North Sea
Transition
Authority

Guidance for Measurement of Carbon Dioxide for Carbon Storage Permit Applications

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Contents

The document can be found on the NSTA's website.

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Introduction

The Oil and Gas Authority ('**OGA**') is now operating as the North Sea Transition Authority ('**NSTA**') and will be referred to as the NSTA in this document. The OGA remains the legal name of the company, and all licences and other legal documentation will continue to refer to the OGA.

The storage of carbon dioxide in the United Kingdom's territorial waters and on the United Kingdom Continental Shelf ('**UKCS**') is subject to a licensing regime overseen by the NSTA. Anyone who wishes to explore for or use a geological feature for the long-term storage of carbon dioxide in a UK offshore area must hold a Carbon Dioxide Appraisal and Storage Licence ('CS Licence'), pursuant to section 18 of the Energy Act 2008 (the '**Act**'). Under a CS Licence, Licensees require the grant of a storage permit by the NSTA for the construction of facilities for the purpose of injection of carbon dioxide with a view to storage within the licensed area and for such storage.

As part of that storage permit application, the CS Licensee must set out how it will meet the NSTA's expectations with respect to the measurement of carbon dioxide ('**CO_2**'). This guidance sets out some of the proposed methods for such measurement and indicates where the CS Licensee will need to reach agreement with the NSTA on its proposed approach.

This guidance is not a substitute for any regulation or law and is not legal advice. It does not have binding legal effect. Where the NSTA departs from the approach set out in this guidance, the NSTA will endeavour to explain this in writing to the person seeking a decision from the NSTA.

The guidance will be kept under review and amended as appropriate in the light of further experience and developing law and practice, and any changes to the NSTA's powers and responsibilities. If the NSTA changes its guidance in a material way, it will publish a revised document.

Regulatory requirements for measurement[1]

There are two distinct regulatory requirements for measurement of bulk quantities of CO_2 transported to and injected into offshore reservoirs:

i. For financial accounting and emissions-trading purposes, the mass of CO_2 sequestrated must be quantified to a level of uncertainty defined by the relevant trading scheme (e.g. the UK Emissions Trading Scheme, '**UK-ETS**') from which carbon credits will accrue. This takes place in two stages:
   - Measurement of bulk fluid quantities (herein referred to as rich CO_2)
   - Determination of CO_2concentration to determine pure CO_2 quantities.

ii. Quantities of CO_2 delivered at each injection point must be determined at a level of uncertainty that is low enough to meet the requirements of the relevant reservoir models.

Measurement of the composition of the bulk fluid must also be determined at all necessary stages so that:

- The phase behaviour of the fluid remains as predicted by the relevant equation of state at the given operating pressure and temperature, for flow assurance purposes. In addition, the phase behaviour must be properly understood for the purposes of reservoir management.
- The presence of contaminants may be identified for the purpose of ensuring integrity of pipelines and associated plant[2].

[1] It should be noted that the NSTA is not the Regulatory Authority for the UK Emissions Trading Scheme (UK-ETS); the CS Licensee should consult the relevant regulator in relation to any requirements under the provisions of the UK-ETS. Nevertheless, areas of overlap do exist and therefore reference is made in this document to certain UK-ETS requirements.
[2] For pipeline integrity purposes, fast-response tuneable diode laser (TDL) analysers are likely to be required to identify the presence of harmful contaminants in real time. For CO_2-accounting purposes, gas chromatography is likely to be the preferred method.

Measurement uncertainty

As with the regulatory requirements described above, measurement uncertainty requirements correspondingly fall into two distinct categories:

i. Measurement of quantities of pure CO_2 sequestrated must satisfy the uncertainty criteria of the Measurement, Monitoring and Reporting Regulations (MMR) of the relevant Emissions Trading Scheme (ETS). The UK-ETS generally requires a measurement uncertainty of less than ±2.5% in mass of CO_2, but it is envisaged that for commercial CCUS applications, the uncertainty requirement may be ±1.5% (mass of CO_2; i.e. including the uncertainty in determining the proportion of CO_2 in the rich fluid via sampling and analysis) or less.
   Allocation metering may be required where shared transportation systems are used to deliver CO_2 to multiple offshore injection hubs. Unless the operatorship across the entire system constitutes a single 'Legal Entity' it should be assumed that the measurement uncertainty at these allocation points will also have to meet the requirements of the UK-ETS.
   Where the process plant features the capability to vent quantities of CO_2, for example during planned maintenance activities, these quantities must be determined at a level of uncertainty that does not cause the overall determination of quantities of CO_2 stored to exceed the limit set by the trading scheme.
   A technical Annex detailing Transport and Shipping entry-requirements with respect to measurement, prepared by the Department for Energy Security and Net Zero, will form part of the UK government contracts with prospective Emitters.

ii. Uncertainty requirements for measurements used to determine injection flowrates will be set by the NSTA on a case-by-case basis. The NSTA may require the storage Operator at the injection stage to carry out a sensitivity analysis to determine whether the target uncertainties are sufficient for the purpose of reservoir management.

Process conditions

The measurement uncertainty mentioned above (±2.5% of mass of CO_2) is only achievable if the measurement takes place on single-phase fluid. The metering station should therefore be situated at a location in the process plant at which this condition is guaranteed, taking account of the predicted phase behaviour of the rich CO_2.

Phase behaviour of CO_2

The measurement of CO_2 may present particular technical challenges. Under typical process conditions, CO_2 may exist in the gas, liquid or supercritical phase. At or near the 'critical point', very large variations in density may occur as the fluid shifts between these phases.

Relatively small amounts of impurities may result in very significant changes in the phase behaviour of the fluid; two-phase flow, with the composition of each phase being different, may result. The concentration of and nature of any impurities may differ from one application to another, depending on the original source of the CO_2.

From the above, it follows that the fluid composition must be determined, and combined with an appropriate Equation of State, so that the phase behaviour may be predicted with a suitable degree of accuracy.

Measurement of rich CO_2 quantities

The proposed method of measurement for determination of bulk quantities of rich CO_2 transported offshore – and the location of the associated measurement system(s) – should be discussed with the NSTA at the design stage.

A paper published in 2020 by NORCE, the Norwegian Research Centre[3], provides valuable practical guidance in the selection of meters at each stage of the CCUS process. In addition, a paper published in 2022 in the Journal of Flow Measurement and Instrumentation provides technical advice on some of the challenges associated with measurement and measurement traceability in CCUS applications[4].

Measurement and sampling

The fluid should be single-phase at the point of measurement. Possible technologies are:

- Differential pressure meters (orifice plate/Venturi).
- Coriolis meter.
- Ultrasonic meter.

Design considerations for each of these is presented below.

Differential Pressure Meters

Differential pressure meters (orifice plates, Venturis) have a long history of use in CO_2 measurement applications. In recent years, diagnostic techniques have been developed for differential pressures in natural gas applications, enabling the adoption of condition-based-monitoring (CBM) strategies. A recent technical paper[5] provides details of analogous techniques in CO_2 applications.

Differential pressure meters require the fluid density and fluid viscosity to be determined. Since the density term in the flow equation occurs under the square root sign, the additional uncertainty in the calculation of mass flow rate, compared with that from ultrasonic meters (see p.8), is reduced by a factor of two. However, the relatively high uncertainty in the determination of viscosity[6] may be a source of increased uncertainty in differential pressure meters compared to other measurement technologies.

[3] NORCE – NORWEGIAN RESEARCH CENTRE AS: Where do we stand on flow metering for CO_2 handling and storage? (NORCE Norwegian Research Centre AS, 38th North Sea Flow Measurement Workshop, 2020. The associated presentation may be accessed at the following URL: https://nfogm.no/wp-content/uploads/2022/01/D3_01-MB-Holstad-JB-Kok-NORCE.pdf
[4] MILLS, Dr. C. et. al. Flow measurement challenges for carbon capture, utilisation and storage, Flow Measurement and Instrumentation, Vol. 88, December 2022
[5] STOCKTON, P; WILSON, A; STEVEN, R; Meeting the Challenges of CO_2 Measurement with a new kind of Orifice Meter; 39th North Sea Flow Measurement Workshop, 2021
[6] HOLLANDER, H; Challenges of designing Custody-Transfer Metering Systems for CO_2, 39th North Sea Flow Measurement Workshop, 2021 – this paper suggests that the uncertainty in viscosity of CO_2 may be ~4% in the liquid phase, and as high as 10% near the critical point.

Unless otherwise agreed with the NSTA, Venturi meters should be flow calibrated in the interests of reducing measurement uncertainty; experience in oil and gas applications has shown that nominally identical Venturis may exhibit significantly divergent discharge coefficients.

Coriolis meters

Coriolis meters have the advantage of providing direct mass measurement, which may be an advantage in some applications[7], and they have been shown to work well on CO_2[8,9]. They, too, feature diagnostic features that can form part of a condition-based monitoring maintenance approach. Coriolis meters are also less susceptible to installation effects and do not require flow conditioning (such as extensive straight lengths of pipe) upstream of the meter, so while the mass footprint of the meter may be high, the space saving may more than compensate for this.

For these and other reasons, the recent review of CCUS measurement technology referred to above describes Coriolis meters as the "most versatile" solution. However, when used in super-critical fluid applications, account must be taken of the relatively high pressure drop that is an inherent feature of Coriolis meters.

Ultrasonic meters

Ultrasonic meters can be used to measure bulk quantities of CO_2. However, they must be configured accordingly, since the speed of sound in CO_2 is significantly lower than, for instance, in natural gas. Ultrasonic meters also offer advanced diagnostic features that may facilitate the adoption of condition-based monitoring strategies. In addition, these meters have the lowest pressure drop of any of the technologies considered here.

Ultrasonic meters provide a volume flow rate, which can be combined with density measurement to yield the mass flow rate. At present, however, it seems that ultrasonic meters need to be calibrated on CO_2, i.e. a calibration on natural gas or air is not transferrable. Therefore the use of ultrasonic meters may be dependent on the availability of a suitable (i.e. traceable) CO_2 flow facility (see p.11).

Ultrasonic meters are likely to be unsuitable in the super-critical phase, due to the high density of the fluid.

[7] As explained elsewhere in this document, the bulk fluid composition must be determined for other purposes and can be combined with an equation of state to yield a calculated fluid density which, combined in turn with a volume flow measurement, will yield the mass flow rate. However, there may nevertheless be advantages to direct mass measurement, especially in applications where the composition may be expected to vary

[8] For instance: VAN PUTTEN, D; Flow meter performance under CO_2 gaseous conditions, 39th North Sea Flow Measurement Workshop, 2021. Coriolis meters are shown to have performed to within 0.2% of the reference flow rate.

[9] JIMBA, J. et. al. Investigation of Coriolis Meter Performance under Liquid, Dense, and Supercritical CCS Transport Conditions, 40th North Sea Flow Measurement Workshop, 2022.

Density determination

Trading schemes such as the UK-ETS specify the uncertainty of the mass flow rate. Differential-pressure and Coriolis technologies measure the mass flow rate directly (though the former requires the density to be determined independently), while ultrasonic meters deliver volume flow rates which, combined with knowledge of the density, can yield mass flow rates.

Density can be determined either:

i. off-line, by analysis of representative samples

ii. on-line, by gas chromatography combined with an Equation of State

iii. on-line, by densitometer (though operation on super-critical fluids is yet to be confirmed)

The uncertainty in each of these methods may be expected to vary depending on the specifics of the proposed application.

Where method (ii) is proposed, an appropriate Equation of State must be used; this should take account of the presence of anticipated impurities present in the gas[10].

Sampling and analysis

The provision of sampling points, designed to deliver representative samples of the bulk fluid for off-line analysis, is a key part of the overall design and must be carefully considered. On-line sampling is generally preferable.

On-line gas chromatographs can be used to determine gas composition. However, the provision of low-uncertainty calibration gas for CO_2 mixtures may present challenges. Work is currently ongoing to address this issue.

The provision of sample handling facilities (for instance, for sub-sampling and mixing) should also be considered at the design stage.

Measurement uncertainty

Operators' uncertainty analyses, demonstrating that the uncertainty requirements of the relevant trading scheme are met, should be available for the NSTA for review.

[10] Expanded Equations of State for CCUS applications are currently under development.

Measurement of CO_2 for reservoir management

Unless otherwise agreed with the NSTA, measurement of quantities of CO_2 injected will be required at each injection point.

Mass fow measurement

The measurement uncertainty should be sufficiently low that reservoir models are not adversely impacted by the quality of the rich CO_2 mass rate data at the well injection point. The uncertainty requirements for pure CO_2 will be kept under review, but these may be less stringent than those for the measurement of rich CO_2 mass. Given the potential practical challenges of CO_2 measurement at the wellhead, requirements for removal and recalibration of meters may be correspondingly less onerous.

Where the measurement takes place subsea, direct measurement is effectively limited to Venturi meters. Alternative approaches are possible where the measurement takes place on the topsides, but in view of their relatively low cost, Venturi meters are likely to be the most suitable where measurement at several injection points is required. Proposals for meter calibration should be discussed and agreed in advance with the NSTA. In subsea meter applications the use of dual (or even triple) instrumentation, to improve measurement redundancy, should be strongly considered.

The use of 'Virtual Metering' systems should be discussed with the NSTA. Experience in hydrocarbon applications has shown that these can provide useful measurement instrumentation following a period of 'tuning' against direct measurement systems.

Sampling and analysis

Unless it may be reasonably assumed that the fluid composition remains unchanged following its determination at bulk levels (according to the procedures outlined in Sampilng and analysis section above), sampling of the fluid may be required at each individual injection point, both for reporting purposes and in order to determine the density of the fluid via an equation of state.

Where the measurement takes place subsea, there may be significant practical and financial challenges associated with sample collection.

Sampling and analysis proposals should be discussed and agreed in advance with the NSTA.

Design considerations and recalibration strategy

Design considerations

Irrespective of the technologies used, practical points to consider are:

- The need to ensure ready access to the measurement station and associated instrumentation for the purpose of calibration and/or verification.
- Sufficient isolation valves should be present to allow the removal of primary and secondary instrumentation at line conditions, i.e. it should be possible to remove the flow meter for recalibration and/or inspection without necessitating a full plant shutdown.
- The provision of diagnostic facilities that may permit the adoption of condition-based and/or risk-based recalibration strategies; it may be preferable to incorporate required features (for instance, additional pressure tappings for differential-pressure metering technologies) even if they are not initially intended to be used, rather than retrofitting them later.
- The provision of sampling systems wherever it is desirable or necessary to determine the composition of the bulk fluid.

Location of measurement points

Quantities of CO_2 delivered to the transportation system from each contributing capture point must be measured at the uncertainties required by the provisions of the ETS.

In addition to these individual measurement stations, there is considerable benefit in having a final measurement station immediately prior to the transport of the bulk fluid offshore. This will allow quantities of CO_2 delivered offshore for injection to be determined at lower levels of uncertainty than the alternative method of calculating the flow rate and composition on the basis of weighted averages of each of the individual contributors. This is especially true where the flow rates and compositions from each of the contributors is expected to be relatively variable.

Where it is not proposed to provide a final measurement station prior to transport of the CO_2 offshore, the NSTA may ask for this to be justified on cost/benefit grounds.

Cost/benefit analyses

In determining the level of financial exposure resulting from a given level of measurement uncertainty, the NSTA recommends the use of the Integrated Risked Exposure model[11].

[11] As set out in STOCKTON, P. Cost Benefit Analyses in the Design of Allocation Systems, 27th North Sea Flow Measurement Workshop, 2009. Available on request from NSTA.

Recalibration strategy

The proposed recalibration strategy should be agreed in advance with the NSTA. This may be either:

- Time-based (i.e., meters and associated instrumentation removed and recalibrated at regular intervals).
- Condition-based (i.e., meters and associated instrumentation removed for recalibration when diagnostic parameters indicate loss of measurement integrity).
- Risk-based (a combination of time-based and condition based).

Flow meter calibration is a key part of any maintenance strategy and should be given due attention by the Operator. This is especially true where condition-based maintenance strategies are envisaged - in these cases it may be years between successive meter calibrations and the negative consequence of any error introduced at this stage may be amplified.

The flow calibration medium must be considered in relation to the proposed measurement technology; in general, it is good metrological practice to calibrate on the proposed ‘in-service’ fluid -where a facility to do so exists. Use of a different fluid carries the risk of introducing systematic bias to the results. However, according to research carried out at several European reference laboratories, Coriolis meters for use in gaseous-phase CO_2 applications may be calibrated on water with no appreciable risk of significant measurement bias.

A UK-based traceable flow calibration facility for smaller (2”) CO_2 meters, using dense-phase fluid as the calibration medium, is currently under development[12]. However, there are currently no plans to provide such a facility for the 6” to 10” meters needed by industry.

[12] See https://www.tuvsud.com/en-gb/press-and-media/2023/april/traceable-co2-liquid-dense-phase-calibration-facility for details.

North Sea Transition Authority

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