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COACH project purity requirements of the carbon dioxide stream for geological storage

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Foreword

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Contents

Foreword	2
Acknowledgements	2
Contents	2
Summary	3
1 Introduction	3
2 Purity of the CO₂ stream for geological storage	3
2.1 Temperature, pressure and impurities	3
2.2 Capture.....	4
2.3 Conditions in the pipelines or transport ship	5
2.4 Impurities.....	5
2.5 Effect of impurities on enhanced oil recovery.....	6
3 Conclusions	6
Glossary	7
References	7

FIGURES

Error! No table of figures entries found.

TABLES

Table 1 temperature and pressure.....	3
---------------------------------------	---

Table 2 Suggested acceptable levels of impurities based on previous research 4

Summary

This report describes the results of a desktop study into the required purity of the carbon dioxide (CO₂) stream for geological storage of CO₂ from a storage perspective. The first part of the report describes the required temperature and pressure conditions to maintain CO₂ in a highly dense state which is favourable for storage. The report also describes impurity requirements as applied to CO₂- enhanced oil recovery and storage programmes currently underway.

1 Introduction

The required purity and conditions of the CO₂ (carbon dioxide) stream are variable dependent on conditions in the storage site, whether the CO₂ will be used for EOR (enhanced oil recovery) or if the site is being used purely for storage and the method of transportation. The potential effect of impurities on the injection well and pipelines must also be considered.

For the COACH project it has been assumed that the CO₂ stream should be of acceptable quality to be usable for EOR or storage in aquifers as both these options are being considered. The requirements given here are based on reported specifications for EOR projects on the basis that the technology for transporting and injecting CO₂ at these specifications has been carried out and is therefore proven. It is also assumed that the storage site conditions will be selected such that CO₂ is stored and injected in a dense phase (above pressures of 70 bars or so, depending on geothermal gradient (Chadwick 2008)).

It was assumed that the CO₂ stream would not be 100% pure CO₂ when captured at source and that purification of the flue gases or feedstock to produce a higher-purity stream would incur a cost, therefore the upper acceptable limits for impurities for CO₂ storage were researched. The values given in this report are based on published data from projects in progress and published experimental results.

2 Purity of the CO₂ stream for geological storage

2.1 TEMPERATURE, PRESSURE AND IMPURITIES

This report sets out the suggested CO₂ requirements of the CO₂ stream for the COACH project based on information from publicly available sources on current practical CO₂ transportation projects and experimental corrosion evidence (Tables 1 and 2). Generally, it is recommended that the purity of the CO₂ stream should be 95% or greater (Shah 2005).

Table 1 temperature and pressure

Temperature in pipeline	< 48.9 °C (Metz et al 2005)
Pressure in pipelines	70 – 140 bar (Tzimas et al 2005)

Depth of burial of pipelines	1-2 m (CO2net 2004, Metz et al 2005)
Temperature in transport ship	Standard semi-refrigerated LPG ships could carry it at -54 °C per 6 bar or -50 °C per 7 bar (Metz et al 2005)
Pressure in transport ship	Standard semi-refrigerated LPG ships could carry it at 6 - 7 bar) (Audus 2006, Metz et al 2005)
Temperature in storage site	Injected in highly dense fluid phase > 31 °C (Svensson et al 2008)
Pressure at storage site	Injected at high pressure, e.g. 100 – 170 bar (wellhead pressure) (Svensson et al 2008, UKDTI 2002)
Density in storage site	Around 700 kg m ⁻³ (CO ₂ is in highly dense fluid phase) (Svensson et al 2008)

Table 2 Suggested acceptable levels of impurities based on previous research

Purity	> 95 % CO ₂ (Shah 2005)
Water H ₂ O	< 0.48 g m ⁻³ in the vapour phase and no free water (Metz et al 2005) < 0.016 g m ⁻³ in Weyburn (UKDTI 2002)
Hydrogen sulphide H ₂ S	< 0.15 g m ⁻³ (Alberta 2006)
Hydrogen , H ₂	< 4% (Yorkshire Forward 2008)
Sulphur Oxides SO _x	< 10 ppm (Audus 2006)
Total sulphur S	< 1.875 g m ⁻³ by weight (Metz et al 2005)
Oxygen O ₂	< 0.013 g m ⁻³ by weight is preferred (Shah 2005) up to 0.07 g m ⁻³ is acceptable (UKDTI 2002)
Nitrogen N ₂	< 0.37 g m ⁻³ (UKDTI 2002)
Nitrogen dioxide NO ₂	< 0.026 g m ⁻³ (Audus 2006)
Nitrogen oxides NO _x	< 0.01% (Yorkshire Forward 2008)
Methane CH ₄	< 0.7 % (UKDTI 2002)
Carbon monoxide CO	< 0.1 % (UKDTI 2002)
Hydrocarbons	< 4% and dew point not exceeding -28.9 °C (Metz et al 2005) Weyburn 0.1 % C ₂ + hydrocarbons (UKDTI 2002)
Argon, Ar	< 4% (Yorkshire Forward 2008)
Glycol	< 4x10 ⁻⁵ L m ⁻³ and at no time should the glycol be present in a liquid state in the pipeline (Metz et al 2005)

2.2 CAPTURE

Typical impurities of Oxy-fuel power plants are oxygen (O₂), sulphur dioxide (SO₂), and nitric oxide (NO). Typical impurities for IGCC (integrated gasification combined cycle) plants are hydrogen (H₂), carbon monoxide (CO) and hydrogen sulphide (H₂S) (Metz et al 2005).

Prior to absorption, the flue gas needs to be cooled and impurities need to be removed. Nitrous and sulphurous oxides, NO_x and SO_x form heat-stable corrosive salts that cause operational problems and solvent losses. Sulphur trioxide (SO₃) also forms corrosive sulphuric acid aerosols (H₂SO₄). Fly ash (ash suspended in exhaust gases of the plant) may cause foaming in the absorber and stripper as well as erosion, corrosion and increased solvent loss (CO₂net 2004). Additionally drying CO₂ with SO₂ present is more difficult (Shah 2005).

2.3 CONDITIONS IN THE PIPELINES OR TRANSPORT SHIP

Carbon dioxide pipelines are typically made of carbon manganese steel (sometimes known as mild steel, comprising mainly carbon and steel with minor amounts of manganese (<1.65%) and other elements). A higher carbon-content makes the carbon steel alloy stronger, more difficult to weld and reduces the temperature tolerance of the alloy. Stainless steel (also known as 'corrosion-resistant' steel) pipelines are more corrosion resistant than carbon steel pipelines as the alloy includes chromium (<11.5%), however they are also more expensive (Shah 2005, Metz et al 2005, Nesic et al 2001, Wikipedia 2008a, b).

In most USA pipelines, pressure of CO₂ is around 120 - 140 bar (CO₂net 2004) though worldwide, pressures of 70 - 140 bar are reported (Tzimas et al 2005). Compressors are generally required along the pipeline every 160 – 400 km to maintain pressure (Metz et al 2005). The majority of CO₂ pipelines in the USA are buried deeper than 1m (CO₂net 2004). Pipeline diameter is dictated by regulations, cost and CO₂ properties. The main advantage of transporting the CO₂ at high pressure is that it requires little compression before injection into the storage site.

Existing ships designed for carrying CO₂ transport it in a liquid phase at 14 - 17 bar and -25 to -30 °C for EOR. However, the quantities that can be transported like this are too small for CCS (they could carry 850 – 1400 tonnes of CO₂) (Svensson et al 2008). Standard semi-refrigerated LPG (liquid petroleum gas) ships designed to carry LPG (liquid petroleum gas) in pressurised and cooled conditions could transport 24000 tonnes of CO₂ at 7 bar and -50 °C which is near the critical point of CO₂ (Svensson et al 2008, Metz et al 2005).

2.4 IMPURITIES

Overall, a pure CO₂ stream is preferred as the cost of compression and power required for processing the CO₂ stream increase as percentage of impurities increases (Shah 2005). A purer CO₂ stream also simplifies assessing the effects of impurities on infrastructure, potential reactions with the storage site lithologies or pore water. There is some variation in the recommended purity of CO₂ in the literature. In this report, the lowest figure has been given on the grounds that the purest CO₂ stream is preferred, however, it may be worth considering raising the recommended limits for these impurities if removal is prohibitively expensive and if the transport network and storage site were able to tolerate the higher levels of impurities.

In general, impurities decrease the critical temperature and increase the critical pressure of CO₂ such that the fluid needs to be kept at a higher pressure to remain in a highly dense phase. There are three notable exceptions however; hydrogen sulphide (H₂S), sulphur dioxide (SO₂) and nitrogen dioxide (NO₂) increase both the critical temperature and pressure, such that more energy is required to maintain the fluid in its highly dense phase.

Water is the most critical impurity for CO₂ transport. Carbon dioxide combines with water to form carbonic acid (H₂CO₃) and also reacts with iron in the steel causing corrosion (Fe + CO₂ + H₂O → FeCO₃ + H₂). Corrosion on carbon steel pipelines can be as much as 0.7 mm/year for experiments with CO₂ and free water at 95 bar and 40 °C tested over 150 - 300 hours with both carbon steel and 0.5 chromium corrosion-resistant alloy (Seiersten 2001).

Dry CO₂ generally does not corrode pipelines. The presence of N₂, NO_x and SO_x impurities also do not contribute to corrosion (Metz 2005). Seiersten (2001) gave the rate of corrosion with dry

highly dense-phase CO₂ to be equivalent to 0.01 mm/year for CO₂ at 90 - 120 bar and 160 -180 days (tested over 200 days) for carbon steel. Some current CO₂ pipelines are protected from external corrosion by cathodic protection, i.e. a small electric current is passed through the pipeline (UKDTI 2002).

Although hydrogen sulphide (H₂S) can enhance the ability of CO₂ to mix with oil for EOR and could be injected with the CO₂, its level is normally restricted due to its toxicity at concentrations as low as 500 ppm and severe irritation as low as 100 ppm (Alberta 2006). The first large pipeline for CO₂ in the USA, the SACROC (Scurry Area Canyon Reef operators Committee) pipeline specified up to 1500 ppm (1.939 g m⁻³) was acceptable, and the Weyburn project specified less than 2% H₂S. It is preferred for safety reasons that for the COACH project, a low concentration of H₂S is present. Hydrogen sulphide also contributes to pipeline corrosion (Metz et al 2005).

For safety reasons, it is preferred that the oxygen content of the CO₂ stream is low to reduce risk of fire (Shah 2005). Also absorption solvents are degraded by oxygen and other impurities (Audus 2006).

The recommended limit for NO_x and SO_x impurities is variable, here the lowest specifications have been given such that the CO₂ stream should be suitable for EOR, aquifer or hydrocarbon field storage and that the critical temperature and pressure of the CO₂ stream should be relatively unaffected. There is great variation in the recommendations, for example, Yorkshire Forward (2008) specifies that up to 100 ppm of SO_x and NO_x can be tolerated from power plant (post combustion, IGCC or oxyfuel plant) for EOR or aquifer storage. However, Audus (2006) recommended that SO_x should be restricted to < 10 ppm and NO₂ restricted to < 20 ppm to reduce solvent losses.

The acceptable limit of methane, CH₄, is given as up to 4% for aquifer storage and up to 2% for EOR by Yorkshire Forward (2008). However, the most stringent figure of 0.07% from UKDTI (2002) has been selected as an idealised figure for the COACH specifications.

2.5 EFFECT OF IMPURITIES ON ENHANCED OIL RECOVERY

Suitability of the stream for EOR depends on the reservoir depth, the oil's API and the minimum miscibility pressure (MMP). Below the MMP (minimum miscibility pressure), CO₂ increases oil recovery by swelling the oil and decreasing the mixture viscosity. Above the MMP, the CO₂ acts as a solvent with the oil. If the impurities in the CO₂ stream have a greater critical temperature than CO₂, the MMP will decrease. Sulphur dioxide (SO₂), hydrogen sulphide (H₂S) and carbon (C₃) decrease MMP whereas oxygen (O₂), nitrogen (N₂), argon (Ar) and nitric oxide (NO) increase MMP (Shah 2005).

3 Conclusions

The CO₂ stream needs to be at least 95% pure in CO₂ to be suitable for geological storage. However, the allowable levels of impurities are dictated more by infrastructure than the geological formation in which the fluid will be stored as pipeline corrosion and safety issues for transport are highly influential on the required purity of the CO₂ stream for storage. The pipeline, compression and injection infrastructure are more sensitive to impurities in the CO₂ stream than the geological reservoir formation.

Glossary

EOR (Enhanced Oil Recovery); Water, CO₂ or other chemicals are injected into an oilfield after primary production (under initial reservoir pressure) to force more oil out of the reservoir.

Minimum Miscibility Pressure (MMP); The pressure above which the injected fluid displaces almost all the oil in the swept region.

Oxy-fuel power plant; Pulverised coal or coal syngas are burned in the presence of oxygen and recycled-CO₂-rich flue gas rather than air.

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