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

CCS Programme

Open Report OR/08/050

BRITISH GEOLOGICAL SURVEY

CCS PROGRAMME

OPEN REPORT OR/08/050

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

C J Vincent

Keywords

Report; keywords.

Bibliographical reference

VINCENT C J COACH PROJECT PURITY REQUIREMENTS OF THE CARBON DIOXIDE STREAM FOR GEOLOGICAL STORAGE . 2010. COACH project purity requirements of the carbon dioxide stream for geological storage . *British Geological Survey Open Report*, OR/08/050. 11pp.

Keyworth, Nottingham British Geological Survey 2010

BRITISH GEOLOGICAL SURVEY

The full range of our publications is available from BGS shops at Nottingham, Edinburgh, London and Cardiff (Welsh publications only) see contact details below or shop online at www.geologyshop.com

The London Information Office also maintains a reference collection of BGS publications, including maps, for consultation.

We publish an annual catalogue of our maps and other publications; this catalogue is available online or from any of the BGS shops.

The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as basic research projects. It also undertakes programmes of technical aid in geology in developing countries.

The British Geological Survey is a component body of the Natural Environment Research Council.

British Geological Survey offices

BGS Central Enquiries Desk

Tel 0115 936 3143 Fax 0115 936 3276
email enquiries@bgs.ac.uk

Kingsley Dunham Centre, Keyworth, Nottingham NG12 5GG

Tel 0115 936 3241 Fax 0115 936 3488
email sales@bgs.ac.uk

Murchison House, West Mains Road, Edinburgh EH9 3LA

Tel 0131 667 1000 Fax 0131 668 2683
email scotsales@bgs.ac.uk

Natural History Museum, Cromwell Road, London SW7 5BD

Tel 020 7589 4090 Fax 020 7584 8270
Tel 020 7942 5344/45 email bgslondon@bgs.ac.uk

Columbus House, Greenmeadow Springs, Tongwynlais, Cardiff CF15 7NE

Tel 029 2052 1962 Fax 029 2052 1963

Forde House, Park Five Business Centre, Harrier Way, Sowton EX2 7HU

Tel 01392 445271 Fax 01392 445371

Maclean Building, Crowmarsh Gifford, Wallingford OX10 8BB

Tel 01491 838800 Fax 01491 692345

Geological Survey of Northern Ireland, Colby House, Stranmillis Court, Belfast BT9 5BF

Tel 028 9038 8462 Fax 028 9038 8461

www.bgs.ac.uk/gsni/

Parent Body

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon SN2 1EU

Tel 01793 411500 Fax 01793 411501
www.nerc.ac.uk

Website www.bgs.ac.uk
Shop online at www.geologyshop.com

Foreword

This report is the published product of a study by the British Geological Survey (BGS) as part of the COACH (Cooperation-action within Carbon Capture and Storage China-EU) EU Framework 6-funded project.

Acknowledgements

The author would like to thank Andy Chadwick and Karen Kirk for their invaluable comments and contribution to this report.

Contents

FIGURES

TABLES

Summary

This report describes the results of a desktop study into the required purity of the carbon dioxide (CO_2) stream for geological storage of CO_2 from a storage perspective. The first part of the report describes the required temperature and pressure conditions to maintain CO_2 in a highly dense state which is favourable for storage. The report also describes impurity requirements as applied to CO_2- enhanced oil recovery and storage programmes currently underway.

1 Introduction

The required purity and conditions of the CO_2 (carbon dioxide) stream are variable dependent on conditions in the storage site, whether the CO_2 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 CO_2 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 CO_2 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 CO_2 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 CO_2 stream would not be 100% pure CO_2 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 CO_2 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 CO_2 stream for geological storage

2.1 TEMPERATURE, PRESSURE AND IMPURITIES

This report sets out the suggested CO_2 requirements of the CO_2 stream for the COACH project based on information from publicly available sources on current practical CO_2 transportation projects and experimental corrosion evidence (Tables 1 and 2). Generally, it is recommended that the purity of the CO_2 stream should be 95% or greater (Shah 2005).

Table 1 temperature and pressure

Temperature in pipeline	< 48.9 ºC (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 ºC per 6 bar or -50 ºC 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 ºC (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_2O	< 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_2S	< 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 ºC (Metz et al 2005) Weyburn 0.1 % C2+ hydrocarbons (UKDTI 2002)
Argon, Ar	< 4% (Yorkshire Forward 2008)
Glycol	< 4×10^{-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 (O_2), sulphur dioxide (SO_2), and nitric oxide (NO). Typical impurities for IGCC (integrated gasification combined cycle) plants are hydrogen (H_2), carbon monoxide (CO) and hydrogen sulphide (H_2S) (Metz et al 2005).

Prior to absorption, the flue gas needs to be cooled and impurities need to be removed. Nitrous and sulphurous oxides, NOx and SOx form heat-stable corrosive salts that cause operational problems and solvent losses. Sulphur trioxide (SO_3) also forms corrosive sulphuric acid aerosols (H_2SO_4). 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 CO_2 with SO_2 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 CO_2 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 CO_2 pipelines in the USA are buried deeper than 1m (CO2net 2004). Pipeline diameter is dictated by regulations, cost and CO_2 properties. The main advantage of transporting the CO_2 at high pressure is that it requires little compression before injection into the storage site.

Existing ships designed for carrying CO_2 transport it in a liquid phase at 14 - 17 bar and -25 to -30 ºC for EOR. However, the quantities that can be transported like this are too small for CCS (they could carry 850 – 1400 tonnes of CO_2) (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 CO_2 at 7 bar and -50 ºC which is near the critical point of CO_2 (Svensson et al 2008, Metz et al 2005).

2.4 IMPURITIES

Overall, a pure CO_2 stream is preferred as the cost of compression and power required for processing the CO_2 stream increase as percentage of impurities increases (Shah 2005). A purer CO_2 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 CO_2 in the literature. In this report, the lowest figure has been given on the grounds that the purest CO_2 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 CO_2 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 (H_2S), sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) 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 CO_2 transport. Carbon dioxide combines with water to form carbonic acid (H_2CO_3) and also reacts with iron in the steel causing corrosion ($Fe + CO_2 + H_2O \rightarrow FeCO_3 + H_2$). Corrosion on carbon steel pipelines can be as much as 0.7 mm/year for experiments with CO_2 and free water at 95 bar and 40 ºC tested over 150 - 300 hours with both carbon steel and 0.5 chromium corrosion-resistant alloy (Seiersten 2001).

Dry CO_2 generally does not corrode pipelines. The presence of N_2, 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 CO_2 to be equivalent to 0.01 mm/year for CO_2 at 90 - 120 bar and 160 -180 days (tested over 200 days) for carbon steel. Some current CO_2 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 (H_2S) can enhance the ability of CO_2 to mix with oil for EOR and could be injected with the CO_2, 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 CO_2 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% H_2S. It is preferred for safety reasons that for the COACH project, a low concentration of H_2S 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 CO_2 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 CO_2 stream should be suitable for EOR, aquifer or hydrocarbon field storage and that the critical temperature and pressure of the CO_2 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 NO_2 restricted to < 20 ppm to reduce solvent losses.

The acceptable limit of methane, CH_4, 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 IMPURITES 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), CO_2 increases oil recovery by swelling the oil and decreasing the mixture viscosity. Above the MMP, the CO_2 acts as a solvent with the oil. If the impurities in the CO_2 stream have a greater critical temperature than CO_2, the MMP will decrease. Sulphur dioxide (SO_2), hydrogen sulphide (H_2S) and carbon (C_3) decrease MMP whereas oxygen (O_2), nitrogen (N_2), argon (Ar) and nitric oxide (NO) increase MMP (Shah 2005).

3 Conclusions

The CO_2 stream needs to be at least 95% pure in CO_2 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 CO_2 stream for storage. The pipeline, compression and injection infrastructure are more sensitive to impurities in the CO_2 stream than the geological reservoir formation.

Glossary

EOR (Enhanced Oil Recovery); Water, CO_2 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-CO_2-rich flue gas rather than air.

References

British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: http://geolib.bgs.ac.uk.

ALBERTA 2006: Workplace health and safety bulletin hydrogen sulphide at the work site CH029 http://employment.alberta.ca/documents/WHS/WHS-PUB_ch029.pdf

AUDUS, H. 2006; IEAGHG Presentation: An update on CCS: recent developments Paris workshop October 2006

CHADWICK, R. A. 2008 pers comm

CO2NET 2004: Capturing and storing carbon dioxide: technical lessons learned September 2004 (internet)

METZ, M., DAVIDSON, O., DE CONINCK, H., LOOS, MANUELA AND MEYER, L. 2005: IPCC special report Carbon dioxide capture and storage.

NESIC, S., NORDSVEEN, M., MAXWELL, N. AND VRHOVAC, M. 2001: Proabilistic modelling of CO2 corrosion laboratory data using neural networks. Corrosion Science **43** pp1373-1392

PTRC 2007: Weyburn poster 2007 IEAGHG Weyburn-Midale CO_2 monitoring and storage project.

SEIERSTEN, M., 2001: Material selection for transportation and disposal of CO2. Proceedings Corrosion 2001, National Association of Corrosion Engineers, paper 01042.

SHAH, M. 2005: Capturing CO_2 from oxy-fuel combustion flue gas. Oxy-fuel combustion workshop, Cottbus, Germany Nov 29-30, 2005.

SVENSSON, R., ODENBERGER, M., JOHNSSON, F. AND STROMBERG, L. 2008: Transportation infrastructure for CCS – experiences and expected development (internet).

TZIMAS, E., GEORGAKAKI, A., GARCIA CORTES, C. AND PETEVES, S.D. 2005: Enhanced oil recovery using carbon dioxide in the European Energy system, Directorate General Joint Research Centre Institute for energy, Petten, the Netherlands, December 2005. Report EUR 21895 EN.

UKDTI 2002: United Kingdom Department of Trade and Industry; Carbon capture and storage, report of the DTI International Technology Service Mission to the USA and Canada, Advanced Power Generation Technology Forum.

WIKIPEDIA 2008A: http://en.wikipedia.org/wiki/Carbon_steel.

WIKIPEDIA 2008B: http://en.wikipedia.org/wiki/Stainless_steel.

YORKSHIRE FORWARD 2008: A carbon capture and storage network for Yorkshire and Humber. An introduction to understanding the transportation of CO_2 from Yorkshire and Humber emitters into offshore storage sites.