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**Carbon dioxide capture —**  
**Part 1:**  
**Performance evaluation methods**  
**for post-combustion CO<sub>2</sub> capture**  
**integrated with a power plant**

*Captage du dioxyde de carbone —*

*Partie 1: Méthodes d'évaluation des performances pour le captage du CO<sub>2</sub> post-combustion intégré à une centrale thermique*

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## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2. [www.iso.org/directives](http://www.iso.org/directives)

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received. [www.iso.org/patents](http://www.iso.org/patents)

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: [Foreword - Supplementary information](#)

This document was prepared by Technical Committee ISO/TC 265, *Carbon dioxide capture, transportation and geological storage*.

A list of all the parts in the ISO 27919 series can be found on the ISO website.

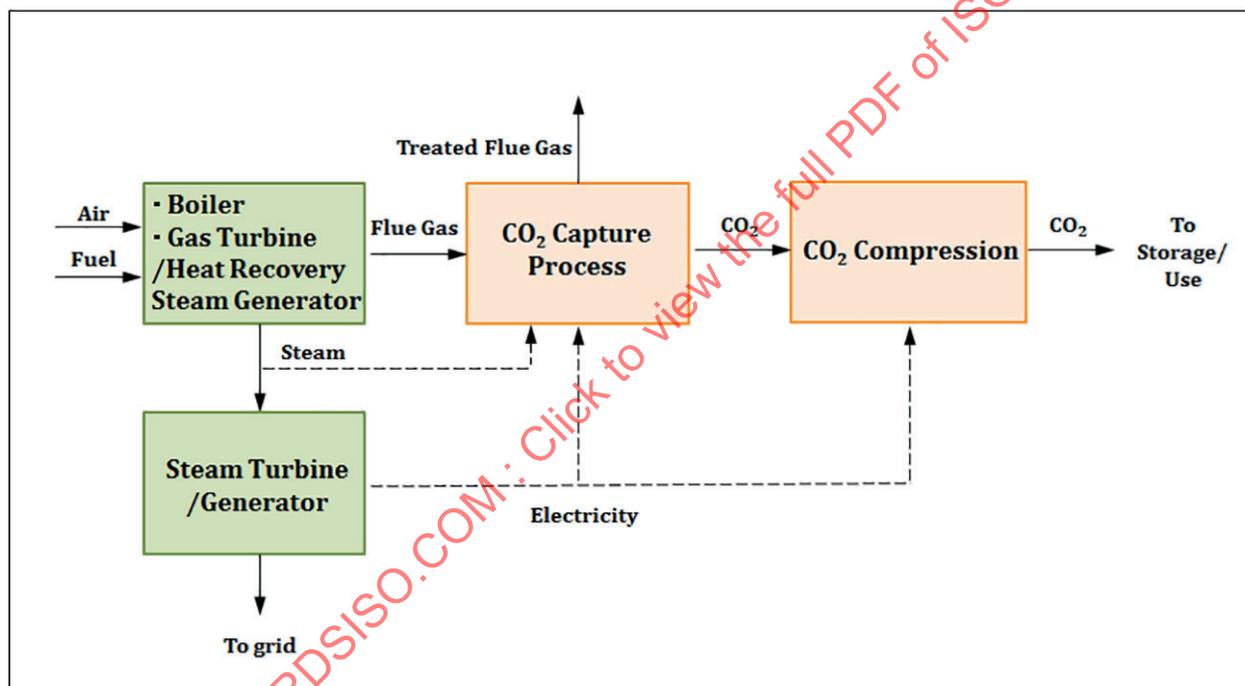
Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at [www.iso.org/members.html](http://www.iso.org/members.html).

## Introduction

It is very important to reduce atmospheric carbon dioxide (CO<sub>2</sub>) emissions in order to meet climate change mitigation targets. Inclusion of carbon dioxide capture and storage (CCS) among the variety of available emission reduction approaches enhances the probability of meeting these targets at the lowest cost to the global economy. CCS captures CO<sub>2</sub> from industrial and energy-related sources and stores it underground in geological formations. It can capture emissions from carbonaceous fuel-based combustion processes, including power generation, and is the only technology capable of dealing directly with emissions from several industrial sectors, such as cement manufacture and fertilizer production.

This document is the first in a series of standards for CO<sub>2</sub> capture. It is limited to evaluation of key performance indicators (KPIs) for post-combustion CO<sub>2</sub> capture (PCC) from a power plant using a liquid-based chemical absorption process. New or revised standards focused on other capture technologies and approaches will be developed at a later date.

PCC is applicable to all combustion-based thermal power plants. A simplified block diagram illustrating the PCC is shown in [Figure 1](#).



**Figure 1 — Simplified block diagram for PCC**

In a typical power generation facility, carbonaceous fuel (e.g. coal, oil, gas, biomass) is combusted with air in a boiler to raise steam that drives a turbine/generator to produce power. In a gas turbine combined cycle system, the combustion occurs in the gas turbine to drive power generation, and steam generated through a heat recovery steam generator (HRSG) contributes to additional power generation. Flue gas from the boiler or gas turbine consists mostly of N<sub>2</sub>, CO<sub>2</sub>, H<sub>2</sub>O and O<sub>2</sub> with smaller amounts of other compounds depending on the fuel used. The CO<sub>2</sub> capture process is located downstream of conventional pollutant controls. Chemical absorption-based PCC usually requires the extraction of steam from the power plant's steam cycle or, depending on the absorption liquid/process employed, the use of lower grade heat sources for absorption liquid regeneration.

The intended readership for this document includes power plant owners and operators, project developers, technology developers and vendors, regulators, and other stakeholders. The document will provide several benefits, as outlined in the clauses below. In brief, it provides a common basis to estimate, measure, evaluate and report on the performance of a PCC plant integrated with a power

plant. It can help various stakeholders to identify potential efficiency improvements among different plant components. It can help to guide the selection of measurement methodologies, and serve as a resource in development of regulations. Finally, it provides the basis for future standards development.

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# Carbon dioxide capture —

## Part 1:

# Performance evaluation methods for post-combustion CO<sub>2</sub> capture integrated with a power plant

## 1 Scope

This document specifies methods for measuring, evaluating and reporting the performance of post-combustion CO<sub>2</sub> capture (PCC) integrated with a power plant, and which separates CO<sub>2</sub> from the power plant flue gas in preparation for subsequent transportation and geological storage. In particular, it provides a common methodology to calculate specific key performance indicators for the PCC plant, requiring the definition of the boundaries of a typical system and the measurements needed to determine the KPIs.

This document covers thermal power plants burning carbonaceous fuels, such as coal, oil, natural gas and biomass-derived fuels, which are producing CO<sub>2</sub> from boilers or gas turbines, and are integrated with CO<sub>2</sub> capture.

The PCC technologies covered by this document are those based on chemical absorption using reactive liquids, such as aqueous amine solutions, potassium carbonate solutions, and aqueous ammonia. Other PCC concepts based on different principles (e.g. adsorption, membranes, cryogenic) are not covered. The PCC plant can be installed for treatment of the full volume of flue gas from the power plant or a fraction of the total (i.e. a slip stream). Captured CO<sub>2</sub> is processed in a compression or liquefaction step as determined by the conditions for transportation and storage.

The KPIs considered in this document are the following:

- a) Specific thermal energy consumption (STEC);
- b) Specific electrical energy consumption (SEC);
- c) Specific equivalent electrical energy consumption (SEEC);
- d) Specific reduction in CO<sub>2</sub> emissions (SRCE);
- e) Specific absorbent consumption (SAC) and specific chemical consumption (SCC).

The calculations are based on measurements at the boundaries of the considered system, particularly of energy and utilities consumption. The integrated system includes the definition of interfaces between the PCC plant and the power plant.

This document includes the following items:

- The system boundary which defines the boundaries of the PCC plant and identifies which streams of energy and mass are crossing these boundaries to help power plant operators identify the key streams that are applicable for their particular case.
- Basic PCC plant performance which defines the parameters that describe the basic performance of the PCC plant.
- Definition of utilities and consumption calculation which lists the utility measurements required and provides guidance on how to convert utility measurements into the values required for the KPIs.

- Guiding principles - Basis for PCC plant performance assessment which describes all guidelines to prepare, set-up and conduct the tests.
- Instruments and measurement methods which lists the standards available for the relevant measurements and considerations to take into account when applying measurement methods to PCC plants.
- Evaluation of key performance indicators which specifies the set of KPIs to be determined and their calculation methods to provide a common way of reporting them.

This document does not provide guidelines for benchmarking, comparing or assessing KPIs of different technologies or different PCC projects.

NOTE For the purposes of this document, thermal energy and electric energy are expressed by the unit of “J” (Joule) and “Wh” (Watt hour) respectively unless otherwise noted, with a prefix of International System of Units (SI) if necessary. (1 J = 1 W·s, 1 Wh = 1 W·h = 3 600 J).

## 2 Normative references

There are no normative references in this document.

## 3 Terms, definitions and symbols

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

### 3.1 Terms and definitions

#### 3.1.1

##### **absorbent**

substance able to absorb liquid or gas

[SOURCE: ISO/TR 27912:2016, definition 3.1]

#### 3.1.2

##### **measurement accuracy**

accuracy of measurement

accuracy

closeness of agreement between a measured quantity value and a true quantity value of a measurand

[SOURCE: ISO/IEC Guide 99:2007, definition 2.13]

#### 3.1.3

##### **auxiliary unit**

unit providing heat, power and/or other utilities for the PCC plant

#### 3.1.4

##### **boiler feed water**

water consisting of the condensate and the make-up water that is sent to the boiler

### 3.1.5 carbon dioxide capture and storage CCS

process consisting of the separation of CO<sub>2</sub> from industrial and energy-related sources, transportation and injection into a geological formation, resulting in long term isolation from the atmosphere

Note 1 to entry: CCS is often referred to as Carbon Capture and Storage. This terminology is not encouraged because it is inaccurate: the objective is the capture of carbon dioxide and not the capture of carbon. Tree plantation is another form of carbon capture that does not describe precisely the physical process of removing CO<sub>2</sub> from industrial emission sources.

Note 2 to entry: The term "sequestration" is also used alternatively to "storage". The term "storage" is preferred since "sequestration" is more generic and can also refer to biological processes (absorption of carbon by living organisms).

Note 3 to entry: Long term means the minimum period necessary for CO<sub>2</sub> geological storage to be considered an effective and environmentally safe climate-change-mitigation-option.

Note 4 to entry: The term carbon dioxide capture, utilization (or use) and storage (CCUS) includes the concept that isolation from the atmosphere could be associated with a beneficial outcome. CCUS is embodied within the definition of CCS to the extent that long term isolation of the CO<sub>2</sub> occurs through storage within geological formations. CCU is Carbon Capture and utilization (or use) without storage within geological formations.

Note 5 to entry: CCS should also ensure long term isolation of CO<sub>2</sub> from oceans, lakes, potable water supplies and other natural resources.

[SOURCE: ISO 27917:2017, definition 3.1.1]

### 3.1.6 carbonaceous fuels

any solid, liquid or gaseous fuels containing carbon atoms

### 3.1.7 capture plant

process and associated equipment that produces a CO<sub>2</sub> stream

### 3.1.8 chemical absorption

process in which CO<sub>2</sub> is absorbed by chemical reaction

### 3.1.9 CO<sub>2</sub> capture efficiency capture efficiency

CO<sub>2</sub> removal efficiency of the capture plant calculated as the amount of CO<sub>2</sub> captured divided by the total amount of CO<sub>2</sub> contained in the flue gas at the inlet of the capture plant

Note 1 to entry: The CO<sub>2</sub> capture efficiency is expressed as a percentage.

### 3.1.10 CO<sub>2</sub> captured

absolute amount of pure CO<sub>2</sub> captured by the capture plant

### 3.1.11 CO<sub>2</sub> stream

stream consisting overwhelmingly of carbon dioxide

[SOURCE: ISO 27917:2017, definition 3.1.1, modified — The Note was deleted.]

### 3.1.12 condensate

water produced by condensation of steam, e.g. a boiler of PCC return to the steam cycle and/or auxiliary boiler

**3.1.13**

**deep flue gas desulfurization**  
**deep FGD**

SO<sub>2</sub> removal unit placed downstream of the main flue gas desulfurization process intended to lower the SO<sub>2</sub> content to the level required by the CO<sub>2</sub> capture plant

Note 1 to entry: Also called a “polishing” FGD.

Note 2 to entry: In the case where no FGD is required by local regulations, and FGD is installed for the purposes of CCS, the new unit will be considered as deep FGD.

**3.1.14**

**dehydrator**

moisture removal system and/or equipment

**3.1.15**

**demineralized water**

water from which the mineral matter or salts have been removed

[SOURCE: ISO/TR 27912:2016, definition 3.24, modified — The second term “demin water” was removed and in the definition the word “of” was replaced by “from”.]

**3.1.16**

**DeNO<sub>x</sub>**

process or equipment used to remove NO<sub>x</sub> from the flue gas

**3.1.17**

**effluent**

liquid discharged to the environment

**3.1.18**

**fuel specific emission**

amount of component generated from complete combustion per unit of heat energy released

**3.1.19**

**host power plant**

power plant from which flue gas is sent to the PCC plant

**3.1.20**

**impurities**

non-CO<sub>2</sub> substances that are part of the CO<sub>2</sub> stream that may be derived from the source materials or the capture process, or added as a result of commingling for transportation, or released or formed as a result of sub-surface storage and/or leakage of CO<sub>2</sub>

[SOURCE: ISO 27917:2017, definition 3.2.12, modified — Notes 1 and 2 were deleted.]

**3.1.21**

**interface**

mechanical, thermal, electrical, or operational common boundary between two elements of a system

[SOURCE: ISO 10795:2011, definition 1.120, modified — The abbreviation “I/F” was deleted.]

**3.1.22**

**key performance indicator**

measure of performance relevant to the PCC plant integrated with a power plant

**3.1.23****measurement uncertainty**

uncertainty of measurement  
uncertainty

non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used

Note 1 to entry: Measurement uncertainty includes components arising from systematic effects, such as components associated with corrections and the assigned quantity values of physical properties, as well as the definitional uncertainty. Sometimes estimated systematic effects are not corrected for; associated measurement uncertainty components are incorporated instead.

Note 2 to entry: The parameter may be, for example, a standard deviation called standard measurement uncertainty (or a specified multiple of it), or the half-width of an interval, having a stated coverage probability.

Note 3 to entry: Measurement uncertainty comprises, in general, many components. Some of these may be evaluated by Type A evaluation of measurement uncertainty from the statistical distribution of the quantity values from a series of measurements and can be characterized by standard deviations. The other components, which may be evaluated by Type B evaluation of measurement uncertainty, can also be characterized by standard deviations, evaluated from probability density functions based on experience or other information.

Note 4 to entry: In general, for a given set of information, it is understood that the measurement uncertainty is associated with a stated quantity value attributed to the measurand. A modification of this value results in a modification of the associated uncertainty.

Note 5 to entry: "Type A evaluation of measurement uncertainty" is defined as an evaluation of a component of measurement uncertainty by a statistical analysis of measured quantity values obtained under defined measurement conditions. "Type B evaluation of measurement uncertainty" is defined as an evaluation of a component of measurement uncertainty determined by means other than a Type A evaluation of measurement uncertainty".

[SOURCE: ISO/IEC Guide 99:2007, definition 2.26, modified — "measurement standards" in Note 1 was changed to "physical properties" and a Note 5 was added.]

**3.1.24****PM**

particulate matter including PM<sub>2.5</sub>, PM<sub>10</sub>, and/or total suspended particulate matter

[SOURCE: ISO 25597:2013, definition 3.21]

**3.1.25****particulate removal**

action to remove particulate matter from the flue gas stream

**3.1.26****PCC plant**

process and associated equipment that produces a CO<sub>2</sub> stream from combustion gases

**3.1.27****permanent plant instrument**

instrument installed in the power plant and capture plant for control and monitoring

**3.1.28****post-combustion CO<sub>2</sub> capture**

capture of carbon dioxide from flue gas stream produced by carbonaceous fuel combustion

[SOURCE: ISO/TR 27912:2016, definition 3.51, modified — In the term, "CO<sub>2</sub>" was added and "fuel air combustion" was modified to "carbonaceous fuel combustion" in the definition.]

**3.1.29****product CO<sub>2</sub> stream**

stream produced by a CO<sub>2</sub> capture and compression/liquefaction process

**3.1.30**

**reclaiming system**

system used to recover CO<sub>2</sub> absorbents for use in the PCC plant to remove the heat stable salts produced by the reaction of organic and inorganic acids with the amine(s) in the absorbents

**3.1.31**

**redundant instrument**

duplicate instrument necessary to plant functioning in case of failure of similar instruments for measurement of the same parameters

**3.1.32**

**reference power plant**

power plant that is considered to be representative of power generation without CO<sub>2</sub> capture

Note 1 to entry: The power plant is either real or hypothetical.

**3.1.33**

**regeneration**

process to regenerate an activity of absorbent after use to its operationally effective state

**3.1.34**

**rejected heat**

heat dissipated to the environment by cooling equipment

**3.1.35**

**specific absorbent consumption**

amount of CO<sub>2</sub> absorbent consumed to capture and compress/liquefy a tonne of CO<sub>2</sub>

**3.1.36**

**specific reduction in CO<sub>2</sub> emissions**

calculated net decrease of the CO<sub>2</sub> emissions per unit output of a reference power plant by implementing the PCC process to the host power plant

Note 1 to entry: This measure of emission reduction is normalised with respect to the output of the power plant.

[SOURCE: ISO 27917:2017, definition 3.2.8, modified — “baseline scenario and the CCS project output” has been replaced by “per unit output of a reference power plant by implementing the PCC process to the host power plant”.]

**3.1.37**

**specific chemical consumption**

amount of chemical consumed to capture and compress/liquefy a tonne of CO<sub>2</sub>

**3.1.38**

**specific equivalent electrical energy consumption**

overall electrical energy consumption attributed to capture and compression/liquefaction of a tonne of CO<sub>2</sub>

**3.1.39**

**specific electrical energy consumption**

electrical energy consumed to capture and compress/liquefy a tonne of CO<sub>2</sub>

**3.1.40**

**specific thermal energy consumption**

thermal energy consumed to capture and compress/liquefy a tonne of CO<sub>2</sub>

**3.1.41****reference conditions**

conditions for a reference point where results of performance evaluation could be adjusted for the purpose of comparability in the reporting of the results and benchmarking

Note 1 to entry: See Annex E which presents standard reference conditions used as a reference point to adjust the results of performance evaluation.

**3.1.42****thermal power plant**

power plant that converts heat e.g. released by the combustion of carbonaceous fuels into electricity

**3.1.43****tie-in point**

point of connection between the utility supply and the PCC plant

Note 1 to entry: This point sits at the PCC plant boundary.

**3.1.44****treated flue gas**

flue gas of which the CO<sub>2</sub> concentration has been reduced after passing through a PCC plant

**3.1.45****utilities**

ancillary services needed in the operation of a process, such as steam, electricity, cooling water (CW), demineralised water, compressed air, refrigeration and effluent disposal

**3.1.46****vent gases**

gases other than flue gases or treated flue gases that are intentionally emitted to the atmosphere

**3.1.47****waste heat**

heat generated by a process that would normally be dissipated to the environment if special measures for its utilization were not implemented

**3.1.48****waste water**

excess water allowed to run to waste from the water circuit

[SOURCE: ISO 1213-1:1993, definition 5.1.18]

**3.1.49****wet-basis**

condition in which a solid, such as a fuel or a gas, such as flue gas, contains moisture

**3.2 Abbreviations**

CCS	carbon dioxide capture and storage
CW	cooling water
DP	differential pressure
FGD	flue gas desulfurization
FSE	fuel specific emission
GTCC	gas turbine combined cycle
HP	high pressure
HRSG	heat recovery steam generator
IP	intermediate pressure

KPI	key performance indicator
LHV	lower heating value
LP	low pressure
MP	medium pressure
NO <sub>x</sub>	nitrogen oxides
PCC <sup>a</sup>	post-combustion CO <sub>2</sub> capture
PM	particulate matter
SAC	specific absorbent consumption
SCC	specific chemical consumption
SCWD	specific cooling water duty
SEC	specific electrical energy consumption
SEEC	specific equivalent electrical energy consumption
SO <sub>x</sub>	sulphur oxides, sulfur oxides
SRCE	specific reduction in CO <sub>2</sub> emissions
STEC	specific thermal energy consumption
<sup>a</sup> PCC is often used for pulverized coal combustion. In this document, it refers to post-combustion CO <sub>2</sub> capture.	

### 3.3 Symbols

The following mathematical symbols are preparatory for revising variables and formulae in [Clause 5](#), [Clause 6](#) and [Clause 9](#) based on the ISO directives and relevant standards.

$c_{p\text{ CW}}$	Specific heat of CW	[kJ]/(kg K)]
$\Delta E$	Fractional increase in plant energy input per unit of product	[-]
$FSE$	Fuel specific emission	[kg/kg]
$h_{\text{steam}}$	Specific enthalpy of steam	[kJ/kg]
$h_{\text{condensate}}$	Specific enthalpy of condensate	[kJ/kg]
$LHV_{\text{fuel}}$	LHV of a fuel	[kJ/kg]
$P_{\text{CW}}$	Electrical power requirement of CW pump	[MW]
$P_{\text{LGP}}$	Change in gross power output due to the steam extraction from the host power plant steam cycle and/or auxiliary unit	[MW]
$P_{\text{PCC}}$	Electrical power requirement of the PCC plant	[MW]
$P_{\text{NET,ref}}$	Net power output of a reference power plant	[MW]
$P_{\text{NET,cap}}$	Net power output of a power plant with a PCC plant	[MW]
$p_e$	Absolute pressure of a gas stream	[kPa]
$p_{\text{CWin}}$	Pressure of CW at the supply side	[kPa]
$p_{\text{CWout}}$	Pressure of CW at the return side	[kPa]
$q_{m\text{CO}_2\text{-comp}_a}$	Mass flow rate of a product CO <sub>2</sub> stream after compression	[t/h]
$q_{m\text{CO}_2\text{-comp}_b}$	Mass flow rate of a product CO <sub>2</sub> stream before compression	[t/h]
$q_{m\text{CO}_2}$	Mass flow rate of a product CO <sub>2</sub> stream	[t/h]

$q_{mCO_2,ref}$	Mass flow rate of CO <sub>2</sub> emission from a reference power plant	[t/h]
$q_{mCO_2e,cap}$	Mass flow rate of CO <sub>2</sub> emission from a power plant with a PCC plant	[t/h]
$q_m$ stream	Mass flow rate of steam to a PCC plant	[kg/h]
$q_m$ condensate	Mass flow rate of condensate from a PCC plant	[kg/h]
$q_m$ absorbent	Consumption rate of absorbent at a PCC plant	[kg/h]
$q_m$ chemical	Consumption rate of a chemical compound at a PCC plant	[kg/h]
$q_V$	Volume flow rate at a measurement or specific condition	[m <sup>3</sup> /h]
$q_{Vr}$	Volume flow rate at the standard temperature (273,15 K) and pressure (100 kPa) conditions	[m <sup>3</sup> /h]
$q_{VrCO_2in}$	Volume flow rates of CO <sub>2</sub> at a PCC plant inlet on a dry basis at the standard temperature (273,15 K) and pressure (100 kPa) conditions	[m <sup>3</sup> /h]
$q_{VrCO_2out}$	Volume flow rates of CO <sub>2</sub> at a PCC plant outlet (treated flue gas emission side) on a dry basis at the standard temperature (273,15 K) and pressure (100 kPa) conditions	[m <sup>3</sup> /h]
$q_{Vrflue\ gas\ in}$	Volume flow rate of a flue gas to a PCC plant on a dry basis at the standard temperature (273,15 K) and pressure (100 kPa) conditions	[m <sup>3</sup> /h]
$q_{Vrflue\ gas\ out}$	Volume flow rate of a flue gas at a PCC plant outlet on a dry basis at the standard temperature (273,15 K) and pressure (100 kPa) conditions	[m <sup>3</sup> /h]
$q_{VrCO_2\ comp\_a}$	Volume flow rate of a product CO <sub>2</sub> stream after compression on a dry basis at the standard temperature (273,15 K) and pressure (100 kPa) conditions	[m <sup>3</sup> /h]
$q_{VrCO_2\ comp\_b}$	Volume flow rate of a product CO <sub>2</sub> stream before compression on a dry basis at the standard temperature (273,15 K) and pressure (100 kPa) conditions	[m <sup>3</sup> /h]
$SAC$	Specific absorbent consumption	[kg/t]
$SCC$	Specific chemical consumption	[kg/t]
$SCWD$	Specific cooling water duty	[m <sup>3</sup> /t]
$SEC$	Specific electrical energy consumption	[kWh/t]
$SEEC$	Specific equivalent electrical energy consumption	[kWh/t]
$SRCE$	Specific reduction in CO <sub>2</sub> emissions	[t/MWh]
$STEC$	Specific thermal energy consumption	[GJ/t]
$T_{CWin}$	Temperature of CW at the supply side	[K]
$T_{CWout}$	Temperature of CW at the return side	[K]
$T_S$	Average temperature of a gas stream	[K]
$w_c$	Percentage of carbon by mass in fuel on an as-fired basis	[%]
$\eta_{CO_2}$	CO <sub>2</sub> capture efficiency	[%]
$\eta_M$	Efficiency of motor	[%]
$\eta_P$	Efficiency of CW pump	[%]

$\eta_{\text{gas to PCC}}$	Proportion of total flue gas flow to a PCC plant	[%]
$\eta_{\text{ref}}$	Net power output efficiency of a reference power plant	[%]
$\eta_{\text{PCC}}$	Net power output efficiency of a power plant with PCC	[%]
$\rho_{\text{CW}}$	Density of CW	[kg/m <sup>3</sup> ]
$\Phi_{\text{CW}}$	Total cooling heat duty at a PCC plant	[kJ/h]
$\varphi_{\text{CO}_2\text{in\_cap}}$	Volume concentration of CO <sub>2</sub> in the flue gas to a PCC plant on a dry basis	[%]
$\varphi_{\text{CO}_2\text{out\_cap}}$	Volume concentration of CO <sub>2</sub> in the flue gas at a PCC plant outlet (treated flue gas emission side) on a dry basis	[%]
$\varphi_{\text{CO}_2\text{out\_comp\_a}}$	Volume concentration of CO <sub>2</sub> in the product CO <sub>2</sub> stream after compression on a dry basis	[%]
$\varphi_{\text{CO}_2\text{out\_comp\_b}}$	Volume concentration of CO <sub>2</sub> in the product CO <sub>2</sub> stream before compression on a dry basis	[%]
(Chemical symbols)		
CO <sub>2</sub>	Gaseous product by reaction of oxygen in air (combustion) with carbon atom in fuel	

## 4 Defining the system boundary

### 4.1 PCC plant integrated with a host power plant

This document is designed to assess the performance of a PCC plant integrated with a carbonaceous fuel-fired thermal power plant, including combined heat and power generation. This document covers the use of all carbonaceous fuel.

A PCC plant integrated with a thermal power plant (also called a host power plant) is characterized as follows:

- Receives flue gas from one or more host power plants. Flue gas may be pre-conditioned within the host power plant(s), within the PCC plant, or a combination of both;
- Typically receives utilities and energy from the host power plant or any other auxiliary units, or delivers energy to the host power plant;
- PCC plant load control is integrated with the host power plant as required by both sides.

Hereafter these applications are called “PCC plant integrated with a host power plant”.

### 4.2 Boundary of the PCC plant, host power plant and utilities

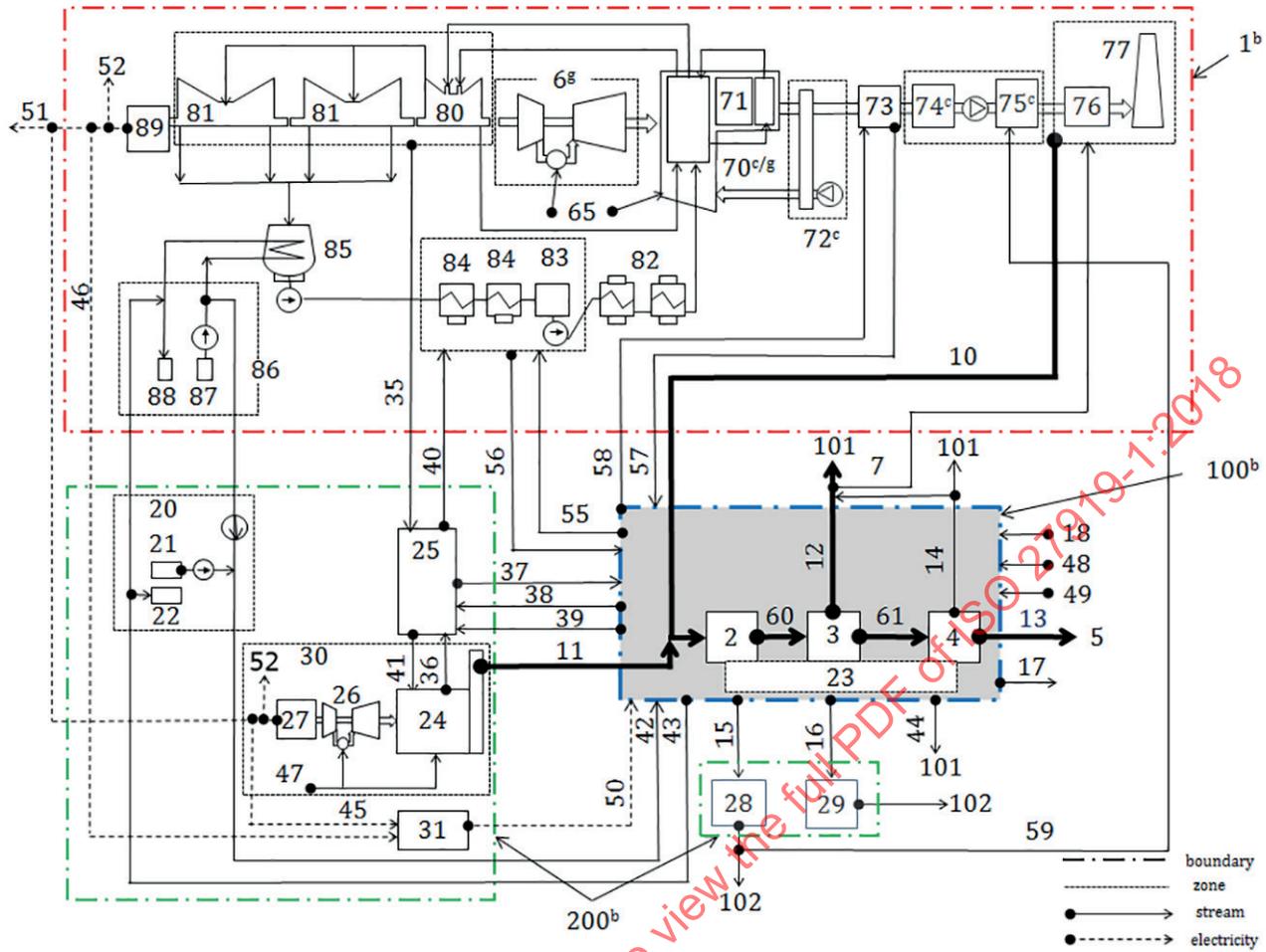
[Figure 2](#) presents a typical boundary of a PCC plant integrated with a host power plant. Minor variations may result from the specific configuration of a host power plant or a PCC plant. [Figure 2](#) represents a comprehensive configuration that includes a carbonaceous fuel-fired boiler or a natural gas combined cycle, which are prevailing types in this field, and includes multiple items that may not be applicable to all cases. The boundary of any PCC plant may include the following interfaces:

- Interface with the host power plant: Important elements at this interface include flue gas (downstream of any existing environmental control systems), electricity and heat transfer media, if these are supplied by a host power plant.

- b) Interface with auxiliary units: It includes the auxiliary boiler or auxiliary gas turbine with HRSG that supplies heat transfer media and electrical power to the PCC plant, instead of, or in combination with, a host power plant in case the modification of, or any operational impact on, a host power plant is quite restricted. Only the utility consumption affecting the performance evaluation of the PCC plant should be included in the consumption calculations (see [Clause 6](#)).
- c) Interface with the environment: The outlet of the PCC plant discharges directly to the atmosphere and waste streams such as waste water, solid waste, and consumables (e.g., filters) should also be included in calculating consumption and utility requirements if present (see [Clause 6](#)).
- d) Interface with CO<sub>2</sub> transportation infrastructure: It is the first flange at the outlet piping from the CO<sub>2</sub> stream compressor or CO<sub>2</sub> stream pump, if applied.

The performance evaluation boundary of a PCC plant integrated with a host power plant is depicted as a thick dashed line – labelled 100 – in [Figure 2](#). Given the complexity of the system, explanations of the various streams and equipment are provided in [Table 1](#) to [Table 5](#).

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**Key**

- |    |  |    |  |
|----|--|----|--|
| 1  | host power plant boundary – this block flow configuration is typical for a coal fired boiler and a GTCC plant  | 45 | electricity from an auxiliary power generation system  |
| 2  | pre-treatment (quencher, deep-FGD, flue gas fan) – conditioning of the flue gas in preparation for separation of CO <sub>2</sub> . This can include removal of contaminants that could damage the absorbent, temperature control to optimize absorber efficiency, etc. | 46 | electricity from the host power plant to the PCC plant   |
| 3  | CO <sub>2</sub> capture section  | 47 | fuel to the auxiliary steam and power generation system  |
| 4  | CO <sub>2</sub> compression/liquefaction section (including CO <sub>2</sub> purification)  | 48 | chemicals  |
| 5  | CO <sub>2</sub> transportation system  | 49 | demineralized water, industrial water  |
| 6  | gas turbine in a GTCC - the item designated as a boiler (70) would be a HRSG and the air preheater and forced draft fan (72), particulate removal system (74), and FGD (75) would be removed   | 50 | electricity diverted to power equipment and systems associated with the PCC plant, including fans, pumps, and the compression system             |
| 7  | ducting to a stack if required (this stream, if it exists, 51 might contain residual CO <sub>2</sub> )   | 51 | net power export   |
| 10 | flue gas from host power plant   | 52 | electricity diverted from the host power plant or the auxiliary power generation system to power other equipment within the same plant or system |
| 11 | flue gas from auxiliary unit (auxiliary steam and power generation system, #30)  | 55 | medium transferring waste heat from the PCC plant to the host power plant – (e.g. boiler feed water for pre-heating)                             |

12	treated flue gas (mostly nitrogen, but might contain residual CO <sub>2</sub> ) to be vented or sent to a stack	56	host power plant waste heat used in the PCC plant or return of PCC plant waste heat used in the host power plant – this stream can represent host power plant waste heat that is used in the absorbent regeneration process in the PCC plant or the return of waste heat that was generated in the PCC plant and used in the host power plant (e.g. boiler feed water preheating)
13	product CO <sub>2</sub> stream, sent for transport	57	medium transferring waste heat from the host power plant to the PCC plant. A common source of waste heat in a host power plant is the heat contained in the flue gas. This stream integrates the heat supplied to the PCC plant by stream 37
14	CO <sub>2</sub> vent stream to the atmosphere required for start-up, shut-down, emergency and during significant operational disturbances	58	power plant waste heat return from PCC plant – this stream represents the return of waste heat from stream 57 to the host power plant
15	waste water sent for treatment	59	use of PCC plant effluent in FGD – waste water from the PCC plant can potentially be used as make-up water in the FGD system
16	waste sent to a waste handling system	60	flue gas after pre-treatment – this stream is the flue gas stream after contaminants have been removed and temperature adjustments have been made in preparation for entering the absorber (from item 2 to 3)
17	by-product	61	product CO <sub>2</sub> stream leaving the CO <sub>2</sub> -capture section prior to entry into the compression system (from item 3 to 4)
18	fresh absorbent	65	fuel to host power plant
20	CW generation system – the cooling system can include cooling towers, a once-through CW system, or air fin coolers	70	boiler – or HRSG in GTCC case
21	CW intake - A CW intake can be common to the host power plant or the PCC plant	71	NO <sub>x</sub> removal system
22	CW outfall - A CW outfall can be common to the host power plant or the PCC plant	72	air preheater and forced draft fan (not applicable in GTCC case)
23	air fin cooler integrated into PCC plant	73	flue gas heat recovery system
24	auxiliary steam generation system - e.g. HRSG on auxiliary gas turbine or auxiliary boiler	74	particulate removal system (not applicable in GTCC case)
25	steam distribution system	75	FGD (not applicable in GTCC case)
26	auxiliary gas turbine	76	flue gas heater, if necessary
27	auxiliary generator	77	stack and treated flue gas duct
28	waste water treatment system	80	high pressure (HP) – intermediate pressure (IP) turbine
29	waste handling system	81	low pressure (LP) turbine
30	auxiliary steam and power generation system	82	HP heaters
31	power distribution system – controls the amount of power diverted to the PCC plant to operate fans, pumps, blowers, and the compression system	83	deaerators
35	steam from a host power plant – although labelled as steam here, this can also be a different thermal energy transfer medium (e.g. hot oil)	84	LP heaters
36	steam from an auxiliary steam generation system – although labelled as steam here, this can also be a different thermal energy transfer medium (e.g. hot oil)	85	steam condenser

37	steam supplied from the host power plant to PCC plant to drive absorbent regeneration and other processes -- although labelled as steam here, this can also be a different thermal energy transfer medium (e.g. hot oil)	86	power plant CW supply system
38	exhaust steam from the PCC to the host power plant -- if steam is the heat transfer medium used in the PCC, any exhaust steam can be returned to the host power plant	87	power plant CW intake
39	steam condensate from the PCC to the host power plant -- if steam is used and condensed in the PCC, this stream returns the condensate to the host power plant	88	power plant CW outfall
40	steam condensate return to the host power plant	89	power plant generator
41	steam condensate return to the auxiliary steam generation system	100	Line representing the PCC plant boundary
42	CW feed -- if the CW system for the host power plant and/or auxiliary unit is used to supply CW to the PCC plant, it is accounted for in this stream	101	atmosphere
43	CW return -- CW returned from the PCC to the host power plant and/or to the auxiliary unit	102	landfill and/or hydrosphere
44	rejected heat from the process cooler integrated into the PCC plant (# 23)	200	auxiliary unit boundary

NOTE All different streams and equipment for this figure are summarized in ascending order in Annex A. Only three superscripts are used. These superscripts indicate either different options related to the type of power system (c for coal, g for a gas) or to demark a system boundary.

- b Boundary.
- c Only in the case of coal fired boiler.
- g Only in the case of GTCC.

**Figure 2 — PCC plant boundary**

Several of the items numbered in [Figure 2](#) have a direct bearing on the KPIs defined in [Clause 1](#). Items related to specific reduction in CO<sub>2</sub> emissions are included in [Table 1](#). These include flue gas streams entering the PCC plant from the host power plant and any auxiliary units as well as streams leaving the PCC plant following CO<sub>2</sub> separation. Note the flue gas streams entering the PCC plant do not necessarily represent all of the CO<sub>2</sub> containing flue gas generated by the host power plant or auxiliary units. The PCC plant may be designed for partial capture, with a certain percentage of the flue gas routed to the PCC plant for treatment while the remaining flue gas and its associated CO<sub>2</sub> simply vented to the atmosphere. This possibility is discussed further in [Clause 5](#).

It should also be noted that the KPIs related to the equivalent electrical energy consumption, i.e. SEEC and SRCE, can be applied to a case with an auxiliary unit defined in [4.2 b](#)). The auxiliary unit can be included with a host power plant when calculating the KPI as explained in [9.4](#) and [9.5](#), if the electricity generated in the auxiliary unit is used to power equipment in the PCC plant and their application is agreed among the related parties due to its specification depending on each project. In this case the interpretation of the above KPI is influenced by both the fuel specific emissions [kg/kJ] explained in [D.2](#) and the heat rate of the auxiliary unit. If these are different from a host power plant, then the main parameters used for each calculation should be listed with the KPI for mutual understanding among the related parties.

**Table 1 — Description of streams and equipment shown in Figure 2 related to the SRCE**

Stream/ Equipment Number	Description
7	Ducting to a stack if required (this stream, if it exists might contain residual CO <sub>2</sub> )
10	Flue gas from host power plant
11	Flue gas from auxiliary unit (auxiliary steam and power generation system, #30)
12	Treated flue gas (mostly nitrogen, but might contain residual CO <sub>2</sub> ) to be vented or sent to a stack
13	Product CO <sub>2</sub> stream, sent for transport

Items related to the KPI for STEC are noted in Table 2. Steam and/or waste heat can be transferred from the host power plant or auxiliary unit to help drive processes in the PCC plant. In addition, waste heat generated in the PCC plant can sometimes be used in the host power plant or the auxiliary unit, as noted in Table 2.

**Table 2 — Description of streams and equipment shown in Figure 2 related to the STEC**

Stream/ Equipment Number	Description
35	Steam from a host power plant – although labelled as steam here, this can also be a different thermal energy transfer medium (e.g. hot oil)
36	Steam from an auxiliary steam generation system – although labelled as steam here, this can also be a different thermal energy transfer medium (e.g. hot oil)
37	Steam supplied from the host power plant to PCC plant to drive absorbent regeneration and other processes – although labelled as steam here, this can also be a different thermal energy transfer medium (e.g. hot oil)
38	Exhaust steam from the PCC plant to the host power plant – if steam is the heat transfer medium used in the PCC plant, any exhaust steam can be returned to the host power plant
39	Steam condensate from the PCC plant to the host power plant – if steam is used and condensed in the PCC plant, this stream returns the condensate to the host power plant
40	Steam condensate return to the host power plant
41	Steam condensate return to the auxiliary steam generation system
42	CW feed – if the CW system for the host power plant and/or auxiliary unit is used to supply CW to the PCC plant, it is accounted for in this stream
43	CW return – CW returned from the PCC plant to the host power plant and/or to the auxiliary unit
44	Rejected heat from the process cooler integrated into the PCC plant (# 23)
55	Medium transferring waste heat from the PCC plant to the host power plant – (e.g. boiler feed water for pre-heating)
56	Host power plant waste heat used in the PCC plant or return of PCC plant waste heat used in the host power plant – this stream can represent host power plant waste heat that is used in the absorbent regeneration process in the PCC plant or the return of waste heat that was generated in the PCC plant and used in the host power plant (e.g. boiler feed water preheating)
57	Medium transferring waste heat from the host power plant to the PCC plant. A common source of waste heat in a host power plant is the heat contained in the flue gas. This stream integrates the heat supplied to the PCC plant by stream 37
58	Power plant waste heat return from PCC plant– this stream represents the return of waste heat from stream 57 to the host power plant

Items related to the KPIs for SEC and SEEC are noted in Table 3. Electricity generated in the host power plant or auxiliary unit can be used to power equipment (including compression) in the PCC plant.

Electrical energy used for these purposes contributes to the SEEC. In addition, steam used by the PCC plant to drive CO<sub>2</sub> separation processes (noted in Table 2) that could have been used to generate electricity in the absence of CO<sub>2</sub> capture also contributes to the SEC and the SEEC.

**Table 3 — Description of streams and equipment shown in Figure 2 related to the SEC and the SEEC**

Stream/ Equipment Number	Description
31	Power distribution system – controls the amount of power diverted to the PCC plant to operate fans, pumps, blowers, and the compression system
45	Electricity from an auxiliary power generation system
46	Electricity from the host power plant to the PCC plant
50	Electricity diverted to power equipment and systems associated with the PCC plant, including fans, pumps, and the compression system
51	Net power export
52	Electricity diverted from the host power plant or the auxiliary power generation system to power other equipment within the same plant or system

Items related to the KPI for specific absorbent and chemical or auxiliary materials consumption or decrease in functional activity are noted in Table 4.

**Table 4 — Description of streams and equipment shown in Figure 2 related to the SAC and the SCC**

Stream/ Equipment Number	Description
15	Waste water sent for treatment
16	Waste sent to a waste handling system
17	By-product
18	Fresh absorbent
48	Chemicals or auxiliary materials
49	Demineralized water, industrial water

Finally, items that are included in Figure 2 but do not have direct impacts on calculation of KPIs are listed in Table 5. The inclusion of these items in Figure 2 provides framing for a better understanding of processes and equipment that do impact KPIs.

**Table 5 — Description of streams and equipment shown in Figure 2**

Stream/ Equipment Number	Description
<b>PCC plant</b>	
2	Pre-treatment (quencher, deep-FGD, flue gas fan) – conditioning of the flue gas in preparation for separation of CO <sub>2</sub> . This can include removal of contaminants that could damage the absorbent or temperature control to optimize absorber efficiency, etc.
3	CO <sub>2</sub> capture section
4	CO <sub>2</sub> stream compression/liquefaction section (including CO <sub>2</sub> stream purification)
b	Boundary.
c	Only in the case of coal fired boiler.
g	Only in the case of GTCC.

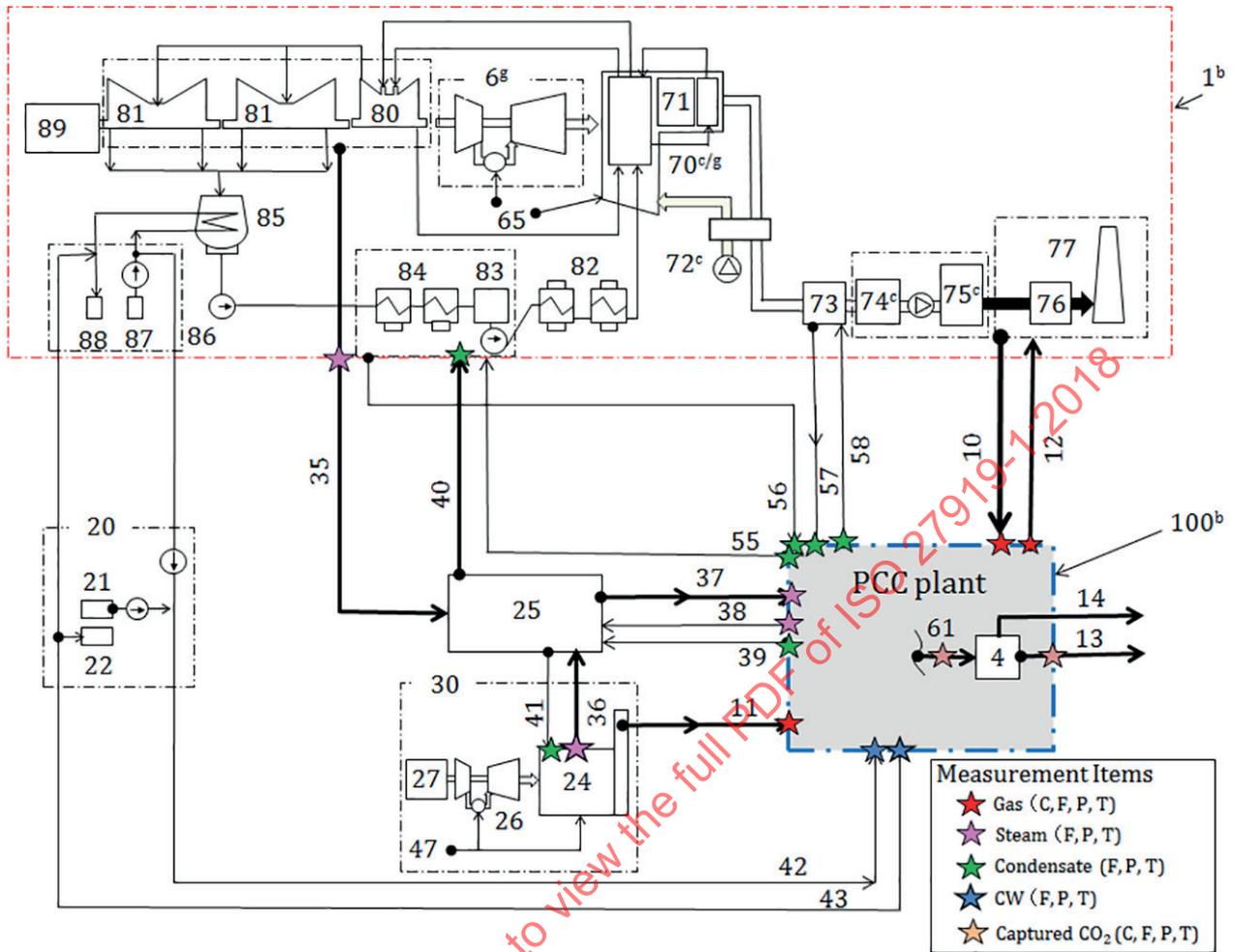
Table 5 (continued)

Stream/ Equipment Number	Description
14	CO <sub>2</sub> vent stream to the atmosphere required for start-up, shut-down, emergency and during significant operational disturbances
23	Air fin cooler integrated into PCC plant
60	Flue gas after pre-treatment – this stream is the flue gas stream after contaminants have been removed and temperature adjustments have been made in preparation for entering the absorber (from item 2 to 3)
61	The product CO <sub>2</sub> stream leaving the CO <sub>2</sub> -capture section prior to entry into the compression system (from item 3 to 4)
100 <sup>b</sup>	PCC plant boundary
<b>Host power plant</b>	
1 <sup>b</sup>	Host power plant boundary – this block flow configuration is typical for a coal fired boiler and a GTCC plant
6 <sup>g</sup>	Gas turbine in a GTCC - the item designated as a boiler (70) would be a HRSG and the air preheater and forced draft fan (72), particulate removal system (74), and FGD (75) would be removed
65	Fuel to host power plant
70 <sup>c/g</sup>	Boiler – or HRSG in GTCC case
71	NO <sub>x</sub> removal system
72 <sup>c</sup>	Air preheater and forced draft fan (not applicable in GTCC case)
73	Flue gas heat recovery system
74 <sup>c</sup>	Particulate removal system (not applicable in GTCC case)
75 <sup>c</sup>	FGD (not applicable in GTCC case)
76	Flue gas heater, if necessary
77	Stack and treated flue gas duct
80	High pressure (HP) – intermediate pressure (IP) turbine
81	Low pressure (LP) turbine
82	HP heaters
83	Deaerators
84	LP heaters
85	Steam condenser
86	Power plant CW supply system
87	Power plant CW intake
88	Power plant CW outfall
89	Power plant generator
<b>Auxiliary unit (where installed)</b>	
20	CW generation system – the cooling system can include cooling towers, a once-through CW system, or air fin coolers
21	CW intake - A CW intake can be common to the host power plant or the PCC plant
22	CW outfall - A CW outfall can be common to the host power plant or the PCC plant
24	Auxiliary steam generation system – e.g. HRSG on auxiliary gas turbine or auxiliary boiler
25	Steam distribution system
26	Auxiliary gas turbine
<sup>b</sup>	Boundary.
<sup>c</sup>	Only in the case of coal fired boiler.
<sup>g</sup>	Only in the case of GTCC.

Table 5 (continued)

Stream/ Equipment Number	Description
27	Auxiliary generator
28	Waste water treatment system
29	Waste handling system
30	Auxiliary steam and power generation system
47	Fuel to the auxiliary steam and power generation system
59	Use of PCC plant effluent in FGD – waste water from the PCC plant can potentially be used as make-up water in the FGD system
200 <sup>b</sup>	Auxiliary unit boundary
<b>Out of boundary</b>	
5	CO <sub>2</sub> transportation
101	Atmosphere
102	Landfill and/or hydrosphere
<sup>b</sup>	Boundary.
<sup>c</sup>	Only in the case of coal fired boiler.
<sup>g</sup>	Only in the case of GTCC.

Evaluation of the KPIs related to energy use and CO<sub>2</sub> emissions is dependent on measurements at several points within the system. These points and their associated streams are illustrated in [Figure 3](#). The stream/equipment numbers used are the same as those used in [Figure 2](#). As indicated, these measurements include concentrations, flow rates, pressures and temperatures for flue gases entering and leaving the PCC and for the product CO<sub>2</sub> stream (#13) sent for transport. In addition, flow, pressure and temperature measurements for steam, condensate, and CW streams entering and leaving the PCC are used in evaluation of the KPIs.



**Key**

- |    |  |    |   |
|----|--|----|---|
| 1  | host power plant boundary - this block flow configuration is typical for a coal fired boiler and a GTCC plant  | 55 | medium transferring waste heat from the PCC plant to the host power plant - (e.g. boiler feed water for pre-heating)  |
| 4  | CO <sub>2</sub> stream compression/liquefaction section (including CO <sub>2</sub> stream purification)  | 56 | host power plant waste heat used in the PCC plant or return of PCC plant waste heat used in the host power plant - this stream can represent host power plant waste heat that is used in the absorbent regeneration process in the PCC plant or the return of waste heat that was generated in the PCC plant and used in the host power plant (e.g. boiler feed water preheating) |
| 6  | gas turbine in a GTCC - the item designated as a boiler (70) would be a HRSG and the air preheater and forced draft fan (72), particulate removal system (74), and FGD (75) would be removed | 57 | medium transferring waste heat from the host power plant to the PCC plant. A common source of waste heat in a host power plant is the heat contained in the flue gas. This stream integrates the heat supplied to the PCC plant by stream 37  |
| 10 | flue gas from host power plant   | 58 | power plant waste heat return from PCC plant - this stream represents the return of waste heat from stream 57 to the host power plant   |
| 11 | flue gas from auxiliary unit (auxiliary steam and power generation system, #30)  | 61 | product CO <sub>2</sub> stream leaving the CO <sub>2</sub> -capture section prior to entry into the compression system (from item 3 to 4)   |
| 12 | treated flue gas (mostly nitrogen, but might contain residual CO <sub>2</sub> ) to be vented or sent to a stack  | 70 | boiler - or HRSG in GTCC case   |
| 13 | product CO <sub>2</sub> stream, sent for transport   |    |   |

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20	CW generation system – the cooling system can include cooling towers, a once-through CW system, or air fin coolers	71	NO <sub>x</sub> removal system
21	CW intake - A CW intake can be common to the host power plant or the PCC plant	72	air preheater and forced draft fan (not applicable in GTCC case)
22	CW outfall - A CW outfall can be common to the host power plant or the PCC plant	73	flue gas heat recovery system
23	air fin cooler integrated into PCC plant	74	particulate removal system (not applicable in GTCC case)
24	auxiliary steam generation system - e.g. HRSG on auxiliary gas turbine or auxiliary boiler	75	FGD (not applicable in GTCC case)
25	steam distribution system	76	flue gas heater, if necessary
26	auxiliary gas turbine	77	stack and treated flue gas duct
27	auxiliary generator	80	high pressure (HP) – intermediate pressure (IP) turbine
30	auxiliary steam and power generation system	81	low pressure (LP) turbine
35	steam from a host power plant – although labelled as steam here, this can also be a different thermal energy transfer medium (e.g. hot oil)	82	HP heaters
36	steam from an auxiliary steam generation system – although labelled as steam here, this can also be a different thermal energy transfer medium (e.g. hot oil)	83	deaerators
37	steam supplied from the host power plant to PCC plant to drive absorbent regeneration and other processes -- although labelled as steam here, this can also be a different thermal energy transfer medium (e.g. hot oil)	84	LP heaters
38	exhaust steam from the PCC to the host power plant – if steam is the heat transfer medium used in the PCC, any exhaust steam can be returned to the host power plant	85	steam condenser
39	steam condensate from the PCC to the host power plant – if steam is used and condensed in the PCC, this stream returns the condensate to the host power plant	86	power plant CW supply system
40	steam condensate return to the host power plant	87	power plant CW intake
41	steam condensate return to the auxiliary steam generation system	88	power plant CW outfall
42	CW feed – if the CW system for the host power plant and/or auxiliary unit is used to supply CW to the PCC plant, it is accounted for in this stream	89	power plant generator
43	CW return – CW returned from the PCC to the host power plant and/or to the auxiliary unit	100	Line representing the PCC plant boundary
47	fuel to the auxiliary steam and power generation system		

NOTE All different streams and equipment for this figure are summarized in ascending order in [Annex A](#).

b Boundary.

c Only in the case of coal fired boiler.

g Only in the case of GTCC.

Measurement items:

C concentration

F flow

P pressure

T temperature

**Figure 3 — Measurement streams/locations used to evaluate KPIs**

The utility consumption evaluation boundaries within the PCC plant boundary for the thermal energy, CW and the electrical consumption are indicated in [Figure 4](#) to [Figure 6](#) respectively, consistent with [Figure 2](#). All flows included in the definitions in [Clause 5](#) cross the PCC plant boundary (line 100 in [Table 5](#)). [Clause 6](#) includes some flows that do not cross the PCC plant boundary. Some of these flows are important when evaluating performance of the host power plant and the PCC plant.

## 5 Definition of basic PCC plant performance

### 5.1 General

This clause defines the parameters that describe the basic performance of the PCC plant and integrated system.

### 5.2 Input and output streams

To calculate the CO<sub>2</sub> capture efficiency, the flow rate, temperature, pressure and composition of the following input streams shall be accounted for:

- a) flue gas from host power plant [stream #10];
- b) flue gas from auxiliary steam and power generation system [stream #11].

Similarly, the following output streams shall be accounted for:

- a) treated gas from PCC plant [stream #12];
- b) untreated exit gas from power plant, auxiliary boiler and/or auxiliary gas turbine not routed through the PCC;
- c) product CO<sub>2</sub> [stream #13];
- d) vent gases and other losses [stream #14].

### 5.3 Capture efficiency of the absorber

The calculation method described in this clause is only valid for flows across the boundary of a PCC plant as described in [Figure 2](#). CO<sub>2</sub> capture efficiency ( $\eta_{\text{CO}_2}$ ) is defined as follows:

$$\eta_{\text{CO}_2} = \frac{q_{Vr\text{CO}_2\text{in}} - q_{Vr\text{CO}_2\text{out}}}{q_{Vr\text{CO}_2\text{in}}} \times 100 \quad (1)$$

where

$q_{Vr\text{CO}_2\text{in}}$  is the volume flow rates of CO<sub>2</sub> at the PCC plant inlet on a dry basis at the standard temperature (273,15 K) and pressure (100 kPa) conditions [m<sup>3</sup>/h];

$q_{Vr\text{CO}_2\text{out}}$  is the volume flow rates of CO<sub>2</sub> at the PCC plant outlet (treated flue gas emission side) on a dry basis at the standard temperature (273,15 K) and pressure (100 kPa) conditions [m<sup>3</sup>/h].

$$q_{VrCO_2in} = q_{Vrflue\ gas\ in} \times \frac{\varphi_{CO_2in\_cap}}{100} \quad (2)$$

The outlet flow rates may vary due to both capture of CO<sub>2</sub> and due to changes in the inlet flow rate. If the inlet rate is not measured at the same time, that variation might not be apparent. To avoid errors that might arise from using two different, independent measurements of the inlet flow rate and of the outlet flow rate, this procedure uses inlet flow values, and inlet and outlet CO<sub>2</sub> volumetric concentrations to make the actual calculation as given in [Formula \(3\)](#).

$$q_{VrCO_2out} = q_{Vrflue\ gas\ in} \times \frac{1 - \frac{\varphi_{CO_2in\_cap}}{100}}{1 - \frac{\varphi_{CO_2out\_cap}}{100}} - q_{Vrflue\ gas\ in} \times \left( 1 - \frac{\varphi_{CO_2in\_cap}}{100} \right) \quad (3)$$

where

$q_{Vrflue\ gas\ in}$  is the volume flow rate of a flue gas to the PCC plant on a dry basis at the standard temperature (273,15 K) and pressure (100 kPa) conditions [m<sup>3</sup>/h];

$\varphi_{CO_2in\_cap}$  is the volume concentration of CO<sub>2</sub> in the flue gas to the PCC plant on a dry basis [%];

$\varphi_{CO_2out\_cap}$  is the volume concentration of CO<sub>2</sub> in the flue gas at the PCC plant outlet (treated flue gas emission side) on a dry basis [%] It is assumed that there is no ingress of air;

The CO<sub>2</sub> concentration is normally measured as a volumetric concentration on the dry basis.

#### 5.4 Flow rate of the product CO<sub>2</sub> stream from a PCC plant

The flow rate of the product CO<sub>2</sub> stream from a PCC plant [t/h] is measured by the flow meter installed in the product CO<sub>2</sub> stream line (either before or after CO<sub>2</sub> stream compression), corrected by the operating condition.

$$q_{mCO_2\_comp\_b} = q_{VrCO_2comp\_b} \times \frac{\varphi_{CO_2out\_comp\_b}}{100} \times \frac{44,0}{22,7 \times 1000} \quad (4)$$

where

$q_{VrCO_2\ comp\_b}$  is the volume flow rate of a product CO<sub>2</sub> stream before compression on a dry basis at the standard temperature (273,15 K) and pressure (100 kPa) conditions [m<sup>3</sup>/h];

$q_{mCO_2\_comp\_b}$  is the mass flow rate of a product CO<sub>2</sub> stream before compression [t/h];

$\varphi_{CO_2out\_comp\_b}$  is the volume concentration of CO<sub>2</sub> in the product CO<sub>2</sub> stream before compression on a dry basis [%].

$$q_{mCO_2\_comp\_a} = q_{VrCO_2comp\_a} \times \frac{\varphi_{CO_2out\_comp\_a}}{100} \times \frac{44,0}{22,7 \times 1000} \quad (5)$$

where

- $q_{VrCO_2comp\_a}$  is the volume flow rate of a product CO<sub>2</sub> stream after compression on a dry basis at the standard temperature (273,15 K) and pressure (100 kPa) conditions [m<sup>3</sup>/h];
- $q_{mCO_2\_comp\_a}$  is the mass flow rate of a product CO<sub>2</sub> stream after compression [t/h];
- $\varphi_{CO_2out\_comp\_a}$  is the volume concentration of CO<sub>2</sub> in the product CO<sub>2</sub> stream after compression on a dry basis [%].

## 5.5 Properties of product CO<sub>2</sub> stream at CO<sub>2</sub> compression system outlet

### 5.5.1 General

The point at the inlet valve of the pipeline defines the system boundary between capture and transportation. The composition, temperature, and pressure of the CO<sub>2</sub> stream at this point shall be within a range that meets the requirements for transportation. Further details are provided in ISO 27913.

### 5.5.2 Compositions of product CO<sub>2</sub> stream

#### 5.5.2.1 Measurement of product CO<sub>2</sub> stream

Product CO<sub>2</sub> stream is defined as the captured and compressed/liquefied CO<sub>2</sub> stream at the interface with the CO<sub>2</sub> transportation. CO<sub>2</sub> purity is defined as the CO<sub>2</sub> concentration of the product CO<sub>2</sub> indicated on a wet basis and should be measured by the recommended measurement methods(s) specified in [Clause 8](#).

#### 5.5.2.2 Impurities in product CO<sub>2</sub> stream

Impurities in the product CO<sub>2</sub> stream (in particular, H<sub>2</sub>O and O<sub>2</sub>) should be defined with regards to transport and storage/usage requirements. Further information on the specification of the product CO<sub>2</sub> stream can be found in ISO 27913:2016, Annex A. In addition, CO<sub>2</sub> emissions from these units need to be accounted for when determining the overall CO<sub>2</sub> balance of the PCC plant with inclusion of minor inlet flows, if any. If the required limits on moisture (H<sub>2</sub>O) and oxygen (O<sub>2</sub>) concentrations are too stringent to be met by the PCC plant as depicted in [Figure 2](#), it may be necessary to install a dehydrator (moisture removal system) and/or an oxygen removal system. These additional units may require additional utilities. The energy consumed by these units should be included in calculations for the energy consumption attributable to CO<sub>2</sub> capture and compression.

#### 5.5.2.3 Measurement of impurities

Concentrations of impurities should be made using methods or instruments as suggested in [Clause 8](#) or by a documented equivalent means. Should a dehydrator or oxygen removal unit be installed in the product CO<sub>2</sub> stream line, concentration of impurities in product CO<sub>2</sub> stream should be measured after these units.

#### 5.5.2.4 Determination of composition of the product CO<sub>2</sub> stream

The concentration of CO<sub>2</sub> stream in the product CO<sub>2</sub> stream can be calculated as the difference between the measured concentrations of all impurities and 100 % if it is difficult to measure a CO<sub>2</sub> concentration very close to 100 % (e.g., greater than 99 %).

### 5.5.3 CO<sub>2</sub> stream compressor system outlet pressure

The outlet pressure of the CO<sub>2</sub> stream compressor should be confirmed before being used in evaluation of the electrical energy consumption of the CO<sub>2</sub> stream compressor. The measuring point should be as

close as possible to the interface point of the transportation so that the pressure loss to the battery limit should be negligible.

#### 5.5.4 Others

It is important to have quality control measures in place that apply to all property values that are measured for use in calculations in this clause. CO<sub>2</sub> stream metering may be required as a means of demonstrating compliance with third party requirements applicable to both transportation and sequestration.

## 6 Definition of utilities and consumption calculation

### 6.1 General

This clause specifies how to evaluate the utility consumption of a PCC plant. The characteristics of the utility system are defined, including heat transfer media; various sources of process water; chemicals, including absorbent; and electrical energy. The concentration of specified impurities in the flue gas differs in each project, which can affect the utilities consumption.

In case an additional CO<sub>2</sub> emitting source is required to provide additional heat or electrical energy, such as auxiliary boiler and/or auxiliary gas turbine, the required energy and utilities for these facilities shall not be included. However, they shall be reported so that they can be evaluated as a whole in [Clause 9](#).

Pieces of equipment with intermittent or batch operation, such as the reclaimers, are evaluated on the average value during an appropriate length of time that takes the average quantity of CO<sub>2</sub> removed during the same period.

The incremental utility consumption related to flue gas pre-treatment for PCC plant should be included in the estimation of overall energy consumption. This includes additional DeNO<sub>x</sub>, FGD and PM-abatement as required in the PCC plant.

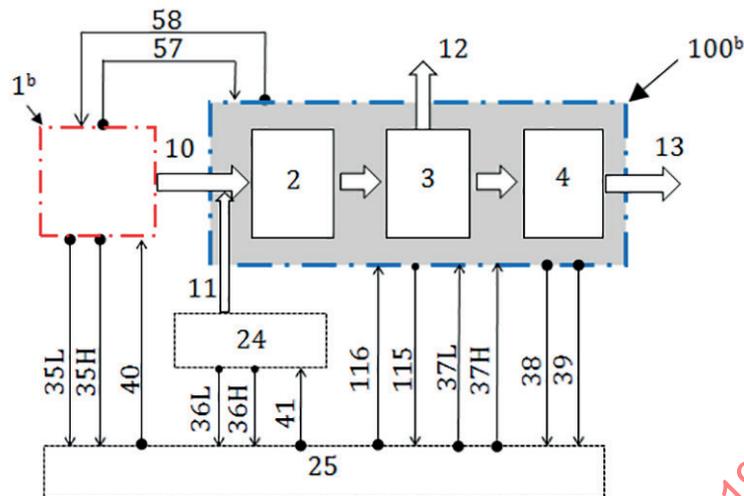
### 6.2 Low-pressure - medium-pressure steam

#### 6.2.1 Definition of utility

The definition of utilities includes the following:

- a) The required steam or thermal energy for the PCC plant is extracted from the steam cycle of the host power plant or from a separate utility plant such as the auxiliary boiler or the HRSG on the auxiliary gas turbine.
- b) The thermal energy in the condensate from the PCC plant, which returns in the condensate system of the host power plant or the separate utility plant is accounted for.
- c) For rotating machinery, such as pumps, blowers, compressors, or steam turbines, MP or HP steam can be used instead of the electrical motors as the driver. Their utility consumption is accounted for. When the steam turbine driver is selected, the outlet steam can be used again for PCC plant and this case is included for evaluation.
- d) For the CO<sub>2</sub> desorption process, it is possible to use other thermal heat sources such as hot water or hot oil, and this is accounted for.

The steam consumption calculation boundary is the crossing points of feed and return lines of the thermal energy including the steam and its condensate with the PCC plant boundary within which the thermal energy is consumed and indicated in [Figure 4](#) with the outside support system to supply and receive and with the reference of each key listed in the table below.



**Key**

- |  |   |
|--|---|
| <p>1 host power plant boundary – this block flow configuration is typical for a coal fired boiler and a GTCC plant</p> <p>2 pretreatment (quencher, deep-FGD, flue gas fan) – conditioning of the flue gas in preparation for separation of CO<sub>2</sub>. This can include removal of contaminants that could damage the absorbent or temperature control to optimize absorber efficiency, etc.</p> <p>3 CO<sub>2</sub> capture section</p> <p>4 CO<sub>2</sub> stream compression/liquefaction section (including CO<sub>2</sub> stream purification)</p> <p>10 flue gas from host power plant</p> <p>11 flue gas from auxiliary unit (auxiliary steam and power generation system, #30)</p> <p>12 treated flue gas (mostly nitrogen, but might contain residual CO<sub>2</sub>) to be vented or sent to a stack</p> <p>13 product CO<sub>2</sub> stream, sent for transport</p> <p>24 auxiliary steam generation system - e.g. HRSG on auxiliary gas turbine or auxiliary boiler</p> <p>25 steam distribution system</p> <p>35L LP steam from a host power plant – although labelled as steam here, this can also be a different thermal energy transfer medium (e.g. hot oil)</p> | <p>36H MP or HP steam from an auxiliary steam generation system – although labelled as steam here, this can also be a different thermal energy transfer medium (e.g. hot oil)</p> <p>37L LP steam supplied from the host power plant to PCC to drive absorbent regeneration and other processes - although labelled as steam here, this can also be a different thermal energy transfer medium (e.g. hot oil)</p> <p>37H MP or HP steam supplied from the host power plant to PCC to drive absorbent regeneration and other processes - although labelled as steam here, this can also be a different thermal energy transfer medium (e.g. hot oil)</p> <p>38 exhaust steam from the PCC to the host power plant – if steam is the heat transfer medium used in the PCC, any exhaust steam can be returned to the host power plant</p> <p>39 steam condensate from the PCC to the host power plant – if steam is used and condensed in the PCC, this stream returns the condensate to the host power plant</p> <p>40 steam condensate return to the host power plant</p> <p>41 steam condensate return the auxiliary steam generation system</p> <p>57 medium transferring waste heat from the host power plant to the PCC plant. A common source of waste heat in a host power plant is the heat contained in the flue gas. This stream integrates the heat supplied to the PCC plant by stream 37</p> <p>58 power plant waste heat return from PCC plant – this stream represents the return of waste heat from stream 57 to the host power plant</p> <p>100 PCC plant boundary</p> <p>115 utilization of waste heat of steam distribution system by PCC (Return)</p> |
|--|---|

- |  |  |
|--|--|
| 35H MP or HP steam from a host power plant – although labelled as steam here, this can also be a different thermal energy transfer medium (e.g. hot oil)             | 116 utilization of waste heat of steam distribution system by PCC (Feed) |
| 36L LP steam from an auxiliary steam generation system – although labelled as steam here, this can also be a different thermal energy transfer medium (e.g. hot oil) |  |
| b Boundary.  |  |

**Figure 4 — PCC plant LP (-MP) Steam consumption calculation boundary**

### 6.2.2 Consumption calculation

The consumption calculation of utilities requires the following:

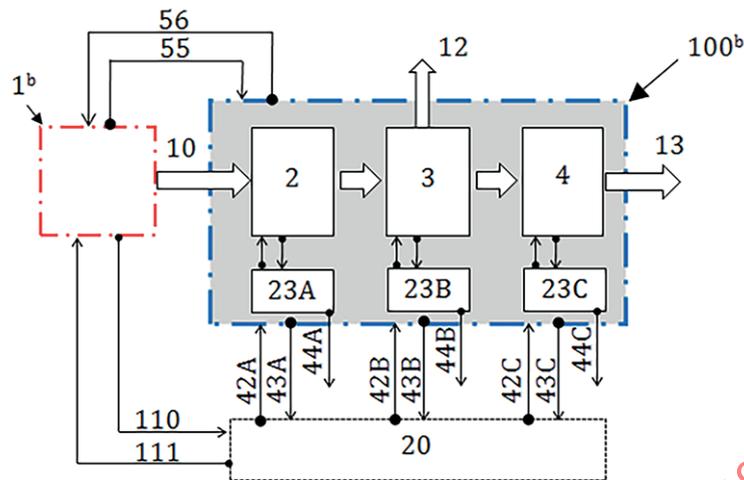
- a) For each tie-in point, flow rate, pressure and temperature should be measured and reported and the enthalpy of each flow should be calculated.
- b) The tie-in points should be close to the PCC plant so that the pressure loss and the heat loss during the transportation from its source, which may cause decrease of heat transfer due to the temperature drop caused or increase of the thermal energy consumption respectively, be considered negligible.
- c) In case of intermittent use, the average flow rate during an appropriate length of time should be applied, unless there are technical reasons for using instantaneous values.
- d) If other heating media, such as hot water and hot oil, are utilized in combination or alternately, the same items of these utilities shown in the above should be measured and reported.

### 6.3 Cooling water

#### 6.3.1 Definition of CW

CW is used at several points. The volume and temperature of CW can be affected by the design parameters and the PCC performance.

When once-through seawater or fresh water for cooling is insufficient, a natural or mechanical draft cooling tower can be used. If it is difficult to secure CW, then air-cooling is an alternative. In case chilled water is needed to supplement CW to achieve the desired absorption temperatures, it is included inside the PCC plant consumption evaluation boundary. A rejected heat duty can be converted to an electrical energy consumption equivalent of a one pass water cooling system as evaluated in 6.4.1. The CW consumption calculation boundary is the crossing points of the CW feed and return lines including the rejected heat dissipated to the atmosphere, if any, with the PCC plant boundary within which the rejected heat is generated and indicated in Figure 5 with its feed source and return sink and with the reference of each key listed in the table below.



**Key**

- |              |   |     |   |
|--------------|---|-----|---|
| 1            | host power plant boundary – this block flow configuration is typical for a coal fired boiler and a GTCC plant   | 42C | CW feed to CO <sub>2</sub> stream compression   |
| 2            | pretreatment (quencher, deep-FGD, flue gas fan) – conditioning of the flue gas in preparation for separation of CO <sub>2</sub> . This can include removal of contaminants that could damage the absorbent, temperature control to optimize absorber efficiency, etc. | 43A | CW return from pre-treatment to the CW generation system  |
| 3            | CO <sub>2</sub> capture section   | 43B | CW return from CO <sub>2</sub> capture to the CW generation system  |
| 4            | CO <sub>2</sub> stream compression/liquefaction section (including CO <sub>2</sub> stream purification)   | 43C | CW return from CO <sub>2</sub> stream compression to the CW generation system   |
| 10           | flue gas from host power plant  | 44A | rejected heat from the process cooler integrated into pre-treatment   |
| 12           | treated flue gas (mostly nitrogen, but might contain residual CO <sub>2</sub> ) to be vented or sent to a stack   | 44B | rejected heat from the process cooler integrated into CO <sub>2</sub> capture   |
| 13           | product CO <sub>2</sub> stream, sent for transport  | 44C | rejected heat from the process cooler integrated with CO <sub>2</sub> stream compression  |
| 20           | CW generation system – the cooling system can include cooling towers, a once-through CW system, or air fin coolers  | 55  | medium transferring waste heat from the PCC plant to the host power plant – (e.g. boiler feed water for pre-heating)  |
| 23A          | air fin cooler integrated into pre-treatment  | 56  | host power plant waste heat used in the PCC plant or return of PCC plant waste heat used in the host power plant – this stream can represent host power plant waste heat that is used in the absorbent regeneration process in the PCC or the return of waste heat that was generated in the PCC and used in the host power plant (e.g. boiler feed water preheating) |
| 23B          | air fin cooler integrated into CO <sub>2</sub> capture  | 100 | PCC plant boundary  |
| 23C          | air fin cooler integrated into CO <sub>2</sub> stream compression   | 110 | CW feed from a host power plant CW system   |
| 42A          | CW feed to pre-treatment  | 111 | CW return to a host power plant CW system   |
| 42B          | CW feed to CO <sub>2</sub> capture  |     |   |
| <sup>b</sup> | Boundary.   |     |   |

**Figure 5 — CW consumption calculation boundary**

### 6.3.2 Consumption calculation

The heat rejected to CW is calculated separately for the three unit blocks shown in [Figure 5](#) to account for the deviation from design performance and design conditions.

If a chiller is used, it shall be included in the CW consumption calculation. If other cooling media, such as boiler feed water or condensate, are used, then heat rejection into these media should not be accounted for. Based on the rejected heat duty the equivalent electrical energy consumption for CW is calculated for the evaluation specified in [Clause 9](#).

## 6.4 Electrical energy

### 6.4.1 Definition of electrical energy consumption evaluation

The electrical energy consumption should be separately measured and reported and consist of the following contributions:

- a) Quencher or flue gas pre-treatment;
- b) CO<sub>2</sub> capture;
- c) CO<sub>2</sub> stream compression;
- d) Utility facilities.

Electrical energy consumption should be evaluated on the same boundary and operating conditions as the overall material and energy balances are calculated.

The determination of the electrical energy consumption for generation of CW is outside the evaluation boundary. The electrical energy consumption for CW pumps can be determined by the calculation of the electrical power required for CW:

$$P_{CW} = \frac{\Phi_{CW}}{3600 \times 1000} \times (p_{CW_{in}} - p_{CW_{out}}) \times \frac{100}{\eta_P} \times \frac{100}{\eta_M} \quad (6)$$

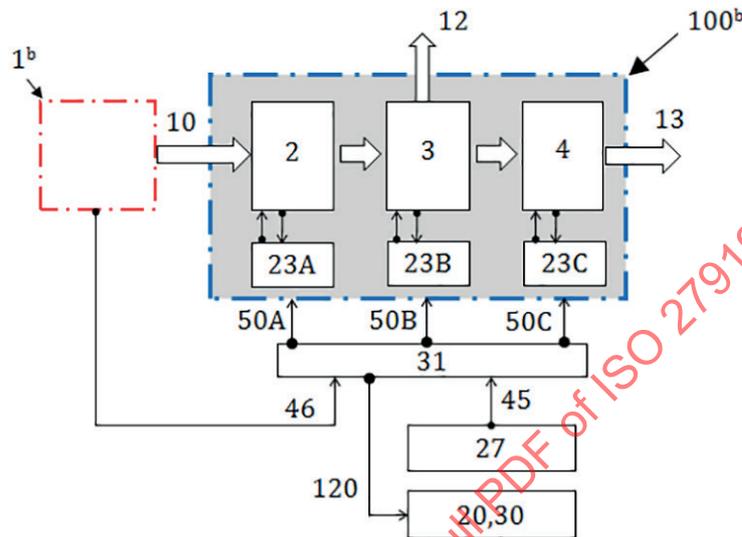
where

- $P_{CW}$  is the electrical power requirement of the CW pump [MW];
- $\Phi_{CW}$  is the total cooling heat duty at the PCC plant [kJ/h];
- $T_{CW_{in}}$  is the temperature of CW at the supply side [K];
- $T_{CW_{out}}$  is the temperature of CW at the return side [K];
- $p_{CW_{in}}$  is the pressure of CW at the supply side [kPa];
- $p_{CW_{out}}$  is the pressure of CW at the return side [kPa];
- $c_{p\ CW}$  is the specific heat of CW [kJ/(kg K)];
- $\rho_{CW}$  is the density of CW [kg/m<sup>3</sup>];
- $\eta_M$  is the efficiency of motor [%] (default value 95 %);
- $\eta_P$  is the efficiency of CW pump [%] (default value 80 %).

If steam is extracted from the host power plant, the CW requirement of the base power plant can be significantly reduced to enable available CW to be used by the PCC plant. The available CW duty is deducted from  $\Phi_{CW}$  in [Formula \(6\)](#). In case an additional CW pump is needed for the supply of CW from

the power plant to the PCC plant, its electrical energy consumption should be included in the overall calculation.

The electrical energy consumption of the steam supply system is outside of the evaluation boundary. The electrical energy consumption calculation boundary is the crossing points of feed lines with the PCC plant boundary within which the electrical energy is consumed and indicated in Figure 6 with its feed source and with the reference of each key listed in the table below.



**Key**

1	host power plant boundary – this block flow configuration is typical for a coal fired boiler and a GTCC plant	27	auxiliary generator
2	pretreatment (quencher, deep-FGD, flue gas fan) – conditioning of the flue gas in preparation for separation of CO <sub>2</sub> . This can include removal of contaminants that could damage the absorbent or temperature control to optimize absorber efficiency, etc.	30	auxiliary steam and power generation system
3	CO <sub>2</sub> capture section	31	power distribution system – controls the amount of power diverted to the PCC plant to operate fans, pumps, blowers, and the compression system
4	CO <sub>2</sub> stream compression/liquefaction section (including CO <sub>2</sub> stream purification)	45	electricity from an auxiliary power generation system
10	flue gas from host power plant	46	electricity from the host power plant
12	treated flue gas (mostly nitrogen, but might contain residual CO <sub>2</sub> ) to be vented or sent to a stack	50A	electricity diverted to power equipment and systems associated with the pre-treatment, including fans, pumps, and the compression system
13	product CO <sub>2</sub> stream, sent for transport	50B	electricity diverted to power equipment and systems associated with the CO <sub>2</sub> capture, including fans, pumps, and the compression system
20	CW generation system – the cooling system can include cooling towers, a once-through CW system, or air fin coolers	50C	electricity diverted to power equipment and systems associated with the CO <sub>2</sub> stream compression, including fans, pumps, and the compression system
23A	air fin cooler integrated into pre-treatment	100	PCC plant boundary
23B	air fin cooler integrated into CO <sub>2</sub> capture	120	power supply to the utility facilities
23C	air fin cooler integrated into CO <sub>2</sub> stream compression		

**Figure 6 — Electrical energy consumption evaluation boundary**

**6.5 Demineralized water and industrial water**

In the PCC plant demineralized water is required for liquid absorbent make up. Industrial water is used in the quencher and CW system. These are not used for the performance evaluation in Clause 8, however the use of demineralized or industrial water should be reported to define the evaluation basis, since it can affect the CW consumption or performance.

**6.6 Absorbent and chemical**

The use of absorbents and chemicals is important for operation of the power plant and also for environmental impact assessments. Absorbent and chemical consumptions should be summarized in the form presented in Table 6. CW temperature can influence the consumption of absorbents. Absorbents for gas components and chemicals required for operation within the PCC boundary depending on the applied technology, such as additives, defoamer and anti-corrosion agent, filters, and demineralized water should be added to the table. This list is not exhaustive.

**Table 6 — Absorbent and chemical consumption summary**

	Absorbent and chemicals		
	Absorbent	Chemical name 1	Chemical name 2
Unit	kg/h as 100 % purity	kg/h as 100 % purity	kg/h as 100 % purity
Quencher (Pre-scrubber)			
Additional pretreatment			
CO <sub>2</sub> recovery			
CO <sub>2</sub> compression			
Utility system	Not included	Not included	Not included
Consumption figures should be reported on an appropriate time-averaged basis.			
NOTE Additional pretreatment requirements should be filled out with basic data such as FGD capacity, flue gas conditions to FGD including SO <sub>x</sub> , oxygen and moisture entering PCC.			

**7 Guiding principles — Basis for PCC plant performance assessment**

**7.1 General**

This clause provides guidance on the conduct of the PCC plant testing, and outlines the steps required to plan and conduct a test of the PCC plant performance. Adherence to this document is recommended to ensure the likelihood of high quality results.

Different relationships exist with the host power plant in respect to the thermal energy supply and related efficiencies. The impact of steam extraction on power plant efficiency can be determined using standards such as those in the IEC 60953 series. This document deals with items specific to integration of PCC plant using the IEC 60953 series to determine the impact on the host power plant.

The performance test should be carried out with the representative configuration of normal operation. Throughout any performance test, emissions other than CO<sub>2</sub> and any discharges to the environment, shall as a minimum, meet requirements of the permitting authorities. Determinations of emissions other than CO<sub>2</sub> are outside of the scope of this document, and as such, no emission limitations or required measurements are specified.

The test plan should specify any other than CO<sub>2</sub> emission levels that affect the result of the assessment.

## 7.2 Guiding principle of the performance test

### 7.2.1 General

The test(s) should be run at a specified CO<sub>2</sub> recovery capacity load that is near the plant condition of interest. Regardless of any test goal, the results of a test should be corrected to the plant reference conditions. If test conditions differ from the plant reference conditions, correction curves should be applied in the evaluations. The test(s) should be designed with the appropriate goal in mind to ensure proper procedures achieve the required operating mode during the test.

The following are actions that should be considered and/or conducted:

- a) Agreement among the relevant parties on scope, measurement accuracy, timing and typical items relating to the performance test should be achieved in advance. This should include the specific objectives, the test programmes and the measuring methods including calibration and the method of plant operation.
- b) A test procedure should be prepared and agreed upon by the relevant parties before beginning the test campaign to allow sufficient time for the test to be set up. The correction methods or curves to the plant reference condition should be previously agreed to in the test procedure.
- c) The schedule of test activity and the detail of test procedure should be further agreed upon by the relevant parties as early as practically possible.
- d) Any deviation from the test procedure and guidelines given in this document should be identified and recorded and the involved parties should agree on a resolution for each recorded deviation to avoid aborting the test run.
- e) The responsibilities of test personnel and the organization conducting the performance test should be agreed upon by the relevant parties, and representatives of all the parties involved in the test should be present to verify that tests are conducted according to the test procedure and the guidelines given in this document. A leader should be designated and made responsible for the conduct of the test.
- f) Pre-test uncertainty analysis should be confirmed. This includes calculating and integrating all deviations of the parameters derived from measured values in accordance with JCGM 100. Target uncertainty agreement can be ensured by selecting the instruments with the appropriate accuracy grade and confirming the accuracy grade of each instrument system.
- g) Measurement locations, which should be prepared at the design stage, should be selected to provide the lowest level of measurement uncertainty. The preferred location is at the test boundary, but it is possible to move the location if it is the best place for determining the required parameters.

### 7.2.2 Power plant and capture unit conditions

Prior to commencement of the tests, the power plant and PCC plant equipment including the auxiliary units should be in good working order. Each should be free of leakage, failures and any other malfunctions that could influence the performance of the PCC plant. Equipment that is not operating properly should be identified and the possible influence of any such malfunctions should be evaluated.

The cleanliness, condition, and age of the equipment should be determined. Cleaning should be completed prior to the test and equipment cleanliness agreed upon.

Any condition that can influence the test results should be kept steady before the test begins, and shall be so maintained throughout the test within the limit of permissible variations to ensure that the facilities can be considered to be in steady state operation.

All chemicals related to PCC plant operation should be analysed to determine and confirm the concentration requirement as per design values. If any concentration is out of the allowable range,

the relevant chemical should be replaced or adjusted by a new and clean chemical additive and/or chemicals.

All effort should be made to conduct the test as close as possible to the plant reference conditions. The plant reference condition is defined by the plant operator as a stable operating condition of the power plant with the rated load operation or the ordinary load operation. Operating parameters should be within the ranges given in the [Table B.2](#), within the 'Allowable maximum deviation from plant reference conditions' column.

The test should be conducted under such conditions that all required measurements referred to in [Clause 5](#) are fulfilled.

The results of the test run can be used to determine the KPIs defined in [Clause 9](#) and the check list of the performance evaluation is explained as a sample procedure to obtain some of the KPIs in [Annex F](#).

Further information is given in [Annex B](#) and in the IEC 60953 series.

## 8 Instruments and measurement methods

### 8.1 General requirement

#### 8.1.1 Introduction

This clause presents the requirements for the instrumentation to be installed or used and the recommended measurement methods.

The instrumentation recommended might become more rigorous and accurate as technology advances. Under the mutual agreement of all parties involved in the tests, more advanced instruments may supersede the recommended instruments recommended, providing that the application of such instruments has demonstrated accuracy and reliability.

Instrument and measurement methods should be followed according to the standards or methods recognized internationally, which are recommended in [Annex C](#), so that these results can be traced. Since these standards are for the different power plant performance tests, they can also be applied for PCC plant integrated with a power plant.

The measurement point list and location are summarized in [Figure 3](#) in [Clause 4](#).

The following clauses indicate the general requirements for the instrumentation and measurement methods for a PCC plant performance test. Detailed description and further information is presented in [Annex C](#).

#### 8.1.2 Instrument classification

Instruments are classified in accordance with both the use of the measured variables and depending on how the measured variables affect the final result.

a) Primary variables: variables that are used in calculations of test results

They are further classified into:

- 1) Class 1 primary variables: those which have a relative sensitivity coefficient of 0,2 (%/%) or greater, which require higher-accuracy instruments with more redundancy than Class 2.

NOTE The relative sensitivity coefficient is defined as a relative change in the result divided by the relative change in a parameter (or variable) evaluated near a desired testing point and expressed as a percentage.

- 2) Class 2 primary variables: those which have a relative sensitivity coefficient of less than 0,2 (%/%).
- b) Secondary variables: Variables that are measured but do not enter into the calculation of the test results. These variables are measured throughout a test period to ensure that the required test condition was not violated.

### 8.1.3 Measurement uncertainty

The measurement of each quantity used for the calculation of the test result is liable to some degree of error and the test result is subject to a degree of uncertainty depending on the combined effect of measurement uncertainties as indicated by the formula defined in ISO/IEC Guide 98-3:2008, 5.1.3.

The measuring uncertainty and calculation procedure of the overall test result uncertainty should be clearly reported, including all inputs and assumptions, formulation and calculation procedure. The measuring uncertainty, as well as the overall test results uncertainties, can be calculated from the uncertainties of the individual measurement as per ISO/IEC Guide 98-3 and the referred standards for instrumentation and measurements of this document.

For pre-test uncertainty analysis, the level of uncertainty for each individual measurement shall be chosen in reasonable relationship with the influence of the reading based on the overall uncertainty requirement and instrument classification. Typical accuracy levels are given in [Table C.1](#) for systematic uncertainty that should be expected for individual measured variables.

### 8.1.4 Calibration of instrument

Primary instrumentation calibration shall be done before the test and it should not be done more than one year before the test. Calibration guidelines are contained in [Annex C](#). Any calibration after the test shall be decided under mutual agreement between parties involved during the test. Degree of calibration shall be chosen in reasonable relationship with the influence of the reading based on the instrument classification, as explained in [Annex C](#).

### 8.1.5 Permanent plant instrument

It is only acceptable to use permanent plant instrumentation for primary variables if they can be demonstrated to meet the overall uncertainty requirements. In the case of flow measurement, all instrument measurements (process pressure, temperature, differential pressure, or pulses from metering device) should be made available because plant flows are often not rigorous enough for the required accuracy.

This document recommends the use of permanent plant instrumentation for tank level variations or any type of cross-check against temporary instrumentation. In case permanent plant instrumentation is used for primary variable measurements, the equipment should be verified before starting the test.

Verification of the permanent plant instrumentation involves a set of checks that establish the evidence (by calibration or inspection) that specified requirements have been met. It provides a means for drift check between values indicated by a measuring instrument and corresponding known values that are consistently smaller than tolerance or allowable limits defined in a standard, test procedure or specification.

### 8.1.6 Redundant instrument

Redundant instruments are two or more devices measuring the same parameter at the same location. Redundant instruments should be used to measure all primary (Class 1 or Class 2) variables.

Other independent instruments in separate locations can also monitor instrument integrity. An example would be a constant enthalpy process in which pressure and temperature in a steam line at one point can be used to verify the pressure and temperature of another location in the line by comparing enthalpies. Flow measurement in the condensate phase obtains a higher accuracy in general than in steam.

## 8.2 Measurement method

### 8.2.1 Flue gas

CO<sub>2</sub> capture efficiency defined in [Formula \(1\)](#) of [5.3](#) is verified in relation to the flue gas conditions in, or close to, the reference conditions.

#### a) Flue gas flow rate

ISO 10780, which requires a multipoint traverse of the stack or duct during sampling to account for components or items distributed along the diameter side, may be used to determine the flue gas flow rate. This can be done at the PCC flue gas inlet sampling locations, using specified measuring methods detailed on referred ISO 10780.

#### b) Moisture measurement

The recognized methods applicable to determine the moisture content of flue gas at the PCC flue gas inlet and emission side outlet are:

- absorption weighing method, which passes the sample gas through an absorption tube and measures its mass increase;
- chilled mirror technology, which uses a mirror that is chilled to dew point for moisture to start condensing on it (ISO 6327);
- capacitive or dielectric instruments methods, which have a material that changes its dielectric properties and increases its capacitance by absorption of moisture.

There are many technologies for moisture measurement purposes that can be applicable, provided that such applications have a demonstrated accuracy equivalent to those required in this document. The application is the same for the moisture content of product CO<sub>2</sub> stream.

#### c) Oxygen and carbon monoxide measurements

Measurement methods based on online analysis by non-dispersive infrared sensors or equivalent, or those based on sampling and manual analysis (titration), such as an Orsat analyser, can be used. Note that NH<sub>3</sub> may be present, and its interference should be checked through evaluation of uncertainties level depending on the PCC process. Applicable recognized equivalent standards are given in [C.8.2](#), and may be used to determine oxygen and CO<sub>2</sub> levels at the PCC flue gas inlet and emission side outlet

### 8.2.2 Product CO<sub>2</sub> stream at the CO<sub>2</sub> compressor outlet

#### a) Purity of product CO<sub>2</sub> stream

CO<sub>2</sub> purity is measured based on the guideline set by the ISO 6974 series, using gas chromatography optimized for high-purity CO<sub>2</sub> converted from natural gas application, employing the general rule for gas chromatography according to the recognized standard.

If the impurity compositions are known, O<sub>2</sub>, moisture and N<sub>2</sub> levels can be measured and their sum deducted from 100 %, also using ISO 6974 optimized for this purpose. The leakage of air, which is the cause of increased uncertainties, should be completely avoided in this sampling.

It is also possible to measure the CO<sub>2</sub> with titration analyser (equivalent to an Orsat analyser); but, this method may require a high level of skill of test personnel.

#### b) Flow rate of the product CO<sub>2</sub> stream

Generally various types of flow metering technologies have been used to meter CO<sub>2</sub> streams across various applications, including CCS systems. Consideration should be given to the pressure drop incurred by installing flow meters in the pipeline to check if this could inadvertently change the

phase and fluid properties of the CO<sub>2</sub> stream (especially if flow conditions lie close to the CO<sub>2</sub> phase boundaries). This will necessitate an accurate understanding of the flow conditions at the given meter locations. Clear knowledge of the fluids density and viscosity is also required.

DP type meters provide the most common flow-measurement device, in particular in CO<sub>2</sub> enhanced oil recovery applications. Its use should be based on a series of ISO 5167, on the condition that the CO<sub>2</sub> stream shall be almost pure and stay as a single, stable phase to maintain measurement accuracy. In this case, special care is necessary when routing the lead pipe connecting to the tap of the DP type meter, as specified in the ISO 5167 series. One of the main drawbacks of orifice plates is their low turndown ratio, which means they have a limited flow rate range over which they can accurately operate.

Turbine meters have been used for decades within industry as a method for measuring both liquid and supercritical CO<sub>2</sub> flow in pipelines. These meters will work in single phase gas, liquid or supercritical fluid, if of the correct design. In the gas phase, ISO 10780 may be used. Applicable standards are recommended in [C.8](#).

Pipelines should be of considerable diameter to economically transport large volumes of CO<sub>2</sub>. This can affect the choice of flow meter, because some types of flow meter can only operate over limited pipeline diameters.

CO<sub>2</sub> gas may give significant problems in flow measurement at supercritical condition due to the difficulty of density determination. There are a number of options, such as electronic devices, ultrasonic flow meters and mass flow techniques (Coriolis type) that may be utilized, if application of such instrument has demonstrated accuracy equivalent to that required by this document. To ensure the accuracy of flow measurements, flowmeters should have required amount of straight pipeline length upstream and downstream of the meter, depending on the type of flow device.

The location before CO<sub>2</sub> compression contains the volume percentage of water with ppm (v) levels of O<sub>2</sub>, N<sub>2</sub>, and NH<sub>3</sub>, if any in some cases. Flow measurement devices such as vortex type are applicable. However, in this case, loss of CO<sub>2</sub> during the compression including the dehydration (1 % to 2 % level generally, depending the process) can be expected and shall be deducted to obtain the interface CO<sub>2</sub> stream flow rate, if these losses can be clarified. If a DP type meter is applied to a low pressure CO<sub>2</sub> line, it can increase the electrical energy consumption, depending on the applied DP type meter.

### 8.2.3 Steam and steam condensate

General flow measurement is based on ISO 5167 and ASME PTC 19.5. Measurement of the steam and the steam condensate is based on IEC 60953-1. The temperature and pressure measurement is integrated in the above measurement and IEC 60953-1 can also be applied.

Other applicable standards are recommended in [Annex C](#).

### 8.2.4 Cooling water

Possible measurement options are shown in IEC 60953-1:1990, 4.3.9, other applicable standard are recommended in [Annex C](#).

IEC 60953-1 can be applied to temperature and pressure measurement.

### 8.2.5 Electric power measurement

Electrical power measurement should be based on IEC 60044 series, IEC 61869 series or ANSI/IEEE 120.

Additional information on watt-meters, which is one option for measurement, is given in [Annex C](#).

### 8.2.6 Measurement of pressure and temperature

The measurement of pressure and temperature is based on IEC 60953-1. Applicable recognized equivalent standards are recommended in [Annex C](#).

### 8.2.7 Data collection and handling

A data acquisition system is used to collect the test data to the extent possible. Other parameters will be recorded manually, such as equipment settings, and significant observation during the test. The observations shall include the date and the time of day, ambient conditions (temperature, pressure and relative humidity). The position of each measurement shall be clearly marked on the flow sheet. They shall be the actual readings without the application of any instrument corrections.

The automatic data collecting equipment shall be calibrated to secure the required accuracy. If the calibration is impractical, each piece of equipment in the measurement loop should be calibrated individually considering the entire measurement loop.

Signal inputs from the instruments should be stored to permit post test data correction for application of new calibration corrections.

The simultaneous reading of certain test points under the same conditions from the multiple instrument inputs should be considered to attain the required accuracy.

## 9 Evaluation of key performance indicators

### 9.1 Introduction

This clause defines the indicators for process performance evaluation of a PCC plant integrated with a power plant. Utility consumption (steam and electrical energy consumption) has a major impact on the process performance of a PCC plant and shall be evaluated using the indicators described in this clause. The process performance should be evaluated under the design condition and the reference conditions specified in [Annex E](#). The symbols used in this clause are defined in [Clause 3](#).

In the calculation of the indicators, the amount of energy (thermal and electrical) is important but the source of the energy is not essential even though any associated CO<sub>2</sub> emissions are. Therefore, utility generated by renewable energy such as sun, wind, water, biomass and geothermal energy can be treated in the same manner as fossil source. However, it is acceptable to offset the energy requirement of the PCC plant through the utilization of waste energy. For example, one can use the recovery of thermal energy from the power plant flue gases to partially meet the heat requirement of the PCC plant.

In addition to the KPIs in this clause, there are other informative performance indicators introduced in annex D in order to evaluate process performance of post-combustion CO<sub>2</sub> capture integrated with a power plant.

### 9.2 Specific thermal energy consumption (STEC)

STEC is the thermal energy consumed to capture and compress/liquefy a tonne of CO<sub>2</sub>. STEC shall be calculated by:

$$STEC = \frac{q_{m\text{ steam}} \times h_{\text{steam}} - q_{m\text{ condensate}} \times h_{\text{condensate}}}{q_{m\text{ CO}_2}} \times \frac{1}{10^6} \quad (7)$$

where

$STEC$  is the specific thermal energy consumption [GJ/t];

$q_{m\text{ CO}_2}$  is the mass flow rate of a product CO<sub>2</sub> stream [t/h].

$$q_{m\text{ CO}_2} = q_{m\text{ CO}_2\text{-comp}_b} \text{ or } q_{m\text{ CO}_2} = q_{m\text{ CO}_2\text{-comp}_a}$$

$q_{m\text{ steam}}$  is the mass flow rate of steam to a PCC plant [kg/h];

$q_{m \text{ condensate}}$  is the mass flow rate of condensate from a PCC plant [kg/h];

$h_{\text{steam}}$  is the specific enthalpy of steam [kJ/kg];

$h_{\text{condensate}}$  is the specific enthalpy of condensate [kJ/kg].

Thermal energy can also be provided by another heat transfer media other than a single steam source with returning it as condensate in which case [Formula \(7\)](#) needs to be modified.

The flow rate of the captured CO<sub>2</sub> stream ( $q_{m\text{CO}_2}$ ) shall be measured by the flow meters installed in the product CO<sub>2</sub> stream line before or after CO<sub>2</sub> stream compression/liquefaction ( $q_{m\text{CO}_2\text{-comp}_a}$  and  $q_{m\text{CO}_2\text{-comp}_b}$ ) as described in [5.4](#).

If a steam turbine driver is applied for compressors or pumps instead of an electric motor, its steam consumption shall be considered to calculate STEC.

### 9.3 Specific electrical energy consumption (SEC)

SEC is the electrical energy consumed to capture and compress/liquefy a tonne of CO<sub>2</sub>. The electrical energy consumption consists of all consumptions at facilities such as flue gas pre-treatment (including quencher), CO<sub>2</sub> capture, CO<sub>2</sub> stream compression and utility system (e.g. CW supply system). They are described in [6.4](#) and informative procedures for obtaining  $P_{\text{PCC}}$  are introduced in Table F.3 of [Annex F](#). Based on the summation of all sources of electrical energy consumption, SEC shall be calculated by:

$$SEC = \frac{P_{\text{PCC}}}{q_{m\text{CO}_2}} \times 1000 \quad (8)$$

where

$SEC$  is the specific electrical energy consumption [kWh/t];

$q_{m\text{CO}_2}$  is the mass flow rate of a product CO<sub>2</sub> stream [t/h];

$P_{\text{PCC}}$  is the electrical power requirement of the PCC plant [MW]

NOTE The electrical energy consumption in the PCC plant is defined by the boundary in [Figure 2](#) and the required electrical energy consumption for CW supply to PCC plant is considered in [Formula \(6\)](#). This calculation needs to take into account any reductions in CW supply to the host power plant and auxiliary unit as described in [6.4.1](#).

The flow rate of the captured CO<sub>2</sub> stream ( $q_{m\text{CO}_2}$ ) should be measured by the flow meters installed in the product CO<sub>2</sub> line before or after CO<sub>2</sub> stream compression/liquefaction ( $q_{m\text{CO}_2\text{-comp}_a}$  and  $q_{m\text{CO}_2\text{-comp}_b}$ ) as described in [5.4](#).

### 9.4 Specific equivalent electrical energy consumption (SEEC)

SEEC is the overall electrical energy consumption attributed to capture and compression/liquefaction of a tonne of CO<sub>2</sub>. SEEC is calculated as the total change in gross power output due to PCC plant divided by the amount of CO<sub>2</sub> captured:

$$SEEC = \frac{P_{\text{LGP}} + P_{\text{PCC}}}{q_{m\text{CO}_2}} \times 1000 \quad (9)$$

where

$SEEC$  is the specific equivalent electrical energy consumption [kWh/t];

$q_{mCO_2}$  is the mass flow rate of a product  $CO_2$  stream [t/h];

$P_{LGP}$  is the change in gross power output due to the steam extraction from the host power plant steam cycle and/or auxiliary unit [MW];

$P_{PCC}$  is the electrical power requirement of the PCC plant [MW].

NOTE For a new power plant, a reference plant can be developed that uses same generation technology but without installation of  $CO_2$  capture.

### 9.5 Specific reduction in $CO_2$ emissions (SRCE)

SRCE is the calculated net decrease of the  $CO_2$  emissions per unit output of a reference power plant by implementing the PCC process to the host power plant.

SRCE can be calculated by:

$$SRCE = \frac{q_{mCO_2,ref}}{P_{NET,ref}} - \frac{q_{mCO_2e,cap}}{P_{NET,cap}} \quad (10)$$

where

$SRCE$  is the specific reduction in  $CO_2$  emissions [t/MWh];

$q_{mCO_2,ref}$  is the mass flow rate of  $CO_2$  emission from a reference power plant [t/h];

$q_{mCO_2e,cap}$  is the mass flow rate of  $CO_2$  emission from a power plant with a PCC plant [t/h];

$P_{NET,ref}$  is the net power output of a reference power plant [MW];

$P_{NET,cap}$  is the net power output of a power plant with a PCC plant [MW].

When the steam and/or electric energy is supplied from an auxiliary unit, the terms in [Formula \(10\)](#) include the total emission and output power of the host power plant and the auxiliary unit.

### 9.6 Specific absorbent consumption and specific chemical consumption (SAC and SCC)

SAC and SCC are the amount of absorbent and chemicals, respectively, which are consumed to capture and compress/liquefy a tonne of  $CO_2$ . SAC and SCC shall be calculated by:

$$SAC = \frac{q_{m\text{ absorbent}}}{q_{mCO_2}} \quad (11)$$

$$SCC = \frac{q_{m\text{ chemical}}}{q_{mCO_2}} \quad (12)$$

where

$SAC$  is the specific absorbent consumption [kg/t];

$SCC$  is the specific chemical consumption [kg/t];

$q_{mCO_2}$  is the mass flow rate of a product  $CO_2$  stream [t/h];

$q_{m \text{ absorbent}}$  is the consumption rate of absorbent at a PCC plant [kg/h];

$q_{m \text{ chemical}}$  is the consumption rate of a chemical compound at a PCC plant [kg/h].

The absorbent that is regenerated by the reclaiming system shall not be included as absorbent consumption, but the absorbent that is discharged from the PCC plant as waste shall be included. Other chemicals used in PCC plant that cannot be regenerated shall be included as chemical consumption.

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## Annex A (informative)

### Summary of streams and equipment nomenclature

#### A.1 General

The purpose of this annex is to summarize the different streams and equipment that could be encountered when using this document.

#### A.2 Summary of streams and equipment nomenclature used in this document.

This annex refers to [Figure 2](#) and [Figure 3](#) of [Clause 4](#). [Table A.1](#) summarizes the different streams and equipment number (in ascending order) as listed in [Table 1](#) to [Table 5](#) of [Clause 4](#).

**Table A.1 — Description of streams and equipment shown in [Figure 2](#) and [Figure 3](#) of [Clause 4](#)**

Stream/ Equipment number	Description	Stream origin/ Equipment loca- tion	Relevant to which KPI evaluation
1 <sup>b</sup>	Host power plant boundary – this block flow configura- tion is typical for a coal fired boiler and a GTCC plant	Host power plant	—
2	Pre-treatment section (quencher, deep-FGD, flue gas fan) – conditioning of the flue gas in preparation for separa- tion of CO <sub>2</sub> . This can include removal of contaminants that could damage the absorbent or temperature control to optimize absorber efficiency, etc.	PCC plant	—
3	CO <sub>2</sub> capture section	PCC plant	—
4	CO <sub>2</sub> stream compression/liquefaction section (including CO <sub>2</sub> stream purification)	PCC plant	—
5	CO <sub>2</sub> transportation system	(Out of boundary)	—
6 <sup>g</sup>	Gas turbine in a GTCC - the item designated as a boiler (70) would be a HRSG and the air preheater and forced draft fan (72), particulate removal system (74), and FGD (75) would be removed	Host power plant	—
7	Ducting to a stack if required (this stream, if it exists, might contain residual CO <sub>2</sub> )	PCC plant	SRCE
10	Flue gas from host power plant	Host power plant	SRCE
11	Flue gas from auxiliary unit (auxiliary steam and power generation system, #30)	Auxiliary unit	SRCE
12	Treated flue gas (mostly nitrogen, but might contain residual CO <sub>2</sub> ) to be vented or sent to a stack	PCC plant	SRCE
13	Product CO <sub>2</sub> stream, sent for transport	PCC plant	SRCE
14	CO <sub>2</sub> vent stream to the atmosphere required for start-up, shut-down, emergency and during significant operation- al disturbances	PCC plant	–
b	Boundary.		
c	Only in the case of coal fired boiler.		
g	Only in the case of GTCC.		

Table A.1 (continued)

Stream/ Equipment number	Description	Stream origin/ Equipment loca- tion	Relevant to which KPI evaluation
15	Waste water sent for treatment	PCC plant	SCC
16	Waste sent to a waste handling system	PCC plant	SAC and SCC
17	By-product	PCC plant	SAC and SCC
18	Fresh absorbent	PCC plant	SAC and SCC
20	CW generation system – the cooling system can include cooling towers, a once-through CW system, or air fin coolers	Auxiliary unit	—
21	CW intake - A CW intake can be common to the host power plant or the PCC plant	Auxiliary unit	—
22	CW outfall - A CW outfall can be common to the host power plant or the PCC plant	Auxiliary unit	—
23	Air fin cooler integrated into PCC plant	PCC plant	—
24	Auxiliary steam generation system - e.g. HRSG on auxiliary gas turbine or auxiliary boiler	Auxiliary unit	—
25	Steam distribution system	Auxiliary unit	—
26	Auxiliary gas turbine	Auxiliary unit	—
27	Auxiliary generator	Auxiliary unit	—
28	Waste water treatment system	Auxiliary unit	—
29	Waste handling system	Auxiliary unit	—
30	Auxiliary steam and power generation system	Auxiliary unit	—
31	Power distribution system – controls the amount of power diverted to the PCC plant to operate fans, pumps, blowers, and the compression system	Auxiliary unit	SEC and SEEC
35	Steam from a host power plant – although labelled as steam here, this can also be a different thermal energy transfer medium (e.g. hot oil)	Host power plant	STEC
36	Steam from an auxiliary steam generation system – although labelled as steam here, this can also be a different thermal energy transfer medium (e.g. hot oil)	Auxiliary unit	STEC
37	Steam supplied from the host power plant to PCC plant to drive absorbent regeneration and other processes – although labelled as steam here, this can also be a different thermal energy transfer medium (e.g. hot oil)	Auxiliary unit	STEC
38	Exhaust steam from the PCC to the host power plant – if steam is the heat transfer medium used in the PCC, any exhaust steam can be returned to the host power plant	PCC plant	STEC
39	Steam condensate from the PCC to the host power plant – if steam is used and condensed in the PCC, this stream returns the condensate to the host power plant	PCC plant	STEC
40	Steam condensate return to the host power plant	Auxiliary unit	STEC
41	Steam condensate return to the auxiliary steam generation system	Auxiliary unit	STEC
42	CW feed – if the CW system for the host power plant and/or auxiliary unit is used to supply CW to the PCC plant, it is accounted for in this stream	Host power plant Auxiliary unit	STEC
b	Boundary.		
c	Only in the case of coal fired boiler.		
g	Only in the case of GTCC.		

Table A.1 (continued)

Stream/ Equipment number	Description	Stream origin/ Equipment loca- tion	Relevant to which KPI evaluation
43	CW return – CW returned from the PCC to the host power plant and/or to the auxiliary unit	PCC plant	STEC
44	Rejected heat from the process cooler integrated into the PCC plant ( 23)	PCC plant	STEC
45	Electricity from an auxiliary power generation system	Auxiliary unit	SEC and SEEC
46	Electricity from the host power plant to the PCC plant	Host power plant	SEC and SEEC
47	Fuel to the auxiliary steam and power generation system	Auxiliary unit	SEC and SEEC
48	Chemicals	PCC plant	SAC and SCC
49	Demineralized water, industrial water	PCC plant	SAC and SCC
50	Electricity diverted to power equipment and systems associated with the PCC plant, including fans, pumps, and the compression system	Auxiliary unit	SEC and SEEC
51	Net power export	Host power plant Auxiliary unit	SEC and SEEC
52	Electricity diverted from the host power plant or the auxiliary power generation system to power other equipment within the same plant or system	Host power plant Auxiliary unit	SEC and SEEC
55	Medium transferring waste heat from the PCC plant to the host power plant – (e.g. boiler feed water for pre-heating)	PCC plant	STEC
56	Host power plant waste heat used in the PCC plant or return of PCC plant waste heat used in the host power plant – this stream can represent host power plant waste heat that is used in the absorbent regeneration process in the PCC plant or the return of waste heat that was generated in the PCC plant and used in the host power plant (e.g. boiler feed water preheating)	Host power plant	STEC
57	Medium transferring waste heat from the host power plant to the PCC plant. A common source of waste heat in a host power plant is the heat contained in the flue gas. This stream integrates the heat supplied to the PCC plant by stream 37	Host power plant	STEC
58	Power plant waste heat return from PCC plant – this stream represents the return of waste heat from stream 57 to the host power plant	PCC plant	STEC
59	Use of PCC plant effluent in FGD – waste water from the PCC plant can potentially be used as make-up water in the FGD system	Auxiliary unit	—
60	Flue gas after pre-treatment – this stream is the flue gas stream after contaminants have been removed and temperature adjustments have been made in preparation for entering the absorber (from item 2 to 3)	PCC plant	—
61	The product CO <sub>2</sub> stream leaving the CO <sub>2</sub> -capture section prior to entry into the compression system (from item 3 to 4)	PCC plant	—
65	Fuel to host power plant	Host power plant	—
b	Boundary.		
c	Only in the case of coal fired boiler.		
g	Only in the case of GTCC.		

Table A.1 (continued)

Stream/ Equipment number	Description	Stream origin/ Equipment loca- tion	Relevant to which KPI evaluation
70 <sup>c/g</sup>	Boiler – or HRSG in GTCC case	Host power plant	—
71	NO <sub>x</sub> removal system	Host power plant	—
72 <sup>c</sup>	Air preheater and forced draft fan (not applicable in GTCC case)	Host Power Plant	—
73	Flue gas heat recovery system	Host power plant	—
74 <sup>c</sup>	Particulate removal system (not applicable in GTCC case)	Host power plant	—
75 <sup>c</sup>	FGD (not applicable in GTCC case)	Host power plant	—
76	Flue gas heater, if necessary	Host power plant	—
77	Stack and treated flue gas duct	Host power plant	—
80	High pressure (HP) – intermediate pressure (IP) turbine	Host power plant	—
81	Low pressure (LP) turbine	Host power plant	—
82	HP heaters	Host power plant	—
83	Deaerators	Host power plant	—
84	LP heaters	Host power plant	—
85	Steam condenser	Host power plant	—
86	Power plant CW supply system	Host power plant	—
87	Power plant CW intake	Host power plant	—
88	Power plant CW outfall	Host power plant	—
89	Power plant generator	Host power plant	—
100 <sup>b</sup>	This line represents the PCC plant boundary	PCC plant	—
101	Atmosphere	(Out of boundary)	—
102	Landfill and/or hydrosphere	(Out of boundary)	—
200 <sup>b</sup>	Auxiliary unit boundary	Auxiliary unit	—
b	Boundary.		
c	Only in the case of coal fired boiler.		
g	Only in the case of GTCC.		

## Annex B (informative)

### Test principles and guidelines

#### B.1 Emissions and any discharges during the test

a) Atmospheric emission

- As CO<sub>2</sub> is captured in a PCC plant, the concentration of flue gas impurities (SO<sub>x</sub>, NO<sub>x</sub>, PM, HCl, HF, N<sub>2</sub>O, Hg and NH<sub>3</sub>) will increase at the outlet of the PCC plant. For the existing local environmental regulations, it may be an issue, since the flue gas impurities would be over the limits.
- The temperature at which the treated flue gas is discharged may also be an issue. Depending on the technology, a temperature decrease of the treated flue gas may occur. The lack of buoyancy could result in poor dispersion of its components.
- Finally, the level of emissions of absorbent and absorbent degradation products might impact the assessment of the key performance indicators.

b) Effluent

Effluent amount, pH, composition, suspended solids concentration, biological oxygen demand, and chemical oxygen demand, and inclusion of regulated substances should be made clear.

c) Waste

The amount of waste generated and its general characteristics regarding handling (water content, viscosity), treatment method (Ca, N, Na or S content, heating value) and category (whether or not it is a hazardous substance, based on local regulations) should be reported.

#### B.2 Additional testing

The owner(s) of the power plant and the PCC plant may wish to perform additional testing to determine plant performance and/or gather data during other conditions, such as load following or plant trips. The terms of the testing and performance criteria should be determined in advance and included in an approved document. This annex may be used as a template for such testing.

#### B.3 Duration and number of test runs

A test run is a complete set of readings with the power plant and PCC plant running at stable operating conditions. A test may be composed of a single test run or a series of test runs. To ensure repeatability of the results, this document recommends that each test be composed of at least two or more test runs. A test composed of different test runs can provide a means to validate and/or reject outlying measurements. The final results used to calculate the KPIs should be the average of different accepted test run results.

The duration of each test run should be determined by operating considerations and the requirements of the involved parties. This document recommends the minimum duration of each test run according to the typology of combustion system used in the power plant as indicated in Table B.1:

**Table B.1 — Minimum duration of each test run**

Fuel type	Test run duration
	h
Solid fuel boiler (e.g. coal, lignite)	2
Fluidized bed/stoker and cyclone (e.g. petcoke, biomass)	4
Gas turbine/combined cycle (including supplementary firing)	1
Oil/gas fired boiler	2

#### **B.4 Pre-tests**

Before starting the test campaign, several pre-tests may be carried out to tune or set up the control settings to reach test condition requirements. They also help to identify any type of anomaly or equipment malfunction. To allow for any corrective action, this document recommends carrying out pre-tests before the test campaign begins.

#### **B.5 Start and stop of the test**

Once the test conditions are established and the stability criteria reached, the test leader should decide to start the test by recording and communicating the time and date to all involved parties. The test will run for the duration that was mutually agreed upon. During this time, the plant should be operated under automatic, stable conditions. Control settings should not be modified during this period. At the end of each test run, the time should be recorded and the test leader should declare the end of the test to all the parties.

If the stability or test conditions are not compliant with the given requirements during the test run, the test leader may decide to stop and abort the test. The data taken during the part of the test run which is compliant with the requirements can be considered acceptable for the evaluation of the performance; the test run can be retained as valid with the exception of where it deviates during the test.

#### **B.6 Electrical and thermal consumption line up**

Prior to beginning the tests, all the electrical consumers should be aligned according to the plant design configuration. Each electrical consumer should be identified and fed by the power plant source referenced in the test plan. Any redundant consumers should be switched off. In case a redundant consumer cannot be switched off, mutual agreement should be reached between the parties involved during the test to measure and deduct any additional consumption during the performance evaluations.

All thermal consumption or steam extraction flows from the power plant should be aligned before starting the test. The steam extractions and PCC plant equipment fed by the power plant should be aligned according to the plant design configuration. Any thermal source coming from other plant or steam generator outside the boundary should be isolated; if this is not possible, it should be measured and deducted during the performance evaluations.

The electrical and thermal consumption line up should be done prior to start the test campaign.

#### **B.7 Test conduct and evaluation principle**

Sufficient readings for each measured parameter should be taken during the test duration to reduce measurement uncertainty as much as possible. When a data acquisition system is used, a minimum of 30 sets of readings for each primary parameter should be recorded for each test run.

The arithmetic average of each reading should be calculated and the stability criteria should be verified. Data acquired during each test run should be reviewed and rejected in part or in whole if they are not compliant with the requirements within the stability criteria.

### B.8 Stability criteria for power plant and PCC plant

The PCC plant should be operated under stable conditions to ensure good quality measurements and performance results. To do this, the power plant should meet stability criteria and requirements given in the applicable international standards (e.g. the IEC 60953 series and ASME PTC 6 and ASME PTC 4). This will ensure that all the interfaces between power plant and PCC plant is stable (e.g. flue gas flow, steam extractions and power supply).

PCC plant parameters that do not interface with the power plant and ambient conditions should also meet the stability criteria outlined in [Table B.2](#) before and during the performance test:

**Table B.2 — Stability criteria for power plant and PCC plant**

Parameter	Allowable standard deviation	Allowable maximum deviation from plant reference conditions
Generator power output	±0,25 %	Note 1
Generator power factor	±1,0 %	Note 3
Generator frequency	±0,25 %	±2,0 %
Generator voltage	—	±5,0 %
Solid fuel characteristics (heating value and constituents)	—	Note 2
Natural gas fuel heating value	—	Note 2
Oxygen leaving boiler/economizer (oil/gas units)	0,2 %-Vol	—
Oxygen leaving boiler/economizer (coal units)	1,0 %-Vol	—
CO <sub>2</sub> stream purity	±0,5 %-Vol	±1,0 %-Vol
CO <sub>2</sub> flow	±1,0 %	±5,0 %
Condensate flow from PCC plant	±1,0 %	±5,0 %
Refrigerant and cooling water temperature	±1,0 K	±5,0 K
Refrigerant and cooling water flow	±1,5 %	±15,0 %
Fuel flow (gas and oil)	±1,3 %	Note 3
Fuel gas pressure	±0,65 %	Note 2
Fuel gas temperature	±3,0 K	Note 2
Exhaust flue gas temperature	±2,0 K	Note 3
Steam pressures (note 4)	±0,5 %	±3,0 %
Steam temperatures (note 4)	±2,0 K	±8,0 K
Ambient temperature (dry bulb)	±2,0 K	Note 3
Ambient temperature (wet bulb)	±2,0 K	Note 3
Ambient pressure	±0,5 %	Note 3
NOTE 1 Refers to applicable steam-turbine or power plant standard.		
NOTE 2 Values taken from fuel specification limits. If the fuel characteristics are not within these limits, the involved parties should agree which correction is to be applied or postpone the tests.		
NOTE 3 This value depends on the maximum or minimum specified value in the plant reference conditions. Beyond this value mutual agreement should be reached for the correction.		
NOTE 4 Parameters are inside of the test boundaries. They are monitored to ensure the entire stability of the power plant operation. The values could be changed, depending on applicable standards of the steam turbine performance test.		

Stability is calculated by the standard deviation of the measurements along each test run. To calculate KPIs, a period of stabilization is required before each test run to ensure it is representative of stable operations.

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## Annex C (informative)

### Instruments and measurement methods

#### C.1 General

The following results are to be determined as part of the performance test standard:

- a) Capture efficiency (see [5.3](#));
- b) Captured CO<sub>2</sub> flow rate of a PCC plant (see [5.4](#));
- c) Properties of CO<sub>2</sub> stream at CO<sub>2</sub> compression system output (see [5.5](#));
- d) Specific thermal energy consumption (see [9.2](#));
- e) Specific electrical energy consumption (see [9.3](#));
- f) Specific equivalent electrical energy consumption (see [9.4](#));
- g) Specific reduction in CO<sub>2</sub> emissions (see [9.5](#));
- h) Specific absorbent consumption and specific chemical consumption (see [9.6](#)).

Items a) to e) are obtained directly from the measurement results. For the item f) to g), LGP: loss of gross power output by the steam extraction from the steam turbine should be measured according to IEC 60953-1 or IEC 60953-2 depending on the type of a host power plant after the operation is established based on the thermal energy requirement/consumption detail obtained by this document. Item h) is calculated by the specific absorbent consumption and the specific chemical consumption forwarded by the technology suppliers.

#### C.2 Measurement points diagram

Suitable measurement equipment should be installed at different points of the PCC plant when evaluating the performance of the PCC plant integrated with a power plant. Before starting the test campaign, the number and the position of all instruments to be installed and used during the tests should be confirmed. For this purpose, this document recommends preparing a measurement points diagram and including it in the test procedure.

The PCC plant and all its interfaces should be represented in this diagram, including the lines or streams that link the equipment to both power plant and PCC plant. The type of sensor (e.g. pressure, temperature, flow meter) that will be used for the performance verification test should also be represented on the relevant line and equipment. [Figure 3](#) shows a typical example of a measurement points diagram.

#### C.3 Instrument classification

Any deviation, if the whole or part of the instrumentation does not fit with the recommendation given here below, should be confirmed.

In the following clauses, accuracy recommendation is given for primary and secondary instrumentation, according to the type of measured physical parameter.

This type of instrumentation is installed temporarily before starting the test campaign and each instrument should be calibrated in a certified laboratory according to the recommendations given in the ISO 17025 and as per C.4.

If there is a high probability of a certain temperature, pressure or velocity profile at a specific measurement point, this document recommends including sufficient measurements to take all possible profiles into account. Averages may be calculated as a weighted average of surface or velocity, depending on the physical parameter, according to the relevant international standards.

Table C.1 shows the typical accuracy and allowable systematic uncertainties for primary instrumentation.

**Table C.1 — Typical accuracy level for the instrumentation**

Measured parameter	Recommended devices	Range	Maximum allowable systematic uncertainty (accuracy)
Pressure	Absolute, gauge and differential	All	±0,3 %
Temperature	RTD <sup>a</sup> for temperatures	<150 °C	±0,3 °C
	Thermocouples for temperatures	>150 °C	±0,6 °C
Flow (water and steam)	Venturi	—	Calibrated: ±0,5 % steam, ±0,4 % water uncalibrated ±1,2 % steam, ±1,1 % water
	Orifice	—	Calibrated: ±0,5 % steam, ±0,4 % water uncalibrated ±0,75 % steam, ±0,70 % water
Flow (Flue gas and CO <sub>2</sub> stream)	Multipoint pitot tube	—	Calibrated: ±5,0 % uncalibrated ±8,0 %
	Coriolis	—	See C8.2
	Ultrasonic	—	See C8.2
	Venturi	—	±1,5 %
Flue gas analysis	Oxygen portable analyser	—	±5,0 % of reading ±2,0 % of span
	Carbon monoxide (Orsat analyser)	—	±0,2 points
	Oxides of nitrogen	—	±10 ppm(v)
	Ammonia	—	To be specified
Electrical power	Wattmeter	—	±0,5 %
	Clamp-on	—	±2,0 %
	Watt-hour counter	—	±0,03 %
Current	Ammeter	—	±0,3 %
Voltage	Voltmeter	—	±0,3 %
Frequency	Electronic revolution meter	—	±0,1 %

<sup>a</sup> RTD: resistance temperature detector.

Table C.1 (continued)

Measured parameter	Recommended devices	Range	Maximum allowable systematic uncertainty (accuracy)
Ambient pressure	Absolute pressure transmitter	—	±0,075 %
Moisture	Hygrometer	—	±2,0 % RH
	Psychrometer	—	±0,5 %
Data acquisition	Digital data logger	—	±0,1 %

<sup>a</sup> RTD: resistance temperature detector.

This document recommends using permanent plant instrumentation in this category.

#### C.4 Calibration requirements

Table C.1 shows the typical accuracy level for the instrumentation to be used to test the performance of a PCC plant. The calibration procedure and the acceptance criteria should meet ASME PTC 19.5, ANSI/IEEE 120, ASTM E2744-16, BS 1041, and ISO/IEC 17025. Any other recognized international standard should be agreed and accepted by the parties involved during the test.

#### C.5 Manual measurement by international standard

The parameters required for the basic PCC plant performance explained in Clause 5 will be measured according to the measurement method explained in 8.2. This should be in accordance with the requirements for temporary instruments either manually operated or a combination of online instruments of primary instrumentation grade.

#### C.6 Online measurement by temporary or permanent plant instrumentation

If the instrumentation or measurement methods to be used are not addressed in this document then they should be subject to agreement between the relevant parties to determine the level of accuracy to be applied to each respective instrument or measurement method.

#### C.7 Flow measurements

All the streams crossing the boundary line of the PCC plant and used for the performance evaluation of the PCC plant should be measured or determined via indirect methods (e.g. heat and mass balance) in cases where a flow device cannot be installed.

The recommended flow devices to be used for flow measurements are given in BS 7405 and accord with the guidelines in ISO/TR 9464. All measurements and evaluations using pressure-drop flow devices should comply with ISO 5167.

This document recommends referring to ISO/TR 15377 if the measured steam flow is beyond that given in ISO 5167.

The main applications for PCC plant performance test flow measurements are given below.

#### C.8 Flue gas and CO<sub>2</sub> stream measurements

##### C.8.1 Flue gas flow rate

To determine volume flow rate, velocity traverse measurements are needed at numerous locations in a plane perpendicular to the flow for large pipe diameters, or in closed conduits where pressure, velocity and temperature profile can be present.

Sampling should take place in a length of straight duct with constant shape and cross-sectional area, as far as possible downstream from any obstruction that may cause a disturbance and produce a change in the direction of flow. ISO 10780 requires that the straight duct that includes the sampling plane should have at least seven hydraulic diameters long straight section and the sampling plane should be located at a distance of five hydraulic diameters from the straight duct inlet to ensure the uncertainty is 3 %. Other conditions specified include the Reynolds number should be higher than 1 200, which corresponds to a flue gas flow rate of (5 to 50) m/s.

The measurements should be according to ISO 3966 and ISO 14164. These measurements should include at least velocity pressure, static pressure, and temperatures at several locations corresponding to the centres of equal areas with a probe inserted into the duct.

Practically, large conduits may be not able to fulfil these duct requirements as per ISO 3966 and ISO 14164. If so, the number of the measurement points should be increased (up to 30) according to the recommendation of ASME PTC 19.5, depending on the actual straight length of the same shape. The details including Pitot type and the number of the sampling points are also referred to in ISO 3966 and ASME PTC 19.5.

The flow may be calculated from velocity, the duct cross-sectional area and the gas density calculated from the flue gas main components analysis. The duct cross-sectional area might be difficult to determine accurately because of obstructions within the duct, or inaccurate dimensions. The plugging of probes by the mist or droplet should be considered, depending on the flue gas quality.

An alternative method or for cross check purposes, the flue gas flow rate could be determined by combustion calculations. However, if all of the flue gas is extracted for treatment, then some slip or inclusion of the air needs to be considered.

### C.8.2 Flue gas composition

This document recommends that the relevant flue gas components ( $\text{CO}_2$ ,  $\text{SO}_x$ ,  $\text{NO}_x$ , or  $\text{O}_2$ ) should be monitored continuously throughout the test, to ensure that the condition of the flue gas is maintained within the acceptable variation range. The distribution of the component concentrations is regarded as uniform, unless removing or mixing of the component occurs near the inlet of the PCC plant.

The impurity components ( $\text{SO}_2$ ,  $\text{SO}_3$ ,  $\text{NO}_2$ ,  $\text{HCl}$ ,  $\text{HF}$ ,  $\text{NH}_3$ ,  $\text{CO}$ ) and PM analysis can impact on design, performance and uncertainty of the measurement of the PCC plant. The methods of measurement of flue gas impurities are not specified in this document and they should be cross-checked and clarified by the provision of information from the flue gas source side.

ISO 10396 describes the method, and provides the guidelines to determine impurities (i.e.  $\text{O}_2$ ,  $\text{CO}$ ,  $\text{NO}_x$  and  $\text{NH}_3$ ) that will be found in the product  $\text{CO}_2$  stream.

The following standards are also recommended:

- ISO 12039, ISO 17179, ISO 10849, EN 1911, ISO 7935, and ISO 15713

By measuring or determining the quantity of impurities, the  $\text{CO}_2$  concentration can also be determined by difference. All impurities (i.e.  $\text{O}_2$ ,  $\text{CO}$ ,  $\text{NO}_x$  and  $\text{NH}_3$  in volumetric concentration) can be measured by the said standards.  $\text{CO}_2$  concentration can then be determined by subtracting the percentages of each impurity from 100 %.

### C.8.3 Treated flue gas composition from PCC plant

Applied standards are shown in [Table C.2](#). If a regulated component is present in the flue gas its measurement is not in the scope of this document, but they should be clarified in the performance test procedure.