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Good plant design for measurement of CO_2 in carbon capture and storage applications

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MEASUREMENT FOCUS GROUP
Focusing on flow measurement and flow-related issues in industry

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Content

- Background & motivation
- Project aims
- Information to be considered
- Expected outcomes

1

Background and motivation

- Technologies to measure CO_2 are available; when impurities are present it becomes very challenging (i.e. pre-conditioning is needed, triple point CO_2, etc.)
- Measuring CO_2 streams with impurities: frequency, flowrate, equipment, main conditions, downstream impact(s), etc.
- Lack of guidelines addressing these issues for diverse CO_2 streams with impurities from industrial processes.

2

CO_2 measurement in CCS applications

- CO_2 present in flue gas from power plants, steam methane reforming or chemical processes.
- CO_2 capture: CO_2 extracted from the waste stream of industrial processes.
- Achieve pure CO_2 stream: purification (i.e. amine scrubbing), dehydration (ensure H_2O levels below 50 μmol mol^{-1}), and liquified.
- Pure CO_2 transportation through pipelines (storage or utilisation).

Murugan, A., et al. NPL Report ENV 23 (2019). *Purity requirements of carbon dioxide for carbon capture and storage.*

Parameter	Type I	Type II	Type III
CO_2—% by volume	>95%	>95%	>96%
H_2S—ppmbw	<10	<20	<10,000
Sulphur—ppmbw	<35	<30	-
Total hydrocarbons—% by volume	<5	<5	-
CH_4—% by volume	-	-	<0.7
C_2 + hydrocarbons—% by volume	-	-	<23,000
CO—% by volume	-	-	<1,000
N_2—% by volume/weight	<4	<4	<300
O_2—ppm by weight/volume	<10	<10	<50
H_2O—#/mmcf* or ppm by volume**	<25*	<30*	<20**

C_2 = carbon; CH_4 = methane; CO = carbon monoxide; CO_2 = carbon dioxide; H_2O = water; H_2S = hydrogen sulfide; mmcf = millions of cubic feet; N_2 = nitrogen; ppm = parts per million; O_2 = oxygen; ppmbw = ppm by weight

World Resources Institute. *Acceptable purity levels of CO_2 for different pipelines used for CO_2 transportation*

3

Project's Aim

The overall aim of the project is Producing a Good Practice Guide for measuring carbon dioxide (CO_2) streams containing diverse levels of impurities.

- To assist developers and allow for the most appropriate measurement techniques to be specified.
- Measurable objectives for the project:

OBJ 1 — Creating a **database on existing guidelines and CO_2 streams** (sources, composition, end-users).

OBJ 2 — Defining the **audience and scope** of the guidelines to ensure industry needs are included,

OBJ 3 — **Drafting and publishing guidelines** covering: the development of policy and regulations and considers environmental aspects linked to the CO_2 streams.

4

Existing guidelines and regulations

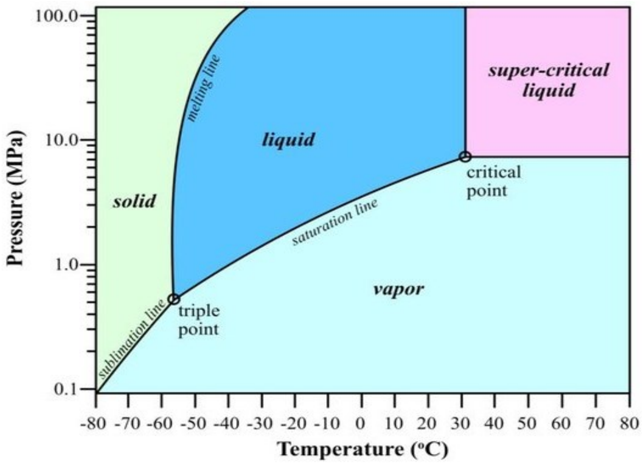
- Measurement accuracy of CO_2
  - Commission Regulation (EU) No 601/2012 – The monitoring and reporting of GHG emissions pursuant
  - OIML R117 Chapter 2 – Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices

- Other references & standards
  - DNV RP-J202 – DNV-RP-F104 Design and Operation of carbon dioxide pipelines, Recommended practice, Edition 2021-02 – Amended 2021-09
  - BS PD 8010: 2004 Part 2 – Subsea pipelines
  - BS EN 14161: 2011 – Petroleum and Natural Gas Industries. Pipeline Transportation Systems Institute of Petroleum Pipeline Code IP6
  - ISO27913:2016 - Carbon dioxide capture, transportation and geological storage — Pipeline transportation systems

Currently, there are no regulations to cover CCUS in the UK

5

Impact of impurities



Phase diagram for CO_2 (from -80 to 80 °C; and between 0.1 and 100.0 MPa), modified from Marini (2007).

- **Triple point** occurs at approximately **-56.6 °C, 0.518 MPa**;
- **Critical point** occurs at approximately **31.1 °C, 7.39 MPa**.

Gierzynski A. (2016)

- Temperature/pressure: small changes can result in changes in phase, density, compressibility, etc.
- Impact on liquid-vapour phase boundary; might cause expansion of the two-phase regime (i.e. unwanted when using pipelines).
- Impurities will affect the CO_2 capture process.
- Equations of states are not valid when having impurities.

6

List of impurities from National Physical Laboratory (NPL)

Component	ISO 27913		Current UK CCUS projects specifications Summary			NPL measurement capability		
	Units	Limit	Units	Limit (Min)	Limit (Max)	Units	Lower limit	Upper limit
CO_2	mol%	≥ 95.0						
N_2 (1)	mol%	4	mol%	1	4	mol%	0.03	0.9
H_2 (1)	mol%	1	mol%	0.005	2	mol%	0.04	1.2
Ar (1)	mol%	4	mol%	1	4	mol%	0.005	0.015
CO (1)	mol%	0.2	mol%	0.01	0.2	mol%	0.0003	0.015
Methane (1)	mol%	4	mol%	1	4	mol%	0.023	0.7
Ethane (1)	mol%	4	mol%	1	4	mol%	0.005	0.01
Propane & Other Aliphatic Hydrocarbons (2)	mol%	0.15 in total	mol%	0.15	2	mol%	0.005	0.01
H_2O	ppm mol	50	ppm mol	20	50	ppm mol	0.62	500
O_2	ppm mol	10	ppm mol	10	20	ppm mol	1.7	500
NOx (NO, NO_2) (3)	ppm mol	10	ppm mol	10	100	ppm mol	0.005	1
SOx (SO, SO_2, SO_3) (4)	ppm mol	10	ppm mol	10	100	ppm mol	0.005	1
H_2S	ppm mol	5	ppm mol	5	20	ppm mol	0.01	100
COS	ppm mol	100				ppm mol	0.01	100
CS_2	ppm mol	20						
NH_3	ppm mol	10	ppm mol	10	1500			
BTEX (5)	ppm mol	15 in total						
Methanol	ppm mol	350						
Solid Particulates (6,7)	mg/Nm³	1 in total	ppm mol	1	1			
Toxic Metal (6)	mg/Nm³	0.15						
VOCs (8)	mg/Nm³	48 in total	ppm mol	20	60			
Acid Forming Compounds (9)	mg/Nm³	150 in total	ppm mol	10	70			
Amines (10,11)	ppb mol	100 in total	ppm mol	0.08	10			
Glycols (12)		NIL	ppm mol	0.025	0.05			
Nitrosamines and Nitramines (13)	µg/Nm³	3 in total						
Naphthalene (14)	ppb mol	100						
Dioxins and Furans (15)	ng/Nm³	0.02 in total						

(1) Combined total ≤ 4.0 mol% (annotation bracketing N_2, H_2, Ar, CO, Methane, Ethane)

Heavy hydrocarbons (C_3+) (annotation pointing to Propane & Other Aliphatic Hydrocarbons)

Max size of 1 µm (annotation pointing to Solid Particulates)

(Cl_2, HF, HCl, HCN) (annotation pointing to Acid Forming Compounds)

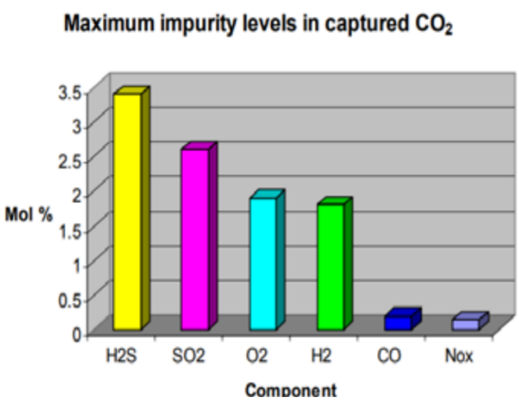
Key

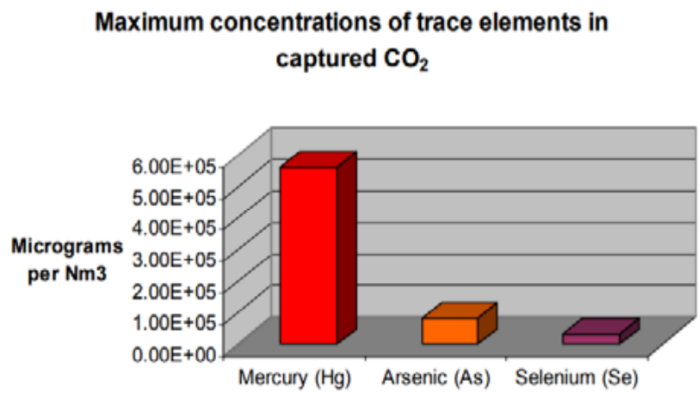
- *NPL measurement capability covers ISO 27913 threshold limit* (green)
- *NPL measurement capability exists but doesn't cover ISO 27913 threshold limit. Additional work required to extend working range (fairly easily)* (orange)
- *NPL measurement capability development in progress* (pink)

7

Impurities in CO_2 from the combustion of different fuels

[Example: emissions from processing coal, oil, petroleum coke and lignite]





- No anticipated corrosion issues due to the presence of these impurities (CO_2 should be sufficiently dry).
- Higher levels of hydrogen sulphide or H_2 would require careful selection of the pipeline material.

8

Murugan, A., et al. NPL Report ENV 23 (2019). *Purity requirements of carbon dioxide for carbon capture and storage.*

Equipment: mass flow rate & composition

Mass flow measurements

CORIOLIS
- ✓ Measures the mass of CO_2 directly
- × Restriction in the pipeline size


Coriolis meter
Source: Emerson

ULTRASONIC
- ✓ Volume based measurement technology
- × Cannot measure accurately when there is gas bubbles in liquid or liquid bubbles in gas

TURBINE
- ✓ Good for large pipeline size and good reproducibility
- × Unable to use in two-phase flow

VENTURI
- ✓ Good for large pipeline size
- × Higher measurement uncertainty


Venturi meter
Source: Primary Flow Signal

Components methods

GC
(Gas Chromatography)
- ✓ Provides high accuracy and good reproducibility
- × The use of carrier gas may incur high operating costs

FTIR
(Fourier-Transform Infrared Spectroscopy)
- ✓ Quick technique to measure CO_2
- × Cannot measure accurately when there is a change in pressure

Challenges: use techniques in laboratories (calibration) and industrial settings; behaviour of CO_2 (triple point: solid, liquid, gas), etc.

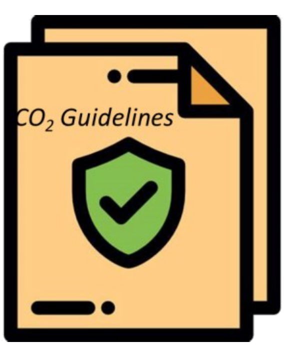
9

Existing uncertainties around CO_2 measurements

- Accuracy & parameters measured
  - ppm, ppt, etc
  - Target impurities & link with triple point (stream conditions)
- Equipment & flexibility
  - Calibration facilities
  - Equipment requirements (i.e. in a laboratory, on-site, etc.)
- Sources & final goal
  - Industrial process
  - Use on-site or conditioning for transportation (storage and utilisation)

10

Expected outcomes



The CO_2 measurement guidelines will:

- Become an addition to the Energy Institute's library, which will also complement the ISO2713 standard.
- Address the CO_2 transportation of CO_2 streams from CO_2 sources to storage sites or utilisation.
- Meet the needs of stakeholders (including policymakers and regulation developers) in the CO_2 sector and used in the decarbonisation sector.

11

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Thank you for your attention

Any Questions?

PROJECT TEAM

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