CO_2 pipelines: challenges and threats

Dr. Sameera Naib and Dr. Daniel Sandana, ROSEN, evaluate the challenges and threats to consider when deciding whether to repurpose existing pipelines or build new pipelines for the transportation of carbon dioxide.

Carbon capture, utilisation and storage (CCUS) has long been recognised as a potential enabler for the global decarbonisation agenda. CCUS involves the capture of carbon dioxide (CO_2), generally from large industrial sources that use either fossil fuels or biomass as fuel.

Planned capacities for CO_2 transport and storage surged dramatically in recent years, with more than 370 million tpy of new CO_2 storage capacity announced since January 2022, with similar capacities for connecting infrastructure.[1] This is a positive outlook for the CCUS industry, signalling strengthened market conditions driven primarily by policy implementation and coordinated alignment of the CCUS value chain stakeholders.

Historically, the majority of commercial projects have been the transport of (almost) pure CO_2. Recent developments around blue hydrogen involve looking at transporting anthropogenic CO_2 from process plants, for example the steam methane reforming (SMR) process, where various impurities could be present. Safety and reliability is vital when transporting CO_2 from the location where it is captured to a storage site.

It is well known that pipelines are being extensively utilised for transporting CO_2 all over the world. With a

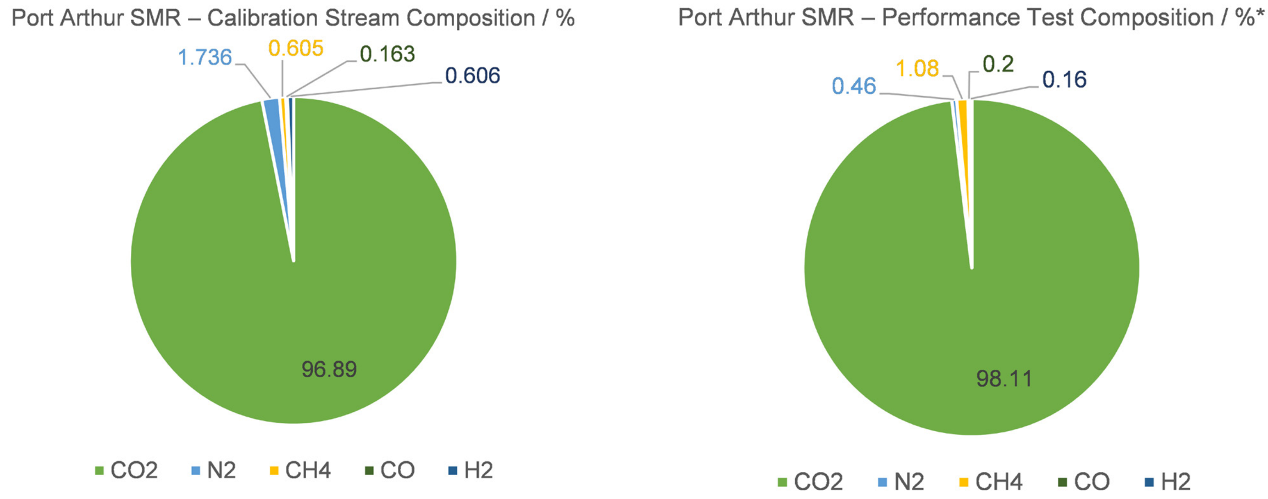


Figure 1. Compositions of CO_2 generated from the SMR process at Port Arthur (Air Products, Texas, US).

sudden increase in demand and production, the infrastructure owners need to choose between laying and constructing a new network, or reusing the existing network of pipelines and further understanding the integrity issues with CO_2 pipelines.

Keeping all these aspects in mind, this article will provide guidance to asset owners regarding the key issues associated with anthropogenic CO_2 pipeline transportation and conversion.

Eternal dilemma – the old or the new

Whether to construct new pipelines with the change in the flow medium, or reuse the existing network, is a constant dilemma for pipeline operators.

In many cases, utilising existing natural gas grids for hydrogen transport is four to six times more cost-effective than constructing new pipelines. In terms of OPEX between a CO_2 transmission network based on repurposed natural gas pipelines, and a CO_2 transmission network made up entirely of new pipelines, there are only limited differences.

It is likely that future CCUS projects will reuse existing hydrocarbon pipelines to a large extent. One can expect that the conversion to CO_2 service will also take advantage of the existing offshore and onshore segments, to achieve storage at depleted reservoir fields, as is the case for projects such as Acorn in Scotland, Hynet in North West England, and L10 in the Dutch North Sea.

Factors to consider

In order to decide whether to reuse old pipelines, or to implement new pipelines along with their potential threats, it is important to consider certain factors. Transporting CO_2 in pipelines comes with its own set of challenges. Though the transportation of CO_2 in general is like other gaseous transport, specific aspects of CO_2 and its production induces certain challenges. Therefore, it is important to consider the following aspects before undertaking the CO_2 transportation:

- The CO_2 composition and its impurities.
- Pipeline integrity challenges and threats.
- Managing conversion and integrity.

CO_2 composition and its impurities

A multitude of impurities can arise from process plants, including SO_X, NO_X, hydrogen sulfide (H_2S), carbon dioxide (CO), and hydrogen, and can enter the transported CO_2. The type and levels of impurities present in the pipeline is dependent on fuel source, process generating flue gases and CO_2 process treatment.

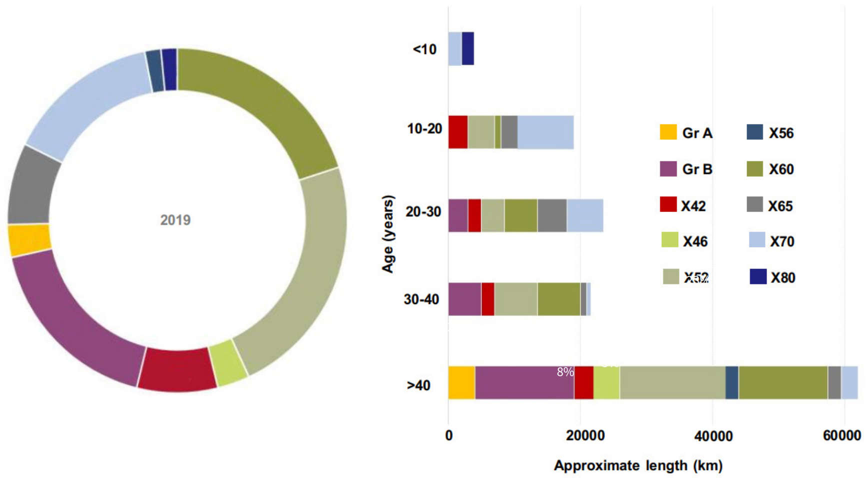
In the case of existing commercial CCUS facilities, there is limited data available on compositions or specifications of the CO_2 streams derived from the SMR process. Nonetheless, the compositions of CO_2 generated from the SMR process at Port Arthur were found (Air Products, Texas, US). This is depicted in Figure 1.[2] The data confirms the presence of impurities in the stream, particularly CO. However, it has curiously omitted the presence of moisture (H_2O) and H_2S. Although desulfurisation usually takes place prior to the reforming process, a small amount in the orders of ppm vol. would be expected to leak through the CO_2 stream and could be responsible for the presence of major integrity threats at the anticipated pressures in the transportation system. H_2O, CO and H_2S would also be considered and monitored within the CO_2 stream post-SMR to manage the integrity of CO_2 pipelines.[3]

Evaluating integrity threats

Pipeline material

For new pipelines, it is important to understand the threats associated with CO_2 compositions and the consequent effect on the pipeline material used. Challenges include fracture control corrosion, flow assurance and operational issues.

Re-purposing existing infrastructure will involve the re-use of existing pipelines. Existing pipelines are generally manufactured from materials in accordance with API 5L/ISO 3183 (Figure 2). These existing pipelines are ageing. This means that they are either approaching, or have already exceeded, their original design life. They are likely to have been originally constructed in accordance with older steelmaking and manufacturing practices and will also tend



(a) (b)

Figure 2. Steel grades in natural gas transmission in Europe (a) 2019 distribution vs (b) age.

to be made from lower grades of steel than their modern equivalents.

There are no recognised international standards dealing specifically with CO_2 pipelines, except for some recommended practices. Re-purposing of existing infrastructure for CO_2 assumes that existing pipelines are suitable, or can be made suitable, for CO_2 service. However, there are various material-related factors that must be considered.

To ensure that pipelines can safely be converted, time-dependent threats such as ageing and degradations could lead to loss of containment in dense CO_2, and therefore need to be identified and managed accordingly.

Ageing and degradation

To manage the long-term integrity of CO_2 pipelines, pipeline engineers must understand the nature of the degradation mechanism(s) they are potentially faced with. In many respects, the management of time-dependent threats in CO_2 pipelines is fundamentally an extension on the knowledge and experience gained through the traditional oil and gas industry. The main difference is that in 'traditional' gas production, CO_2 is mainly an unwanted by-product or impurity, while for CCUS, CO_2 is the primary fluid being transported. Therefore, CO_2 will likely be at a higher partial pressure and may have its own inherent impurities, leading to a higher risk of internal corrosion.

For oil and gas infrastructure, a simplified rule is generally accepted: that the risk of internal corrosion in transporting facilities will remain low, as long as no free (separated) water phase is present. This means that an effective mitigation of internal time-dependent threats for CO_2 pipelines is to keep the water content below saturation levels, or its solubility limits in the CO_2 stream. Operators of existing CO_2 pipelines in the US generally impose a strict water level specification, below 50 ppm, which is usually considered to be effective for full dehydration. Operators must understand their specific situation and the need to implement control over these threats.

Cracking and fracture

Transgranular stress corrosion cracking (SCC) of steel is a common occurrence in the CO_2-CO-H_2O system. The presence of H_2O is critical for the incidence of cracking. An increase of the CO activity in CO_2-H_2O systems increases the susceptibility to cracking, i.e., the crack growth rate is greater, and the minimum initial stress that is to be applied for SCC occurrence is lower.

The presence of H_2S can lead to different types of sour cracking, mainly sulfide SCC and hydrogen-induced cracking (HIC). These threats and their respective mitigation requirements have been well documented in the oil and gas industry, particularly through the standard NACE MR0175/ISO 15156. If a CO_2 pipeline is expected to see significant levels of H_2S during service, sour resistant steels will need to be considered in order to prevent catastrophic failure of the pipeline.

CO_2 pipelines are more susceptible to long running ductile fracture (than natural gas pipelines) because the CO_2 will be transported in its dense phase, and more importantly because of the specific decompression behaviour of dense CO_2 to a two-phase mixture.

The principal concern for the required mechanical properties of CO_2 pipelines is generally considered to be related to the control of fracture propagation, and particularly how preventing (or arresting) a long running ductile fracture will be achieved. The means of averting propagating ductile fractures consists of specifying a line pipe with a sufficiently high toughness and/or fitting of mechanical crack arrestors at regular intervals along the pipeline length. Due to the presence of these 'impurities' in SMR-generated CO_2 compositions, it will therefore be necessary to understand the expected composition envelope in deriving the suitable fracture toughness requirements.

Managing the conversion

One of the major challenges associated with re-purposing existing pipelines for CO_2 service is ensuring the material properties, particularly toughness, are adequate to prevent long running ductile propagation. Other construction data will also be required as part of the evaluation of the suitability to conversion. This means that pipeline duty holders will need to have suitable documentation of pipeline and material 'DNA'.

Another factor which needs to be considered is that most of the existing hydrocarbon pipelines have been in service for more than 30 years and are close to, or beyond, their original design life. Original design and construction documentation and mill test certificates are likely to have been lost, or to be incomplete.

Additionally, there is no mandatory requirement for toughness testing. Consequently, there is no guarantee that the old lines will meet the CO_2 required fracture control material-related criteria, due to the evolvement of steelmaking and manufacturing practices. Therefore, the operator has to decide on the criteria and requirements based on thorough research and understanding.

This means that intelligent targeted linepipe material sampling strategies will need to be deployed to access the materials key 'DNA' parameters, for example, toughness and strength. In-line inspection (ILI) technologies could play an important role when such approaches are taken. For example, RoMatPGS can provide a direct, valuable picture of the pipe steel grade properties and material and construction differences, from which targeted cost-effective sampling strategies can be made.

There are major operational challenges in deploying an ILI tool in CO_2 service. They are summarised below:

- Chemical degradation and explosive decompression due to interaction with dense CO_2.
- High wear in dry environments.
- Damage of electronic components due to the build-up of electrostatic charge on tools, as a result of movement of cups along the pipe wall in dry environment.

Although these challenges exist, they are not insurmountable and can be effectively managed through careful attention to material selection and tool design.

Conclusion

CCUS has not yet been implemented to the extent predicted 10 years ago, however, the underlying requirement for the technology remains. Indeed, the current interest and proposed investment in the hydrogen economy as an enabler for decarbonisation will necessitate the use for CCUS as part of the generation of 'blue' hydrogen. It is therefore an opportune time to revisit the integrity challenges associated with CO_2 transport.

There is plenty of industry evidence that proves CO_2 pipelines are an established 'technology' and can be safely managed by applying a due level of caution and mitigation, i.e., dehydration. This demands that water specification limits are well understood and defined in line with the pipeline operational framework.

Given the ongoing uncertainties referenced above, it would appear prudent for operators to consider each proposed conversion at a bespoke case-by-case level, with there being a potential need for project specific testing.

References

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