Risk Aspects Related to Pipeline Transmission of CO2

Workshop on Future Large CO2 Compression Systems
Gaithersburg March 30-31, 2009

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What is this talk about?

- Intro:
  - About risk management
  - About CCS
  - About CO₂ pipeline transportation

- Risk aspects
  - Is CO₂ dangerous?
  - Concerns about CO2 transmission
  - Dispersion assessments
RISK and Rewards

- No risk – no business

- Risk Management is to:
  - Understand and control the risks
  - Take the right risks
  - Balance risk and reward for all stakeholders

Opportunities

Risks
Risk management strategies

- Quantitative Risk Assessment
- Qualitative Risk Assessment
- Codes and Procedures
- Rules and Regulations

- Prescriptive risk management
  - Regulatory driven
  - Repetitive technology

V.S.

- Analytical risk management
  - Operator driven
  - Evolving technology
The basic elements of risk assessment

What Can Go Wrong?
Hazard Identification

How Often?
Frequency Analysis

How Big?
Consequence Analysis

So What?
Risk Assessment

What Do I Do?
Risk Mitigation

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09 April 2009
Types of risks in CCS

- Political risks (incentives, future regulations, legal responsibilities)
- Commercial uncertainties (energy prices, value of CO₂, land rights)
- Reliability (new technologies, different medium)
- Safety risks (releases and dispersion)
- Environmental risks (releases and dispersion)
Risk acceptance

- Risk acceptance involves a subjective balancing of benefits with risks.

- Two people who may agree on the degree of risk involved may disagree on its acceptability.

- *Environmental risks* are linked to consequences of significance to the nature and the people using it.

- *Environmental risk* is thus a public concern

- The public can not always see the benefits of taking the risks
Two key challenges – for all of us

Need for energy

Climate change
Carbon Capture and Storage – The solution?

Capture
- Fossil power plants
- Natural Gas CO₂ reduction
- Other industrial processes

Transport
- Pipelines
- Ships

Storage
- Empty oil or gas reservoirs
- Saline aquifers
- Enhanced Oil Recovery
Transportation of Super Critical CO2

- The CO₂ sources and sinks are not all in geographical proximity.
- The need for pipelines for CCS may therefore be considerable.
CO₂ pipelines – a booming industry?

IEA’s proposed mix of means to stabilize the CO₂ concentration in the atmosphere to 450 ppm by 2030 includes 2.3 Gt/year by CCS.

This would imply that the future amount of captured CO₂ will be in the same order of magnitude as today’s natural gas production.
**CO₂ – A different risk exposure**

- **😊 CO₂ is inflammable**
- **😊 CO₂ is not toxic in normal concentration**
- **😊 A single CO₂ release has insignificant environmental impact**

- **😢 Other chemical constituents (as H₂S) carried in the CO₂ may harm people and the environment**

- **😢 Concentrated CO₂ can displace oxygen and cause asphyxia**

- **😢 Elevated CO₂ levels causes neurological effects ranging from flushed skin, muscle twitches and raised blood pressure to disorientation, convulsions, unconsciousness and death (IDLH¹) level is set to 4%)**

- **😢 CO₂ is heavier than air and may fill up sunken areas and confined spaces. Safety zones for NG can therefore not be adopted directly.**

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¹) IDLH: “Immediately Dangerous to Life and Health”
UK HSE Exposure Criteria

Asphyxia by O2 displacement ≈ 30%  

- 1% mortality  
- 50% mortality  

Air exhaled by humans (4% - 5%)  

Dry air (0.04%)
CO₂ – An enhanced risk exposure

- The future CO₂ pipeline infrastructure may become several hundreds times larger than today.
- The CO₂ will be transported in highly concentrated form at high pressure (dense phase).
- The need to locate CHP coal power plants near consumers implies that CO₂ pipelines will pass through more densely populated areas.
- Thus, large populations will be exposed to a risk, which for them will be perceived as new.
Concerns related to CO$_2$ transmission

**Root causes:**
- Emergency blowdown of large dense phase inventories
- Accidental denting
- CO$_2$ corrosion leaks in case of accidental intake of water
- Material compatibility (elastomers, polymers)
- Ductile fracture (“un-zipping”)

**Consequences:**
- Dispersion of concentrated CO$_2$
- Dispersion of toxic impurities
- Pipeline damage/downtime
Frequency Analysis

The incident rate for onshore natural gas pipelines is $\approx 0.00008 \text{ km}^{-1} \text{ yr}^{-1}$ due to:
- Corrosion (30%)
- Third party (42%)
- Design (7%)
- Incorrect operation (13%)
- Natural hazards (8%)

The incident rate (from only 10 incidents) for CO$_2$ pipelines is $\approx 0.00032 \text{ km}^{-1} \text{ yr}^{-1}$ due to:
- Corrosion (20%)
- Third party (10%)
- Relief valve failure (40%)
- Weld/gasket/valve packing failure (30%)
CO₂ corrosion

- CO₂ in free water phase creates carbonic acid \((\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3)\) which is highly corrosive to C-Mn steels

- At high partial pressures of CO₂ the corrosion rates are expected to be dramatically higher than experienced for O&G pipelines

- We do not have models for predicting CO₂ corrosion rates which are valid for \(P>10\) bar and \(T<20^\circ\text{C}\)

- Experimental data for high pressure CO₂ are few

- We have little insight in the effect of impurities. Mixtures of CO₂ streams from different sources makes the picture complex.
CO₂ corrosion

- Design basis:
  Dehydration to ensure no formation of free water under any operational condition. (No corrosion allowance needed.)

- What if an accidental intake of humidity?
  - Can the pipeline be considered undamaged if the situation is quickly restored to normal?
  - Should/can the pipeline be inspected for corrosion damage?
  - What kind of monitoring is required?

⇒ There is a need to understand more about corrosion rates in case of accidental intake of humidity
Consequence analyses: Dispersion modeling

- Today’s **software** for release and dispersion analyses are incomplete with respect to CO2
  - Phase transformations directly between gas and solid (deposition/sublimation)
- The calculations models have not been sufficiently validated by **large scale experiments**
- Proper understanding of CO₂ dispersion is essential to setting **safety zones** (land sequestration) and determine insurance liability
BP tests at Spadeadam in UK (DF1)
Dispersion Modelling Examples (1)
Dispersion Modelling Examples (2)

10% hazard range
100 mm diameter pipeline
150 barg pressure
① Onshore
② Underground
③ Underwater
④ Offshore platform
Dispersion Modelling Examples (3)

Venting 100% CO₂ with 200ppm H₂S at 416 tonnes/hr (10,000 Tonnes/day) through 36” vent with 0.5m/s wind.
Blue isosurface = 0.5% CO₂ (LTEL)
Green isosurface = 13ppm H₂S (odour threshold)
Approach:
Recommended Practice for design of CO₂ pipelines

- Existing pipeline design codes do not adequately address issues which are specific to CO₂ transmission

- DNV is developing a Recommended Practice (RP) for transportation of dense phase CO₂, together with 12 industry partners

- The RP will supplement current design codes such as ASME B31.8, ISO 13623, DNV OS-F101, API RP1111, BSI PD 8010, EN 14161, EN-1594.

- Phase 1:
  - A guideline incorporating current knowledge
  - To be issued in 2009

- Phase 2:
  - Investigations into selected knowledge gaps
  - A revised guideline within 2 – 3 years
RISK and Rewards

- No risk – no business …

- … but risks have to be managed!

Thank you!