when calculating the required wall thickness for straight pipe called the material performance factor (M_f). M_f is related to the effect of H_2 on steels of different grades and as the partial pressure of H_2 increases and is shown here as Figure 2.

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 2 - Table IX-5B from ASME B31.12

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" Pipe @ 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" Pipe @ 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 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" Pipe @ 1400 psig up to 300 °F

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X42	1.535”
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X56	0.998”
X60	1.046”
X65	1.019”
X70	1.122”
X80	1.024”

Table 3 - B31.8 Wall Thickness for 42" Pipe @ 1400 psig up to 300 °F

Grade	Wall Thickness
X42	0.972”
X52	0.785”
X56	0.73”
X60	0.981”
X65	0.628”
X70	0.583”
X80	0.49”

Table 4 - B31.8 Wall Thickness for 30" Pipe @ 1400 psig up to 300 °F

Grade	Wall Thickness
X42	0.964”
X52	0.779”
X56	0.724”
X60	0.676”
X65	0.623”
X70	0.579”
X80	0.507”

2.4 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 the evidence is showing 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 not likely be at the 1400 psig used in Table 1 – B31.12 Wall Thickness for 42" Pipe @ 1400 psig up to 300 °F

Grade	Wall Thickness
X42	1.535”
X52	1.399”
X56	1.397”
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X80	1.024”

Table 3 and Table 4.

For new pipelines in hydrogen service, Asset Owners must consider the costs and advantages of different line sizes, pressure ratings and 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.