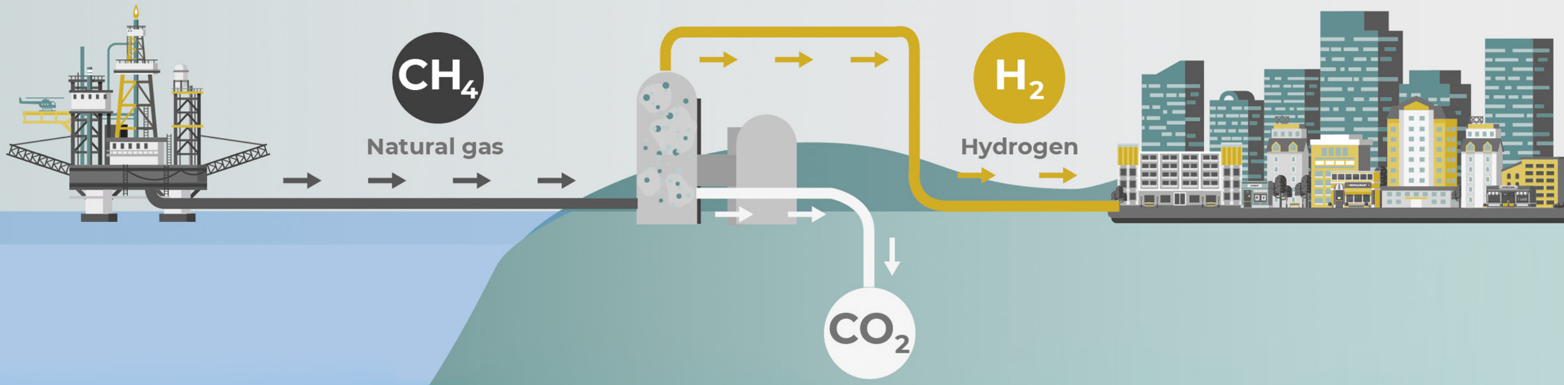
THE MOVE TO BLUE



John Anderton, Atmos International, discusses the rise of blue hydrogen and the important role of pipeline simulation.

Following December 2023's COP28 in the UAE, many world leaders collectively agreed to move away from fossil fuels in pursuit of net zero emissions.[1] The agreement culminated in the launch of the Buildings Breakthrough agenda, which aims to decarbonise high emission sectors like power, steel production and transportation with a view to reaching near zero emissions by 2030.[2]

With alternative fuels being considered more rapidly now than ever, many nations have already been investing in the production of cleaner fuels, with hydrogen being a primary example.

Hydrogen colours

There are a range of methods for producing hydrogen (Table 1). Green and yellow hydrogen are produced using renewable energy sources, with yellow hydrogen being a more recent method that produces hydrogen via electrolysis using solar power, whereas brown and grey hydrogen are sourced from fossil fuels such as natural gas, black coal or lignite (brown coal).

Blue hydrogen is formed when the carbon generated through the process of steam reforming is captured and stored underground during carbon capture, utilisation and storage (CCUS).[3] Despite sitting towards the middle of Table 1, blue hydrogen is often viewed as carbon neutral or low-carbon because emissions are not released into the atmosphere, and it is gaining popularity as an alternative fuel.

In the UK for example, blue hydrogen makes up a significant part of the energy transition, with funding for more blue hydrogen plants expected in the future[4] and other blue hydrogen projects have received investment in mainland Europe to assist in the CCUS process.[5]

Pipelines are crucial in the transportation of natural gas to hydrogen plants, the production and downstream transportation of blue hydrogen and the CCUS process (Figure 1). However, the pipelines involved in blue hydrogen production need to be analysed and monitored using pipeline simulation. This article will explore some of the challenges that pipeline operators will face and how simulation software is instrumental to efficient operations.

Existing natural gas pipeline infrastructure

With current natural gas pipeline infrastructure being considered for hydrogen fuel production as part of a circular economy, there is a possibility that existing infrastructure will be used for blue hydrogen,[6] but this carries its own risks.

The molecular makeup of hydrogen is smaller than other natural gas molecules and hydrogen gas is capable of dissociating into protons, resulting in the pipeline wall absorbing the protons. This presents an increased risk of leak events on existing infrastructure where there are likely to be more defects in the pipeline, such as cracks or dislocations in the pipe wall.

Combined with hardware instrumentation, simulation software is capable of providing leak detection on a blue hydrogen pipeline, supporting existing pipeline infrastructure that already faces issues like cracks or dislocations in the pipe wall.

By continuously calculating the pipeline's volume balance, an online model can calculate the total flow into the system minus the total flow out and make corrections depending on inventory changes. Using sequential probability ratio testing (SPRT), leak probability can be measured against no-leak probability and then tested against blue hydrogen's threshold values to provide leak alarms.

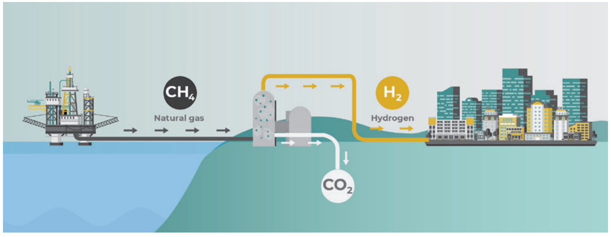


Figure 1. The process for producing blue hydrogen.

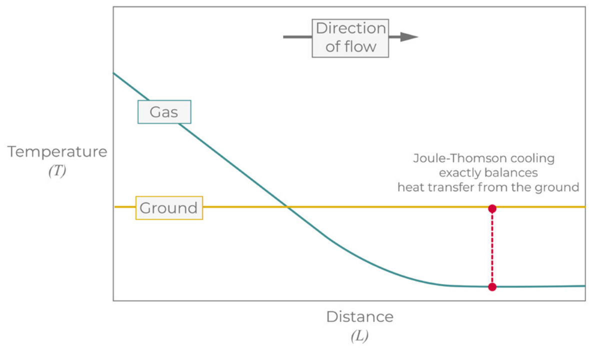


Figure 2. Temperature along an example flowing gas pipeline.

Hydrogen attack and embrittlement

For steel and other alloy pipelines containing hydrogen at high temperatures, a methane reaction called high temperature hydrogen attack (HTHA) can occur, causing pipeline metal degradation. Blue hydrogen is produced at high temperatures through steam reforming so pipeline operators need to factor HTHA in as a potential risk.

At low temperatures, hydrogen can also cause damage to pipeline integrity, with hydrogen embrittlement (HE) occurring when hydrogen is absorbed into the pipeline wall. Similarly, operators need to consider HE as part of their operations. A range of factors can cause hydrogen's temperature to fluctuate in the pipeline.

Generally, gases are very hot at the inlet but progressively drop in temperature after being exposed to an after-cooler.[7] Further along the pipeline, temperature drops significantly again due to the Joule-Thomson effect, with the temperature eventually balancing out (Figure 2). No two pipelines are the same however, and these temperature events can occur at varying points in a pipeline section.

For blue hydrogen specifically, thermal modelling of the pipeline is crucial because calculating heat transfer can determine where there could be a risk of HE and HTHA.

Solving heat transfer (q) should consider factors like the temperature of the blue hydrogen (^{T}fluid), the pipe wall and the ambient medium (^{T}ambient), otherwise known as the environment around the pipeline.

An overall heat transfer coefficient can be calculated and modelled using the following equation:

$$q = U \cdot A \cdot ({}^{T}\text{fluid} - {}^{T}\text{ambient})$$

Table 1. Different types of hydrogen and their production methods

Colour code	Brown	Grey	Blue	Turquoise	Pink	Yellow	Green
Energy source	Coal or lignite	Natural gas	Any non-renewable energy source	Methane	Nuclear energy	Solar power	Any renewable energy source
Process of production	Gasification	Steam reformation	Steam reformation and carbon capture and storage (CCS)	Pyrolysis	Electrolysis	Electrolysis	Electrolysis
Highest to lowest greenhouse gas emissions	→						
Lowest to highest acceptance level	→						

With visibility of temperature fluctuations along a pipeline transporting blue hydrogen, operators determine where there is a risk of hydrogen attack or embrittlement in the network and where leak detection might be required in the future.

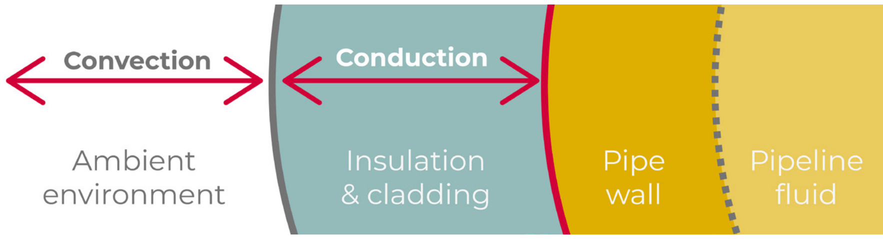


Figure 3. An example of radial heat transfer in an unburied pipeline.

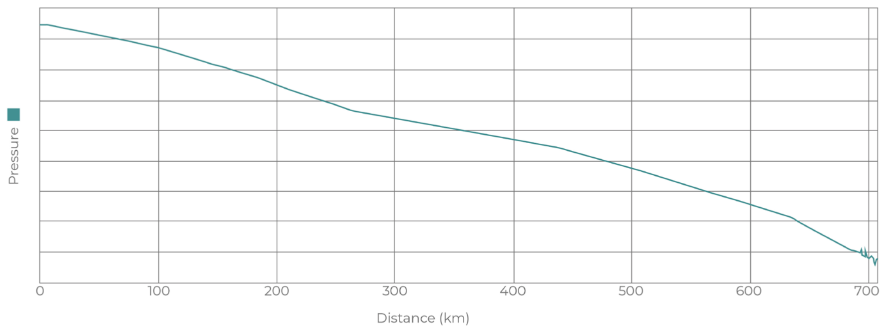


Figure 4. Visibility of pipeline pressure at every point in Gassco's offshore pipeline.

Reskilling pipeline operators

Hydrogen is a relatively new pipeline operation, with blue hydrogen only recently gaining momentum as a method of production for a hydrogen operator. To ensure safe and effective blue hydrogen operations, pipeline operators will need to reskill quickly.

Simulation software equipped with a training system can prepare operators with the behaviour of a blue hydrogen pipeline before they move into live operations. By presenting an offline model of the pipeline in a test environment, a training simulator can help operators learn how the pipeline behaves, and understand the appropriate actions to take in the event of a leak or other abnormal activity so they can act accordingly.

Visibility and understanding of blue hydrogen fuel data

The high cost of installing instrumentation in remote locations or areas without power or communication often means there is no measurement between some pipeline sections. However, when a new fuel like blue hydrogen is introduced to a pipeline that already has blind spots in the data, there is a greater risk of the data between the inlet and the outlet not matching. In a blue hydrogen pipeline, flow, pressure and temperature data will differ to natural gases, so visibility of the data is crucial.

Using a supervisory control and data acquisition (SCADA) system, simulation software can create a 'digital twin' that shows not only the pipeline's flow, pressure and temperature data, but also the whole pipeline's gas composition and velocity. Norwegian pipeline operator, Gassco, operates a proprietary simulation suite to plug the gaps in its offshore pipeline network's data to ensure accurate and reliable calculations across its entire subsea network.[8]

Providing an optimal amount of pipeline data will support operators as they reskill for blue hydrogen operations.

The gravity of blue hydrogen

Hydrogen's molecular makeup is considerably different to that of natural gas, so the risk of leakage is greater. Hydrogen is 14 times lighter than air and 57 times lighter than gasoline vapour so it can also leak quickly into an open environment. Paired with greenhouse gas emissions, hydrogen's flammability in the air ranges from 4 - 75%, meaning a blue hydrogen leak can pose damage to people, property and the immediate environment, as well as net zero efforts.[9]

Understanding blue hydrogen's properties and the magnitude of risk involved in a hydrogen leak is crucial before transporting the fuel. Simulation software can protect people, property and the environment with optimisation features that ensure the pipeline operates within allowable limits. Using machine learning, recommendations can be made to operators that reduce risk and ensure safe operations, all while meeting the demands of blue hydrogen customers downstream.

Pipeline simulation is a vital requirement of hydrogen fuel transportation

As blue hydrogen continues to gain momentum, pipeline simulation software will be a crucial component of effective operations, just as it supports the other hydrogen colours.

References

1. https://www.cop28.com/en/news/2023/12/COP28-delivers-historic-consensus-in-Dubai-to-accelerate-climate-action
2. https://globalabc.org/our-work/fostering-collaboration
3. https://www.weforum.org/agenda/2021/07/clean-energy-green-hydrogen/
4. https://www.theguardian.com/commentisfree/2023/dec/04/uk-government-hydrogen-plan-oil-industry-taxpayer-blue-hydrogen-climate-crisis
5. https://www.hydrogeninsight.com/production/second-major-blue-hydrogen-project-reaches-final-investment-decision-in-rotterdam/2-1-1574743
6. https://www.sciencedirect.com/science/article/pii/S0360319923021134
7. https://www.atmosi.com/en/resources/books/the-atmos-book-of-pipeline-simulation-chapter-six/
8. https://www.atmosi.com/en/resources/case-studies/gassco-cs/
9. https://h2tools.org/bestpractices/hydrogen-compared-other-fuels