WHITE PAPER

Methods for measuring impurities in CO_2

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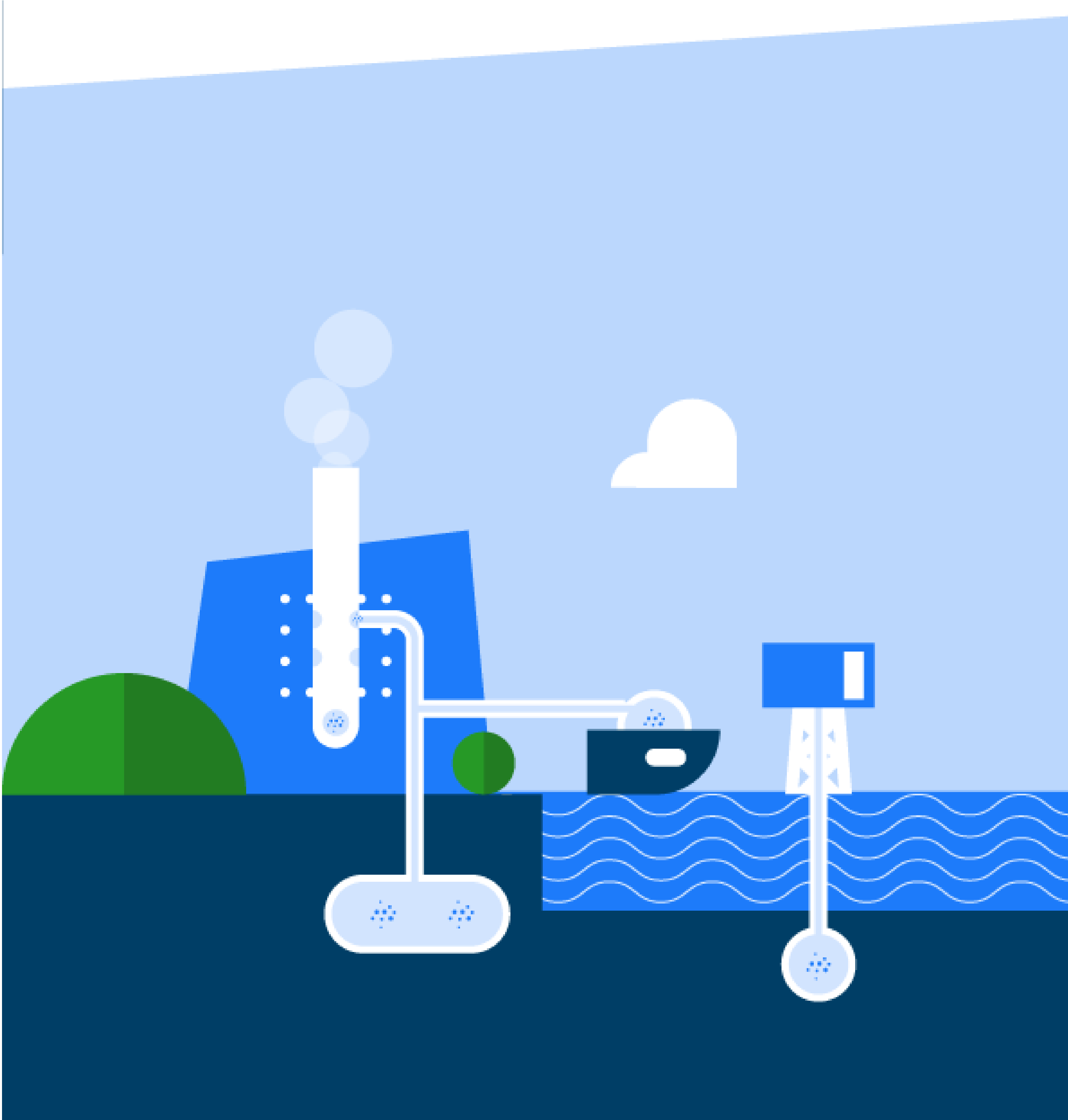

Summary

As the global interest in Carbon Capture, Utilisation and Storage (CCUS) is growing, securing the purity of the captured CO_2 is a key objective to maintain transportation and storage infrastructure, ensure long-term stability of stored CO_2 and protect occupational health and safety.

Today, limited legislation governs and controls the purity, and the individual storage suppliers each decide their own specifications. Measuring the full range of components required is far from straightforward and often involves a setup of many different instruments.

By clarifying the capabilities of commercially available equipment and the challenges unique to CCUS applications, this paper aims to support plant operators, gas analysis laboratories, and regulatory bodies in designing robust monitoring strategies, ultimately enabling safe and efficient large-scale CO_2 transport and storage.

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Abbreviations

CLD	Chemiluminescence detector
CRDS	Cavity Ring-Down Spectroscopy
DID	Discharge ionisation detector
ELPI+	Electrical Low-Pressure Impactor
FID	Flame ionisation detector
FPD	Flame photometric detector
FTD	Flame thermionic detector
FTIR	Fourier Transform Infrared Spectroscopy
MS	Mass Spectrometry
Meth-FID	Methaniser and flame ionisation detector
NCD	Nitrogen chemiluminescence detector
NDIR	Non-dispersive infrared
NDIR/UV-Vis	Nondispersive infrared/ultraviolet-visible spectroscopy
OFCEAS	Optical Feedback Cavity Enhanced Absorption Spectroscopy
PDHID	Pulsed discharge helium ionisation detector
PID	Photoionization Detector
PTR-ToF-MS	Proton Transfer Time-of-Flight Mass Spectrometry
SCD	Sulphur Chemiluminescent Detector
SIFT-MS	Selected-ion flow-tube mass spectrometry
TCD	Thermal Conductivity Detector
TDLS	Tunable Diode Laser System
THC	Total Hydrocarbon
UV	Ultraviolet

Introduction

The growing carbon capture, utilisation and storage (CCUS) industry has created an increasing demand for quantitative purity measurements of the CO_2 product gas. While the food and beverage industry adheres to well-established standards for CO_2 purity, these standards are not always directly applicable to CCUS due to the higher complexity of the CO_2 infrastructure involved and the long-term storage aspect. The effects of CO_2 impurities on corrosion of materials and the physical properties of liquified CO_2 are active areas of research.

Currently, individual storage suppliers each determine the required specifications for CO_2 storage purity, considering present knowledge regarding corrosion, compound reactivity, the effects on physical properties of liquified CO_2 and safety considerations. As the research is ongoing, the requirements are updated frequently.

Table 1 lists the available specifications in December 2025 with the maximum allowable mole-based concentrations of CO_2 product gas impurities provided by Northern Lights, Aramis, Porthos, International Society of Beverage Technologists (ISBT) and European Industrial Gases Association (EIGA) [1], [2], [3], [4], [5].

Measuring and quantifying the full list of impurities across the relevant concentration ranges is complex, requiring several measurement methods. Commercially available stationary measurement solutions for internal quality control exist, designed for analysis of the compounds relevant to the food and beverage industries.

Possible solutions for this purpose include, e.g. Carboscan 300, Carbon Dioxide Quality Control Analysis System (CDQC) and MAX-Bev CO_2 Purity Monitoring System [6], [7], [8]. A full discussion of these is beyond the scope of this paper; however, to the best of our knowledge, no such system can measure the full range of components relevant for CCUS purposes.

Furthermore, for independent compliance measurements, transportable equipment suitable for continuous, online monitoring is often preferred, although batch analysis, sometimes for practical reasons, is the best option.

The aim of this white paper is to provide stakeholders, such as plant owners, consultants, gas analysis laboratories and supervising authorities, with an overview of suitable techniques applicable to measuring CO_2 impurities.

Specifically, commercially available equipment for the purpose of compliance measurements is reviewed, focusing on the most common principles for measurements, field control, performance control and control in laboratories.

Table 2 lists the applicable measurement methods for quantification of all components, which will each be further discussed in a later section.

CO_2 specifications

Component		Northern Lights [3] (ppm-mol)	Aramis [2]		Porthos [1] (ppm-mol)	ISBT [5] (v/v)	EIGA [4] (v/v)
			Ships (ppm-mol)	Pipelines (ppm-mol)			
Carbon dioxide	CO_2	Balance (Minimum 99.81%)	Balance	≥ 95 %	≥ 95 %	≥ 99.90 %	≥ 99.90 %
Water	H_2O	≤ 30 ppm	≤ 30 ppm	≤ 70 ppm	≤ 70 ppm	≤ 20 ppm	≤ 20 ppm
Oxygen	O_2	≤ 10 ppm	≤ 10 ppm	≤ 40 ppm	≤ 40 ppm	≤ 30 ppm	≤ 30 ppm
Sulphur oxides	SO_x	≤ 10 ppm	≤ 10 ppm	-	-	-	-
Sulphur dioxide	SO_2	-	-	-	-	≤ 1 ppm	-
Total sulphur	-	-	-	-	≤ 20 ppm	≤ 0.1 ppm[i]	≤ 0.1 ppm[i]
$H_2S+COS+SO_x+DMS$[ii]	-	-	-	≤ 20 ppm	-	-	-
Nitrous oxides	NO_x	≤ 1.5 ppm	≤ 1.5 ppm	≤ 2.5 ppm	≤ 5 ppm	≤ 5 ppm	-
Nitrogen monoxide	NO	-	-	-	-	≤ 2.5 ppm	≤ 2.5 ppm
Nitrogen dioxide	NO_2	-	-	-	-	≤ 2.5 ppm	≤ 2.5 ppm
$O_2+N_2+H_2+Ar+CH_4+CO$	-	-	≤ 2,000 ppm	≤ 4 %	≤ 4 %	-	-
Hydrogen sulphide	H_2S	≤ 1 ppm	≤ 5 ppm	≤ 5 ppm	≤ 5 ppm	-	-
Amines	-	≤ 10 ppm	≤ 10 ppm	≤ 1 ppm	≤ 1 ppm	-	-
Ammonia	NH_3	≤ 10 ppm	≤ 10 ppm	≤ 3 ppm	≤ 3 ppm	≤ 2.5 ppm	≤ 2.5 ppm
Formaldehyde	CH_2O	≤ 20 ppm	≤ 20 ppm	-	-	-	-

Acetaldehyde	CH_3CHO	≤ 20 ppm	≤ 20 ppm	-	-	≤ 0.2 ppm	≤ 0.2 ppm
Aldehydes	-	-	-	≤ 10 ppm	≤ 10 ppm	-	-
Mercury	Hg	≤ 0.0003 ppm	≤ 0.03 ppm	-	-	-	-
Carbon monoxide	CO	≤ 100 ppm	≤ 1,200 ppm	≤ 750 ppm	≤ 750 ppm	≤ 10 ppm	≤ 10 ppm
Hydrogen	H_2	≤ 50 ppm	≤ 500 ppm	≤ 7,500 ppm	≤ 7,500 ppm	-	-
Cadmium, Thallium	Cd + Tl	-	≤ 30 ppb	-	-	-	-
Methane	CH_4	≤ 100 ppm	-	≤ 1 %	≤ 1 %	-	-
Nitrogen	N_2	≤ 50 ppm	-	≤ 2.4 %	≤ 2.4 %	-	-
Argon	Ar	≤ 100 ppm	-	≤ 0.4 %	≤ 0.4 %	-	-
Methanol	CH_3OH	≤ 30 ppm	≤ 40 ppm	≤ 620 ppm	≤ 620 ppm	≤ 10 ppm	≤ 10 ppm
Ethanol	C_2H_5OH	≤ 1 ppm	≤ 20 ppm	≤ 20 ppm	≤ 20 ppm	-	-
Total Volatile Organic Compounds	TVOC	≤ 10 ppm[iii]	≤ 10 ppm	≤ 10 ppm	≤ 10 ppm[iv]	≤ 50 ppm[v]	-
Total Volatile Hydrocarbons	-	-	-	-	-	-	≤ 50 ppm[vi]
Mono-Ethylene Glycol	MEG	≤ 0.2 ppm	-	Follow dew-point specification	Follow dew-point specification	-	-
Tri-Ethylene Glycol	TEG	≤ 0.2 ppm	-	Follow dew-point specification	Follow dew-point specification	-	-
BTEX[vii]	BTEX	≤ 0.5 ppm[vii]	-	-	-	-	-
Ethylene	C_2H_4	≤ 50 ppm	-	-	-	-	-
Hydrogen Cyanide	HCN	≤ 100 ppm	-	≤ 2 ppm	≤ 2 ppm	ND[viii]	≤ 0.5 ppm
Vinyl chloride	C_2H_3Cl	-	-	-	-	ND[viii]	-
Aliphatic Hydrocarbons	C_2+/C_3+	C_3+ ≤ 1,100 ppm[ix]	-	C_2+ ≤ 1,200 ppm	C_2+ ≤ 1,200 ppm[x]	-	-

Aromatic Hydrocarbons	-	-	-	-	≤ 0.1 ppm[xi]	≤ 0.02 ppm [xii]	≤ 0.02 ppm
Ethane	C_2H_6	≤ 75 ppm	-	-	-	-	-
Solids, particles, dust	-	≤ 1 µm	≤ 1 µm	≤ 1 µm	-	-	-
Carboxylic acids and amides	-	-	-	≤ 1 ppm	≤ 1 ppm	-	-
P-containing compounds	-	-	-	≤ 1 ppm	≤ 1 ppm	-	-
Non-Volatile Residue	NVR	-	-	-	-	≤ 10 ppm w/w	≤ 10 ppm w/w
Non-Volatile Organic Residue	NVOR	-	-	-	-	≤ 5 ppm w/w	≤ 5 ppm w/w
Phosphine						≤ 0.3 ppm	
Ethylene oxide						≤ 0.2 ppm	
Dew point	-	-	-	-10°C at 20 bars	-10°C at 20 bars	-	-
Toxic compounds		-	-	-	[xiii]	-	-

Table 1. CO_2 specifications listing the maximum allowable concentration of each impurity provided by different companies and projects available in December 2025.

i Excluding SO_2
ii DMS: Dimethyl Sulphide, $(CH_3)_2S$.

iii Total Volatile Organic Compounds (VOC) are VOC in addition to the ones listed separately in this specification, i.e., Ethanol, Methanol, Formaldehyde, Acetaldehyde and BTEX, and includes the following components: 1-propanol < 1 ppm-mol, 2-butanol < 1 ppm-mol, 1,2,4-trimethylbenzene < 5 ppm-mol.
iv Excl. methane, total aliphatic hydrocarbons (C_2 to C_{10}), methanol, ethanol and aldehydes.
v Calculated as methane, of which ≤ 20 ppm v/v is non-methane hydrocarbons.
vi THC might be considered as TVOC in some cases, but chemically, TVOC and THC differ.
vii BTEX refers to the following chemical compounds: Benzene, Toluene, Ethylbenzene and Xylene
viii Not detectable by the method
ix Total amount of hydrocarbons not to exceed 1,100 ppm-mol. Individual limits for groups of HCs: C_3 < 1,100 ppm-mol, C_4-C_5 < 815 ppm-mol, C_6-C_7 < 75 ppm-mol, C_8-C_9 < 8 ppm-mol.
x C_2 to C_{10}
xi C_6 to C_{10}, incl. BTEX
xii C_6H_6
xiii Toxic compounds: although CO_2 and other gases like H_2 and N_2 can pose a risk of asphyxiation, Porthos would like to know other components in the stream which impose risk on personal safety to be considered in Porthos´ HSE policy.

Measuring methods

Table 2 describes the most suitable measuring methods for each component listed in Table 1, with a focus on continuous measurements.

Component		Measuring method
Carbon dioxide	CO_2	- Chemical absorption using caustic solution (CO_2 Purity Tester) [9] - FTIR optimised for relevant concentrations [6]
Water	H_2O	- Electrometric moisture analyser with aluminium oxide dielectric constant (capacitive) change type sensor [5] - Laser-based trace moisture analyser based on CRDS [10], [11] - Dew point detector - TDLS, which is based on absorption spectroscopy [12] - Optical Feedback Cavity Enhanced Absorption Spectroscopy (OFCEAS) laser [13] - FTIR optimised for relevant concentrations [6] - Quartz crystal microbalance [14]
Oxygen	O_2	- Electrolytic cell suitable for measuring in CO_2 [15] - GC with a discharge ionisation detector [4], [5] - OFCEAS laser [13] - GC-PDHID or GC-TCD [11]
Sulphur oxides	SO_x	- UV fluorescence [4] - FTIR [6], [16] - GC- SCD [5] - GC equipped with a dual FPD [17] - NDIR/UV-Vis photometer [13] - Impinger sampling in aqueous solution of hydrogen peroxide followed by analysis with ion chromatography [18]
Sulphur dioxide	SO_2	
Total sulphur		- UV fluorescence [19]
Nitrous oxides	NO_x	- CLD can be used in a CO_2 matrix if the equipment is calibrated using a suitable calibration gas [4], [5] - FTIR [6], [16] - CRDS [11] - NDIR/UV-Vis photometer [13]
Nitrogen monoxide	NO	
Nitrogen dioxide	NO_2	
Hydrogen sulphide	H_2S	- PTR-ToF-MS [20], [21] - GC- SCD [4], [11] - OFCEAS laser [13] - Impinger sampling in aqueous solution of Zn-acetate followed by detection with e.g. spectrophotometry [22]
Amines		- PTR-ToF-MS [20] - GC [4] - GC- NCD [11] - Impinger sampling in aqueous sulfamic acid followed by analysis with GC-MS/MS/MS [23]

Ammonia	NH_3	- CLD configured to measure NH_3 along with NO_x [24] - GC [17], and GC-MS [11] - FTIR [6], [11], [16] - NDIR [11] - SIFT-MS [11] - Impinger sampling in aqueous solution of sulfuric acid followed by analysis with continuous flow analysis [25], ion chromatography [26] or spectrophotometry [27]
Formaldehyde	CH_2O	- PTR-ToF-MS [20] - Fluorescence measurement following wet-chemical Hantzsch reaction and chemical conversion [28] - CRDS [28] - High-resolution laser differential optical absorption spectroscopy (custom-built equipment) [28] - Impinger sampling in 2,4-dinitrophenyl solution followed by analysis with e.g. spectrophotometry [29]
Acetaldehyde	CH_3CHO	- PTR-ToF-MS [20] - GC-FID [4], [5], [17] - FTIR [6], [16] - Impinger sampling in 2,4-dinitrophenyl solution followed by analysis with e.g. spectrophotometry [29]
Aldehydes		- FTIR [16] - Impinger sampling in 2,4-dinitrophenyl solution followed by analysis with e.g. spectrophotometry [29]
Mercury	Hg	- Atomic absorption spectrometry [11] - Impinger sampling (gas-phase Hg) in $KMnO_4$ in sulfuric acid followed by analysis with atomic absorption spectrometry [30]
Carbon monoxide	CO	- GC-Meth-FID [11] - GC-TCD [11] - GC-PDHID [11] - GC-DID [4], [5] - NDIR [11] - FTIR [6], [16]
Hydrogen	H_2	- GC-TCD [11] - GC-DID [5]
Methane	CH_4	- GC-DID [5] - GC-FID [11] - GC-TCD [11]
Nitrogen	N_2	- GC-DID [5] - GC-TCD [11]
Argon	Ar	- GC-DID [5] - GC-TCD [11]
Methanol	CH_3OH	- PTR-ToF-MS [20] - GC-FID [4], [5]
Ethanol	C_2H_5OH	- PTR-ToF-MS [20] - GC-FID [4], [5]

Total Volatile Organic Compounds	TVOC	- FID [31]
Mono-Ethylene Glycol	MEG	- PTR-ToF-MS [20]
Tri-Ethylene Glycol	TEG	- PTR-ToF-MS [20]
BTEX	BTEX	- PTR-ToF-MS [20] - GC-PID [4], [5] - GC-FID) [17] - FTIR [6]
Ethylene	C_2H_4	- PTR-ToF-MS [20] - GC-FID [4], [5], [17]
Hydrogen Cyanide	HCN	- Compound specific detector tube for colourimetry [6] - GC-FTD [4], [32] - PTR-ToF-MS [21] - Impinger sampling in aqueous solution of sodium hydroxide followed by analysis with e.g. spectrophotometry [33]
Aliphatic Hydrocarbons	C_3+	- GC-Meth-FID [4], [11] - GC-FID [4], [11] - GC-TCD [4], [11] - THC analyser [4], utilising a FID [34]
Total Volatile Hydrocarbons		- GC [17] - FTIR [6], [16]
Ethane	C_2H_6	- GC-Meth-FID [11] - GC-FID [11] - GC-TCD [11]
Solids, particles, dust		- ELPI+ [35]
Non-Volatile Residue	NVR	- Analysis of dry ice snow prepared from liquid CO_2 [5] - Dry impinger method for determining condensable particulate emissions [36]
Non-Volatile Organic Residue	NVOR	

Table 2. Overview of components in CO_2 specifications and a selection of measuring principles suitable for measuring the impurities in the permitted concentrations.

General considerations

This section discusses general considerations when selecting measurement principles.

Detection and quantification limits

The detection limit denotes the lowest concentration of a component which a given measuring principle can detect with reasonable accuracy, often defined with a specific statistical certainty relative to the baseline noise. Likewise, the quantification limit denotes the lowest concentration of a component which can be quantified with reasonable accuracy. The quantification limit is typically 2 to 3 times the detection limit. Both limits depend on the measuring principle and the specific design of the individual analyser.

An applicable rule of thumb to use when selecting a measuring principle is that the detection limit should not exceed 10% of the specification limit. In cases where it is not possible to achieve such a low detection limit, a higher level may be accepted, but it should never exceed 50% of the specification limit. Otherwise, it should be considered if another analyser with a lower detection limit is available.

Continuous monitoring equipment typically has a fixed detection limit, which is determined by the physical construction and design of the equipment, along with the measuring principle it uses. If continuous monitoring equipment does not have a detection limit low enough to obtain a satisfactory measurement, then it is recommended to search for another type of monitoring equipment, possibly with a different measurement principle.

Periodic measurements using active sampling, where gas is drawn through a collection medium and subsequently analysed in the lab, are more flexible regarding their detection limits. It typically depends on the amount of gas drawn through a sampling medium and the detection limit of the subsequent analysis.

The accumulated detection limit can usually be lowered by increasing the amount of extracted gas, either by increasing the flow rate or by increasing the sampling time. However, there are also limitations here that can make a measurement method unsuitable if either the required flow rate or the required sampling time becomes disproportionately high.

Measurement range

Most analysers work within a certain range given by lower and upper concentration limits. The accuracy is typically larger for small ranges and is an important parameter to consider. If measurements are conducted on a CO_2 product gas stream where large fluctuations in impurity concentrations are expected, the detection limit of the selected method should be sufficiently low; however, potential peaks should also be captured within the upper limit of the range.

This is most relevant for continuous monitoring equipment, where the inability to register a short-term peak can result in an incorrectly calculated average over a longer period. Since most components in a CO_2 product gas stream have very low specification limits, any large peaks exceeding the monitoring equipment’s range will likely cause the process to be stopped and part of the produced CO_2 gas to be discarded.

Response time

For continuous monitoring equipment, the time it takes from a change occurring in the gas stream until the monitoring equipment registers this change at a well-defined percentage of the true value is called the response time. The importance of the response time depends on how stable the process being measured is. If the process is very stable and large fluctuations are not expected, a longer response time may be acceptable.

Conversely, if the process has frequent and/or large fluctuations, a short response time is important to ensure that the correct process value is always recorded.

Most modern continuous monitoring equipment has a relatively short response time. However, the overall response time will also be affected by the sampling system used. It is therefore important to ensure that the distance between the sampling point on the CO_2 product gas stream and the monitoring equipment is not too long if a short response time is required. At the same time, the sampling system should not have excessive dead time, which can also affect response time.

Interferences

Depending on the measurement principle and the composition of the sample gas, some components may affect the results of other components, leading the displayed result to be either higher or lower than the actual content in the gas. This is called interference and can, in some cases, significantly impact the suitability of the measurement principle for a given component.

The significance of interference depends on both the concentration of the component to be measured and the concentration of any interfering components. In CO_2 product gas streams, measurements are generally required at very low levels, so interference from other components is significant. It is therefore important to choose a method that is either not significantly affected by interference or employ methods to compensate for known interferences.

Standards and certification

The optimal choice when selecting a measurement method is one for which a European or international standard exists. However, standards do not exist for all components typically required for CO_2 product gas. The alternative is to find a method from a recognised institution, such as the US-EPA, VDI, or similar organisations.

Similarly, it is generally preferable if continuous monitoring equipment is certified according to a relevant standard, such as EN 15267-3. This ensures that the equipment meets certain requirements and can generally deliver reliable results. Even if monitoring equipment is certified, it is important to ensure that the certification applies to the relevant measurement ranges and that the equipment is suitable for measurements in a CO_2 matrix.

For many of the components, certified monitoring equipment does not exist. In such cases, it must be assessed whether the supplier´s specifications are suitable for the intended purpose. In most cases, it is recommended to perform tests under relevant conditions before measuring, verifying that the equipment is suitable.

Discussion

In this section, the challenges of measuring each component are discussed in detail, addressing the strengths and weaknesses of the possible measurement techniques.

General considerations

As shown in the tables above, no single measurement principle can quantify all the components from the CO_2 specifications. Some equipment is specifically designed for CO_2 purity control in the food and beverage industry, making it suitable for a range of relevant components [6], [17]. On the other hand, the specifications for Northern Lights, Aramis and Porthos include a wider range of components and therefore require a wider set of monitoring equipment. Generally, it is recommended to reduce the amount of monitoring equipment used to simplify the setup by choosing measuring principles suitable for multiple components.

The CO_2 specifications are based on the current knowledge concerning corrosion of materials used for piping and storage, operational requirements of processing equipment, energy requirements through the whole storage process, environmental safety, human working environment and general safety at the storage location. The components listed in the CO_2 specifications are generally selected based on the variety of sources and capturing technologies used [37].

In the following sections, the different measuring methods for the components will be discussed.

CO_2

The CO_2 specifications require between 95-99.90% CO_2 in the received product gas (Table 1) and can vary significantly depending on source and capture method. The concentration of CO_2 can be determined by using a CO_2 Purity Tester utilising chemical absorption by a caustic solution [8]. The method detects the presence of any gas that is insoluble in KOH, including N_2, O_2, Ar, etc.

However, a limitation of this method is that compounds present in the product gas, that are soluble in KOH, such as H_2O, will be falsely identified as CO_2. Hence, a drying procedure, which is installed in most plants, should be performed prior to using the purity tester. The method furthermore requires manual handling, which is related to uncertainties both regarding handling the sample and the caustic solution, along with the uncertainties related to reading the results of the measurement [9].

Standard regulatory measurements required for flue gas include several of the impurities also relevant for CO_2, but the change in gas matrix, along with more stringent concentration limits, can cause challenges. Flue gas contains up to 25 % CO_2 depending on the fuel [38]. Conducting measurements in a pure CO_2 matrix can potentially complicate the measurements of the impurities, due to the physical and chemical properties of CO_2, which will be discussed in the following paragraphs [39].

H_2O

The concentration limit lies between 20 ppm and 70 ppm, depending on the specification (Table 1). The concentration limit of H_2O results from studies investigating the effect of H_2O on chemical reactions occurring in the CO_2 and corrosion of materials [36]. A range of chemical reactions require the presence of H_2O to occur, and high corrosion rates have been found under saturated conditions [37].

The different measuring principles presented in Table 2 for measuring H_2O each have their strengths and challenges, which should be considered when planning the measurement. While the electrometric moisture analyser is suitable for general monitoring of moisture, the FTIR spectroscopy is a method for multi-gas analysis, which broadens the method´s applicability.

The measuring principle of FTIR is the absorbance of infrared radiation by the gaseous compounds, and the use of FTIR can be challenged by interfering spectra and the limit of detection [16]. whereas the detection limit of standard FTIR equipment is not sufficiently low for H_2O, specialised equipment specifically developed for measuring CO_2 purity in the food and beverage industry exists [6].

O_2

The O_2 threshold concentration ranges between 10 ppm and 40 ppm in the five considered CO_2 purity specifications (Table 1). The presence of O_2 can influence the physical properties of CO_2 and thereby potentially affect the transportation and storage of CO_2 [37]. Furthermore, O_2 reacts with impurities such as NO_x, SO_x and H_2S and promotes the formation of strong acids with corrosive effects [37].

The concentration of O_2 can be measured using an electrolytic cell, GC with different types of detectors or using an OFCEAS laser. The choice of detector for measuring O_2 is important, as the sensitivity and detection limit vary between the detectors, and the choice of detector can depend on the concentration limit, along with the potential to use the detector simultaneously for other compounds.

SO_x

The content of SO_x (SO, SO_2 and SO_3) in the product gas is limited to a maximum of 10 ppm (Table 1), due to its ability to form corrosive acids such as H_2SO_4 and H_2SO_3. Furthermore, SO_x reduce the solubility of H_2O in CO_2, increasing the risk of water drop-out and, in turn, the risk of corrosion [37].

There are several opportunities for measuring the concentration of SO_x in CO_2, with some methods being only applicable to SO_x (e.g. UV), while others are suitable for several other components, such as FTIR or GC. If using NDIR/ for measuring SO_2, the high level of CO_2 in the product gas may interfere with the measurement as SO_2 and CO_2 have overlapping absorption bands [40]. If using NDIR/ for measuring SO_2, the high level of CO_2 in the product gas may interfere with the measurement as SO_2 and CO_2 have overlapping absorption bands [40].

NO_x

NO_x ($NO + NO_2$) and especially NO_2 are highly reactive and are limited to a maximum of 5 ppm (Table 1). NO_2 facilitates and takes part in reactions forming both HNO_3 and H_2SO_4, both compounds which result in significant corrosion. Furthermore, like SO_x, the presence of high levels of NO_2 also decreases the solubility of H_2O in CO_2 [37]. Furthermore, like SO_x, the presence of high levels of NO_2 also decreases the solubility of H_2O in CO_2 [37].

The standard method for measuring NO_x is by CLD according to EN 14211:2024 (EU Directive 2008/50/EF) [41]. However, quenching effects occur when the carrier gas is CO_2 instead of N_2, as CO_2 can affect the chemiluminescent reaction and reduce the signal intensity of NO_x [42]. The quenching effect can be determined by calibration of the CLD prior to measurements in CO_2.

Alternatively, NO_x can be measured by either FTIR, CRDS or NDIR/UV-Vis photometer to avoid interference by CO_2 [4], [5], [6], [11], [13].

H_2S

Hydrogen sulphide (H_2S) can react with water to form H_2SO_4, or with O_2, SO_2 or NO_2 to form water. Additionally, H_2S is highly toxic for humans even at low concentrations [37]. The concentration limit for H_2S is set with a maximum of 5 ppm (Table 1), as the limit for Northern Lights specifications has been updated during 2025.

The methods suitable for measuring H_2S content (PTR-ToF-MS, OFCEAS laser and GC) are applicable to a broad range of components from the specifications [4], [13]. For PTR-ToF-MS, it should be noted that the proton affinity of H_2S is close to that of water, resulting in a significant humidity dependency, which should be considered in the calibration.

Ammonia

The ammonia (NH_3) threshold varies between 2.5-10 ppm (Table 1) NH_3 can react with H_2SO_4, HNO_3 or H_2O and CO_2 to form ammonium salts [43].

NH_3 can be measured using a configured CLD, which simultaneously measures NO_x [24]. Furthermore, FTIR [6], NDIR, SIFT-MS and GC-MS can be used [11], [17].

Volatile organic compounds

Volatile organic compounds are compounds with high vapour pressure [44]. The group of volatile organic compounds includes the following components in this paper: formaldehyde, acetaldehyde, methanol, ethanol, ethane, ethylene, amines, hydrogen cyanide and BTEX (benzene, toluene, ethylbenzene and xylenes).

Methanol and ethanol can cause liquid drop-out by altering the dew point of CO_2, which can lead to corrosion [37]. The concentration limits for methanol and ethanol are in the range of 10-620 ppm and 1-20 ppm, respectively, depending on specification and transport conditions (Table 1).

Hydrogen Cyanide (HCN) can form acids in the presence of H_2O, thereby increasing the risk of corrosion. Additionally, HCN is highly toxic for humans at even low levels (0.9 ppm) in air [37]. The concentration limits set in the CO_2 specifications range from 0.5 ppm to 100 ppm (Table 1).

The concentration of total volatile organic compounds can be measured using a FID, but it might be limited by the content of O_2 in the gas, as a low level of O_2 limits the application of the FID [31].

In the following, specific volatile organic compounds are listed which are in focus in the different CO_2 specifications (Table 2).

Formaldehyde, acetaldehyde, methanol, ethanol, ethylene, and hydrogen cyanide can all be measured using PTR-ToF-MS, which can detect all six compounds simultaneously [20]. Determination of formaldehyde is highly dependent on the water concentrations, as the proton affinity of formaldehyde is close to the proton affinity of water. Furthermore, interference between ethanol and acetaldehyde fragments should be handled carefully [45].

Formaldehyde, acetaldehyde, methanol, ethanol, ethane and ethylene can also be measured by GC-FID [4], [5], [11], whereas hydrogen cyanide requires another detector, e.g. FTD [32].

The methods (CRDS, custom-built equipment and fluorescence measurement) for measuring formaldehyde are tested in a gas matrix of atmospheric air. Still, it is unclear whether the measuring principles will work in a CO_2 matrix [28]. The high level of CO_2 can affect both optical measurements and chemical reactions in the measurements. CRDS can show interference with CO_2, but the potential influence on formaldehyde measurement is unknown [46].

HCN can further be measured using GC-NCD [4], [37] and GC-FTD or SIFT-MS [11].

Ethane can further be measured using GC-Meth-FID or GC-TCD [11].

Amines

The maximum level of amines allowed according to the specifications (Table 1) is 10 ppm. The presence of amines and degradation products can, in combination with CO_2 and H_2O, create corrosive environments and affect the system integrity [37]. The total concentration of amines (according to the EIGA specifications, Table 1) can be measured using a GC-NCD [4], [11]. PTR-ToF-MS can be used to measure the concentration of individual amines and degradation products, but it is not suitable for determining the total concentration of amines.

Benzene, Toluene, Ethylbenzene and Xylenes (BTEX)

Measurement methods listed as suitable for measuring BTEX are a combination of methods applicable to measure the different compounds individually and methods able to provide the concentration of BTEX based on either a response factor for benzene obtained by using a permeation tube [17], or by measuring benzene as a part of total aromatics [6].

Metals

Mercury (Hg) is the only metal mentioned in the CO_2 specifications (Table 1) and a concentration limit is only presented by Northern Lights and Porthos when considering transport by ship. The traceable limits are set to a maximum of 30 ppb and are likely caused by concerns about galvanic corrosion potentially occurring through the different steps of the storage process [37]. Hg can be measured using atomic absorption spectrometry [11].

Non-condensable gases

Non-condensable gases encompass CO, H_2, CH_4, N_2 and Ar. The concentration limits of non-condensable gases are between 50 ppm and 100 ppm for Northern Lights, while the range is 750 ppm to 2.4 mol% for Porthos, which, for both specifications, are a bit higher than the more reactive components (Table 1). The non-condensable gases do not cause corrosion but can affect the thermodynamic properties of the CO_2 product stream [37].

The five non-condensable gases listed here can all be measured using either GC-DID or GC-TCD [5], [11], and the choice of detector depends on the sensitivity needed. It should be noted that CO can be measured using a wider range of measuring principles listed in Table 2, some of which are also suitable for other components.

The concentration of Ar is challenging to determine, as Ar is used as a carrier gas for a wide range of compounds when using GC, while a different column and carrier gas would be required to quantify the concentration of Ar. When no additional source of Ar is present, the content of Ar can be calculated from the atmospheric composition based on the measured O_2 or N_2 concentration in the gas matrix.

Glycols

Mono-ethylene (MEG) and tri-ethylene (TEG) glycols are the glycols mentioned in the CO_2 specifications with allowed traceable concentrations below 0.2 ppm for Northern Lights. For Porthos and Aramis, the allowable concentration follows the dew point specification (Table 1), as glycols in the presence of H_2O raise the dew point temperature.

The traceable concentrations of glycols are restricted to low values, as the presence of glycols can increase the risk of forming a liquid phase and thereby corrosion. Furthermore, degradation products of glycols can shorten equipment lifespan and potentially cause leaks [37]. Both MEG and TEG can be measured using, e.g. GC-MS or PTR-ToF-MS.

Hydrocarbons

The group of hydrocarbons considered here comprise the components: total hydrocarbons, aliphatic hydrocarbons (C3+) and ethane. Hydrocarbons, as a group, have been divided into subgroups based on their physical properties and chemical structures. Hydrocarbons heavier than CO_2 will impact the CO_2 dew point and potentially cause liquid drop-out, which can promote corrosion [37]. The concentration limits for hydrocarbons are set based on their potential influence on the CO_2 dew point.

Total and aliphatic hydrocarbons can be measured using GC-FID [4], [17]. Several commercial solutions have been developed for the food and beverage industry, applicable to these components, including FTIR [6] and a THC analyser using an FID to measure hydrocarbons [34].

Solids, particles and dust

The limit related to solids, particles and dust describes the particle cut-off diameter above which all particles should be removed, but below that diameter, no limit is set. The cut-off diameter for Northern Lights specifications follows the ISO 27913, and the cut-off diameter is set to below 1 µm. Liquid and solid particles can potentially cause clogging at injection sites and damage equipment in the storage pipeline [37]. The particle number and size distribution can be measured by ELPI+ [35].

Aramis describes a requirement for dust removal at given diameters instead of monitoring the concentration of solids, particles and dust. Aramis is planning to install filters at relevant locations in the pipeline prior to compressors and terminal stations [2].

Conclusion

Current CO_2 purity specifications set by transport and storage operators reflect the best available understanding of corrosion mechanisms, chemical reactivity, operational constraints, and safety considerations. No single measurement principle can cover the full spectrum of relevant impurities, making careful considerations necessary when planning the measurements.

This whitepaper has outlined the key considerations that guide the selection of measurement methods, including detection limits, measurement ranges, response times, interferences, etc. It also highlights suitable techniques for each impurity class, emphasising both their strengths and their limitations when applied to a CO_2 matrix.

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