Re-purposing pipelines for hydrogen storage and transportation

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In the UK, 30% of greenhouse gas (GHG) emissions come from domestic heating and cooking. One popular suggested solution to reduce these emissions is switching the heating network from natural gas to hydrogen as the combustion of hydrogen produces just water vapour and heat and no CO₂ (carbon dioxide) emissions.

With 45,000km of pipeline installed in the North Sea, there is considerable opportunity to take advantage of this infrastructure. In a recent study for the Oil and Gas Technology Centre (OGTC), Xodus explored the feasibility of converting the subsea pipeline infrastructure for hydrogen service and how this would fit with a future energy industry that also requires carbon capture and storage (CCS). The analysis was divided into three parts:

- A materials analysis to review the restrictions imposed by hydrogen service
- A geographical information systems (GIS) study to identify key strategic locations in England and Scotland based on existing storage and production infrastructures
- The measures needed for qualifying the existing pipelines for hydrogen service.

Safety and performance of hydrogen pipelines

To phase out fossil fuels and meet increasing energy demand, a ‘hydrogen economy’ is being created to provide energy in several forms (see Figure 1). The transport of hydrogen by pipelines is highly proven. As of 2016, there were around 4,500km of hydrogen pipelines worldwide[i]. These pipelines are mainly operated by industrial gas producers and located near large refineries and chemical plants.

The longest network of pipelines is found in the US, around 2,600km, and Western Europe – mainly in Belgium, Germany, France, and the Netherlands. The pipeline size is typically 8-12 inches, which is sufficient to satisfy specific plant requirements. Pipeline pressures vary according to the networks and, in general, range from 3 bar to 100 bar. More frequently, these hydrogen pipelines operate in the range 40 to 60 bar[ii].

Existing hydrogen pipelines are constructed with common API 5L or ASTM grade carbon steels, as are long-distance offshore pipelines in the North Sea. The safety and performance of these carbon steel pipelines for transporting hydrogen gas is dependent on a variety of degradation mechanisms promoted by the material interaction with hydrogen. For example, hydrogen embrittlement and/or assisted cracking, reduction of fatigue resistance, and the reduction of tensile ductility and notch tensile strength.

Metallurgy requirements

One major approach used to reduce hydrogen damage is the control of the metallurgy of the material to decrease its susceptibility. Key criteria to consider for pipelines transmitting high pressure hydrogen gases is high toughness and low hardness of the material. These properties are achieved by a combination of low carbon content, control of the cleanliness of the steel, and control of the microstructure. The steel chemistry, microstructure, hardness, and strength level can also impact toughness and affect the susceptibility to hydrogen embrittlement.

There is some experimental evidence that high strength carbon steel is more prone to embrittlement, thus should be avoided. Steels with high tensile strengths see the greatest loss in fracture toughness in hydrogen service. Low strength steels fail in a ductile mode in hydrogen environments, while higher strength carbon steels fracture in a brittle mode.

The use of API 5L grades X42 and X52 in hydrogen service has been extensively proven in operating pressures up to 140 bar with very few reported problems[iii]. This is attributed to the relatively low strength of these alloys, which imparts resistance to hydrogen embrittlement and the other brittle fracture mechanisms.

If the above requirements are not met or cannot be proven in existing pipes, an option is to limit the operating stress level in the pipe to 30% of the specified minimum yield strength (SMYS), or 20% of the specified ultimate tensile strength to reduce the risks of hydrogen embrittlement[iii].
Pipeline conversion

The suitability of existing UK subsea pipelines for conversion to hydrogen service depends on several factors including the material, operating pressure, age and overall condition.

As detailed data on material specifications or operating pressures and temperatures of the existing subsea oil and gas pipelines across the UKCS is not readily available, a comprehensive assessment for the entire pipe network has not been possible. A material compatibility map of the UK pipeline infrastructure has been prepared by Xodus (see Figure 2). This shows pipelines ranked into suitability categories. The ranking criteria is based on the following assumptions:

- Fluid currently transported in the pipeline
- Pipelines that are currently used to transport natural gas are most likely to be suited to hydrogen. This is because water pipelines are most likely to have suffered from internal corrosion metal loss, and crude oil pipelines would have to undergo heavy cleaning to remove traces of hydrocarbons and other impurities.

"The consultancy reviewed a sample of pipelines within the Southern North Sea and found that 22 of 53 gas pipelines, roughly 40%, would be suitable for hydrogen" (Source: Xodus Group)

Pipeline age

Pipelines material grades below X52 are recommended. Though there is no publicly available data on pipeline grades, the trend in recent years has been towards higher material grades. Based on experience, pipelines built between 1980 and 2000 are more likely to be a suitable material grade.

Pipeline diameter

The focus of the study was on larger pipelines of 6” and above which could maximise transport capacity. Currently, the National Data Repository (a data service managed by the Oil and Gas Authority) does not contain the material grades for the UKCS pipelines and therefore, it has not been possible to specify the exact pipelines that are most suitable for hydrogen service. However, the assumptions made to construct the map have been shown to be correct. The Aberdeen-headquartered energy consultancy reviewed a sample of pipelines within the Southern North Sea and found that 22 of 53 gas pipelines, roughly 40%, would be suitable for hydrogen. Key locations and pipelines were then further identified based on an optimum combination of generation, transport and storage infrastructure. Two scenarios were considered:

- Blue hydrogen generated and stored onshore with CO₂ from CCS, sent offshore for storage in depleted wells
- Green hydrogen produced offshore using wind energy and sent onshore for storage and use via existing offshore pipelines

Pipelines for storage

Assuming 40% of pipelines are suitable for re-purposing it hydrogen service is generally representative of the North Sea as a whole. By then removing 10% for integrity challenges, nearly a third of pipelines across the basin could be deemed acceptable for hydrogen service. This would relate to 13,500km of pipelines.

On a highly conservative basis, assuming all of these suitable pipelines are 10” diameter, operating at 40 bar pressure and 10°C with a closed-in system, 2,366,550 kg (2,367 T) of hydrogen could be stored in the pipelines. Dynamic simulations are required to understand the operational challenges.

Sufficient to say, the pipeline design and operating history as well as a comprehensive internal and external inspection should be considered when converting existing subsea pipelines to hydrogen service. Before starting hydrogen service, hydrostatic pressure and leak tests may be required as per the relevant design codes. Stringent de-watering and drying procedures are also required.

For pipelines that are considered incompatible with hydrogen service due to material compatibility, novel technologies such as polymer liners can be explored to overcome material challenges. Other potential solutions include using fibre reinforced polymer (FRP) pipelines for hydrogen distribution.

Positive potential for re-purposing

The investigation has shown that the conversion of subsea pipelines from hydrocarbon transport to hydrogen service is feasible. Notably, conversion of onshore pipelines for hydrogen service has been successfully achieved in the US and the Netherlands, sometimes with pipelines more than 40 years old. However, the subsea location of the offshore pipelines creates additional difficulties in terms of access for inspection and testing.

For conversion activity of any extent to take place, it is imperative that adequate physical testing and cleaning of the asset take place. This is particularly important if the detailed material properties and dimension of the pipeline cannot be acquired.

Furthermore, when selecting pipelines for conversion, lines that carried natural gas in their original service should be preferred over water or crude oil lines, as they are more likely to have greater cleanliness and mechanical integrity.

Overall, the study by Xodus has provided a robust methodology for assessing which parts of the oil and gas infrastructure could be most effectively converted for hydrogen service. It also provides preliminary results on what areas should be targeted for further research.

Figure 2. UK Subsea Pipeline Network by Assumed Material Compatibility

Source: Xodus Group

References

1. The Hydrogen Analysis Resource Center’ website
2. Nexas. ‘Hydrogen Delivery Infrastructure Options Analysis’ Final Report