Safe Pipeline Transmission of CO_2

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Together with major industry partners, Det Norske Veritas (DNV) is developing new guidelines for design and operation of onshore and offshore pipelines for the transmission of CO_2. The purpose of this article is to give a wider audience insight into the ongoing industrial collaboration on developing a new guideline for design and operation of onshore and offshore pipelines for transmission of CO_2. The reason behind this initiative is given in the article. The guideline will give provisions for specific issues related to transmission of dense CO_2, and these specific issues are also addressed.

Introduction

There is growing worldwide recognition that global warming is a likely result of excessive anthropogenic greenhouse gas emissions into the atmosphere. The need for a reduction of these emissions is driving the efforts of several industry players and research institutes in the direction of developing a wide energy portfolio of cleaner energy solutions.

Acknowledging the fact that fossil fuels are likely to remain one of the primary sources of energy for the future decades, solutions for carbon capture and storage (CCS) are becoming ever more relevant. Particularly in North America and Europe today, environmental consciousness has led to the development of several feasibility studies and demonstration plants for the capture, transmission, injection and storage of CO_2.

A complete CCS cycle requires safe and cost-efficient solutions for transmission of the CO_2 from the capturing facility to the location of permanent storage. For transmission of large quantities of CO_2 over moderate distances, pipelines are considered the most cost-efficient solution. Onshore pipelines for transmission of CO_2 have existed in North America for several decades, primarily for the purpose of enhanced oil recovery. Operational experience with offshore CO_2 transmission pipelines is limited, however.

The current initiative originates from DNV's long engagement in developing standards and guidelines for offshore pipelines and the identified need to develop more specific guidelines for safe and cost-efficient design and operation of CO_2 pipelines. The new guideline will give "how to" answers and address the important issues related to both onshore and offshore CO_2 pipelines.

Industry Joining Forces

Stakeholders now demand a robust, traceable and transparent approach that gives credibility to responsible management of risks and uncertainties of CO_2 pipeline transmission. One barrier to effective large-scale deployment of CCS is the lack of recognized standards and guidelines.

DNV has, therefore, initiated a Joint Industry Project (JIP) with the objective of developing an industry guideline for transmission of CO_2 in pipelines. The planned date of issuing the new guideline is by the end of July 2009. The industry partners are StatoilHydro, BP, Shell, Vattenfall, Dong Energy, Petrobras, Arcelormittal, Gassco, Gassnova SF — the Norwegian state enterprise for carbon capture and storage, and ILF Consulting Engineers. Government representatives from the Netherlands, Norway, and the UK are involved as observers. Sintef, Institute for Energy Technology (IFE) and Polytec will assist on the technical content.

The Starting Point

During the last decade significant effort has been put into research on the social, economical, political and technical issues related to large-scale deployment of CCS. However, several technical issues remain unsolved. Through a comprehensive literature review and gathering of experience from existing CO_2 pipeline operators, the latest available knowledge will be applied as the starting point for developing the guideline.

Particularly for offshore pipelines, DNV conducted in 2007 a gap analysis on behalf of the Norwegian gas network operator Gassco, identifying the main technical challenges differentiating CO_2 pipelines from conventional oil and gas pipelines. Some examples of the knowledge gaps include fast propagating ductile fractures, materials compatibility, internal corrosion, effects of contaminants, safety and issues related to re-qualification of existing pipelines for transmission of CO_2.

What Is Dense Phase CO_2?

The physical state of CO_2 varies depending on pressure and temperature. It can exist as a solid, liquid, vapor (gas) or a supercritical fluid, as presented in Figure 1. The term "dense phase" is a collective term for CO_2 when it is in either the supercritical or liquid states. For most CCS projects economics will drive the need to transport CO_2 in its dense phase since vapor phase transmission would require considerably larger diameter pipelines for the same mass flow rate.

There is relatively little experience worldwide in managing the risks associated with CO_2, compared with oil and gas. The major accident hazards presented by handling high-pressure CO_2 offshore or onshore need to be considered.

Material Compatibility

Dense phase CO_2 is highly invasive and capable of dissolving materials. This property means that the selection of materials for seals, instruments, controls and other safety-critical components should be approached with great care.

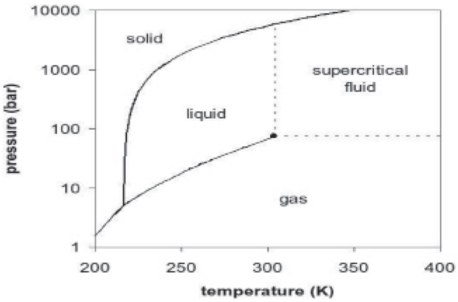

Figure 1: CO_2 phase diagram, as a function of temperature and pressure.

Seal elastomers are known to be vulnerable to explosive decompression damage, particularly when exposed to supercritical CO_2. Explosive decompression is a condition that occurs after an elastomer is exposed to high-pressure gas or supercritical fluid. The pressure compresses the gas/fluid and forces it into the microscopic pores of the elastomer.

While operating under the pressurized condition, no harmful effects are noted. The problem occurs when the system is rapidly depressurized. As the pressure outside the elastomer falls below that of the gas contained in the elastomer, the gas begins to expand and move toward the surface, leading to fractures or ruptures in the elastomer.

CO_2 readily dissolves in water to form carbonic acidic solution that is highly corrosive to many engineering materials. The accelerating effect this has on corrosion rates is a particularly important safety issue when considering the maintenance schedules and operating life expectancies for pipelines that were not originally designed for CO_2 use.

Structural Integrity

Due to the vulnerability of most pipelines to the presence of carbonic acid, one of the most critical factors to control is the water content of the CO_2 entering the pipeline. Carbonic acid can lead to corrosion rates up to 1-2 mm within two weeks. A defective dehydration unit within the CO_2 capture facility could lead to free water either flowing into the pipeline or precipitating out along the pipeline. If this water collects at low points, corrosion could be an immediate issue. In contrast to CO_2 gas, dense phase CO_2 has the ability to store several hundred ppm of water, depending on the temperature. However, if the pressure falls, water may precipitate out and create carbonic acid.

Fracture propagation and arrest in high-pressure pipelines has been the subject of study for many years but there is only limited experience with CO_2 pipelines. Propagating fractures initiate at sites where an initial flaw, most often the result of corrosion or mechanical damage (e.g. digger impact or anchor impact if the pipeline is subsea), has exceeded the critical length or crack tip opening displacement. There are two fracture-failure mechanisms, namely, brittle and ductile, and both can result in pipelines unzipping very rapidly along a considerable distance sometimes measured in kilometers.

Depressurization of a dense phase CO_2 pipeline can, if not carefully controlled, result in a significant proportion of the original inventory being deposited as solid CO_2 at low points within the pipeline. At atmospheric pressure these solids will be at -78°C and therefore there is the potential for metallurgical damage to occur. Also, if the solid CO_2 is then warmed rapidly, say by the reintroduction of dense phase CO_2, there is a likelihood of pipeline over-pressurization due to the rapid increase in volume as the solid sublimes into the vapor phase.

Depressurizing a pipeline in a manner that prevents solid formation and excessive material cooling can be achieved during normal operations, but should an uncontrolled depressurization occur, for example, due to a leak, the solids and cooling issues will occur and have to be considered in the design process.

Hydrates may cause ice plugs which could clog the pipeline system. There is a degree of uncertainty as to whether free water in dense phase CO_2 will form hydrates before carbonic acid, but there will be a dependency on the CO_2 pressure, temperature and, not the least, the water content. If the pressure is high, there is a higher risk for hydrate formation. If the pressure is low, there is a higher likelihood for corrosion.

Safety Issues

The dangers of breathing in elevated concentrations of CO_2 are well known to people such as divers, submariners, anaesthetists and astronauts. Outside these specialist communities, knowledge about the impact of breathing elevated concentrations of CO_2 is generally low. Concentrated CO_2 inventories may be present, for example, as part of a fire-suppression system, but the potential for persons to be exposed to CO_2 inhalation are usually localized and the associated safety risks can be effectively managed through localized hazard-management measures.

With the advent of CCS, pipeline systems are likely to have inventories of dense phase CO_2 in the order of tens if not hundreds of thousands of metric tons. The potential exists for widespread population exposure to elevated concentrations of CO_2.

It is known that, in addition to the hazard of asphyxiation due to released CO_2 displacing oxygen in the air, the inhalation of elevated concentrations of CO_2 can increase the acidity of the blood, triggering adverse effects on the respiratory, cardiovascular and central nervous systems. Depending on the CO_2 concentration inhaled and the exposure duration, toxicological symptoms in humans range from headaches, increased respiratory and heart rates, dizziness, muscle twitching, confusion, unconsciousness, coma and death.

Breathing air with a CO_2 concentration of above 5% can pose a significant hazard to people due to the toxicological effects. Inhaling 30% CO_2 would be fatal within just minutes, well before asphyxiation impairment could occur.

It is essential that the risks to people and the environment in the vicinity of a CO_2 pipeline be robustly assessed and effectively managed down to an acceptable level. To achieve this, CO_2 hazard-management processes, techniques and tools require critical examination and validation. The guideline will describe best practice within this subject area.

Recommended Practice

Today, there exists no recommended practice or a guideline on transmission of supercritical CO_2, and the challenge is to combine the different standards with today's CO_2 transmission practice.

There are various codes and standards available that are applicable to pipeline design and operation including the U.S. Federal Code of Regulations, ASME Standards B31.4 and B31.8, IP6, BS EN 14161, BS PD 8010, ISO13623, API RP1111 and DNV OS-F101. The guideline under development will provide specific guidance with respect to CO_2 and will supplement the existing pipeline design standards. ***P&GJ***

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