T-VER-P-TOOL-02-05

Tool to Calculate the Mass Flow of a Greenhouse Gas in a Gaseous Stream

Version 01

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1. Introduction

This document is a tool for determining the mass flow of greenhouse gases. It is calculated by measuring the total volume flow rate or the mass flow of the gas stream. Volumetric fractions of gas in the gas stream and the composition of the gas and water content. This includes specifying the method/data source of the parameters to be monitored.

2. Definitions

- **Absolute humidity -** the ratio between the mass of H_2O (vapor phase) in the gas and the mass of the dry gas.
- **Dry basis** - a parameter: that does not account for the H_2O present in the gas.
- **Gaseous stream** - a mixture of gaseous components which may contain different fractions of N_2, CO_2, O_2, CO, H_2, CH_4, N_2O, NO, NO_2, SO_2, SF_6, PFCs and H_2O in the vapor phase and its absolute pressure must be below 10 atm or 1.013 MPa.[1] Other gases may be present (e.g. hydrocarbons) provided their total concentration represents less than 1% (v/v) of the total.[2] A dry gas or dry gaseous stream excludes the H_2O fraction and a wet gas or wet gaseous stream includes the H_2O fraction.
- **Moisture content** - the H_2O concentration in mass of H_2O (vapor phase) per volume of dry gas at normal conditions, also referred to as NPT conditions, expressed in mg H_2O/m^3 dry gas.
- **Normal conditions** - as 0^oC (273.15 K, 32^oF) and 1 atm (101.325 kN/m^2 101.325 kPa, 14.69 psia, 29.92 in Hg, 760 torr)
- **Relative humidity -** the ratio between the partial pressure of H_2O in the gas and the saturation pressure at a given temperature.
- **Saturation (absolute) humidity** - the maximum amount of H_2O (vapor phase) that the gas can contain at a given temperature and pressure, expressed as mass of H_2O per mass of the dry gas.
- **Wet basis** - A parameter: that accounts for the H_2O present in the gas.

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[1] This condition is required because it is assumed in the calculations that the gas stream behaves as an ideal binary mixture of water vapor and an ideal gas. If the gaseous stream contains larger fractions of other gases, such as hydrocarbons other than methane or HFCs, the gas cannot be considered to be an ideal gas mixture. Moderate pressures will assure that gases behave as ideal gases.

[2] For the cases of landfill gas and exhaust gases from thermal oxidation using natural gas, it will be assumed that the total concentration of other gases represents less than 1% (v/v).

3. Applicability

Typical applications of this tool are methodologies where the flow and composition of residual or flared gases or exhaust gases are measured for the determination of baseline or project emissions. Methodologies where CO_2 is the particular and only gas of interest should continue to adopt material balances as the means of flow determination and may not adopt this tool as material balances are the cost effective way of monitoring flow of CO_2.In defining the base case there are conditions as follows:

(a) The gaseous stream the tool should be applied to;

(b) For which greenhouse gases the mass flow should be determined;

(c) In which time intervals the flow of the gaseous stream should be measured; and

(d) Situations where the simplification offered for calculating the molecular mass of the gaseous stream (equations (3) or (17)) is not valid (such as the gaseous stream is predominantly composed of a gas other than N_2)

4. Determination of the mass flow rate of greenhouse gases in the gas stream.

Calculation of the mass flow rate of greenhouse gases in the gas stream. This defines the following computational parameters.

Table 1 details the mass flow rate of greenhouse gases in the gas stream.

Parameter	unit	Description
$F_{i,t}$	kg/hr	The mass flow of a greenhouse gas i (CO_2, CH_4, N_2O, SF_6 or PFC) in the gas stream for a period t.

The mass flow of a greenhouse gas i in a gaseous stream ($F_{i,t}$) is determined through measurement of the flow and volumetric fraction of the gaseous stream. Table 2 shows the different ways to make these measurements and the corresponding calculation option for $F_{i,t}$. Project participants should document in project design document (PDD) which option is applied. $F_{i,t}$ should be calculated following the steps/guidance described for each option below.

Table 2 Measurement options

Option	Flow of gaseous stream	Volumetric fraction
A	Volume flow – dry basis	dry or wet basis[3]
B	Volume flow – dry basis	dry basis
C	Volume flow – wet basis	wet basis
D	Mass flow – dry basis	dry or wet basis
E	Mass flow – wet basis	dry basis

Option	Flow of gaseous stream	Volumetric fraction
F	Mass flow – wet basis	wet basis

4.1 Determination of the absolute humidity of the gaseous stream

The absolute humidity is a parameter: required for Options B and E. It can be determined from measurement of the moisture content (Option 1), or by assuming the gaseous stream is dry or saturated in a simplified conservative approach (Option 2). Project participants should document in the PDD which option they apply.

Option 1: Calculation using measurement of the moisture content

This option provides a procedure to determine the absolute humidity of the gaseous stream ($m_{H2O,t,db}$) from measurements of the moisture content of the gas, according to equation (1).

$$m_{H2O,t,db} = \frac{C_{H2O,t,db,n}}{10^{-6} \times \rho_{t,db,n}} \qquad \text{Equation (1)}$$

Where;

$m_{H2O,t,db}$ = Absolute humidity of the gaseous stream in time interval t on a dry basis (kg H_2O/kg dry gas)

$C_{H2O,t,db,n}$ = Moisture content of the gaseous stream in time interval t on a dry basis at normal conditions (mg H_2O/m^3 dry gas)

$\rho_{t,db,n}$ = Moisture content of the gaseous stream in time interval t on a dry basis at normal conditions

[3] Flow measurement on a dry basis is not feasible at reasonable costs for a wet gaseous stream, so there will be no difference in the readings for volumetric fraction in wet basis analyzers and dry basis analyzers and both types can be used indistinctly for calculation Options A and D.

1) The density of the gaseous stream on a dry basis at normal conditions ($\rho_{t,db,n}$) is determined as follows:

$$\rho_{t,db,n} = \frac{P_n \times MM_{t,db}}{R_u \times T_n} \qquad \text{Equation (2)}$$

Where;

$\rho_{t,db,n}$ = Density of the gaseous stream in time interval t on a dry basis at normal conditions (kg dry gas/m^3 dry gas)

P_n = Absolute pressure at normal conditions (Pa)

T_n = Temperature at normal conditions (K)

$MM_{t,db}$ = Molecular mass of the gaseous stream in a time interval t on a dry basis (kg dry gas/kmol dry gas)

R_u = Universal ideal gases constant (Pa.m^3 /kmol.K)

2) The determination of the molecular mass of the gaseous stream ($MM_{t,db}$) requires measuring the volumetric fraction of all gases (k) in the gaseous stream. However as a simplification, the volumetric fraction of only the gases k that are greenhouse gases and are considered in the emission reduction calculation in the underlying methodology must be monitored and the difference to 100% may be considered as pure nitrogen. The simplification is not acceptable if it is differently specified in the underlying methodology. The molecular mass of the gaseous stream ($MM_{t,db}$) is estimated as follows:

$$MM_{t,db} = \sum_{k}(v_{k,t,db} \times MM_k) \qquad \text{Equation (3)}$$

Where;

$MM_{t,db}$ = Molecular mass of the gaseous stream in time interval t on a dry basis (kg dry gas/kmol dry gas)

$v_{k,t,db}$ = Volumetric fraction of gas k in the gaseous stream in time interval t on a dry basis (m^3 gas k/m^3 dry gas)

MM_k = Molecular mass of gas k (kg/kmol)

k = All gases, except H_2O, contained in the gaseous stream (e.g. N_2, CO_2, O_2, CO, H_2, CH_4, N_2O, NO, NO_2, SO_2, SF_6 and PFC)

Option 2: Simplified calculation without measurement of the moisture content

This option provides a simple and conservative approach to determine the absolute humidity by assuming the gaseous stream is dry or saturated depending on which is the conservative situation.[4] If it is conservative to assume that the gaseous stream is dry, then $m_{H2O,t,db}$ is assumed to equal 0 . If it is conservative to assume that the gaseous stream is saturated, then $m_{H2O,t,db}$ is assumed to equal the saturation absolute humidity ($m_{H2O,t,db,sat}$) and calculated using equation (4).

$$m_{H2O,t,db,sat} = \frac{P_{H2O,t,sat} \times MM_{H2O}}{(P_t - p_{H2O,t,sat}) \times MM_{t,db}} \qquad \text{Equation (4)}$$

Where

$m_{H2O,t,db,sat}$	=	Saturation absolute humidity in time interval t on a dry basis (kg H_2O/kg dry gas)
$p_{H2O,t,sat}$	=	Saturation pressure of H_2O at temperature Tt in time interval t (Pa)
T_t	=	Temperature of the gaseous stream in time interval t (K)
P_t	=	Absolute pressure of the gaseous stream in time interval t (Pa)
MM_{H2O}	=	Molecular mass of H_2O (kg H_2O/kmol H_2O)
$MM_{t,db}$	=	Molecular mass of the gaseous stream in a time interval t on a dry basis (kg dry gas/kmol dry gas)

1) The molecular mass of the gaseous stream ($MM_{t,db}$) is estimated using equation (3).

Option A

Flow measurement on a dry basis cannot be made for a wet gaseous stream. Therefore, it is necessary to demonstrate that the gaseous stream is dry to use this option. There are two ways to do this:

[4] An assumption that the gaseous stream is saturated is conservative for the situation that the mass flow of greenhouse gas i is underestimated (applicable for calculating baseline emissions). Conversely, an assumption that the gas stream is dry is conservative for the situation that the greenhouse gas i is overestimated (applicable for calculating project emissions)

(a) Measure the moisture content of the gaseous stream ($C_{H2O,t,db,n}$) and demonstrate that this is less or equal to 0.05 kg H_2O/m^3dry gas; or

(b) Demonstrate that the temperature of the gaseous stream (T_t) is less than 60 ºC (333.15 K) at the flow measurement point.

If it cannot be demonstrated that the gaseous stream is dry, then the flow measurement should be assumed to be on a wet basis and the corresponding option from Table 2 should be applied instead.

$$F_{i,t} = V_{t,db} \times v_{i,t,db} \times \rho_{i,t} \qquad \text{Equation (5)}$$

With:

$$\rho_{i,t} = \frac{P_t \times MM_i}{R_u \times T_t} \qquad \text{Equation (6)}$$

Where:

$F_{i,t}$	=	Mass flow of greenhouse gas i in the gaseous stream in time interval t (kg gas/h)
$V_{t,db}$	=	Volumetric flow of the gaseous stream in time interval t on a dry basis (m^3 dry gas/h)
$v_{i,t,db}$	=	Volumetric fraction of greenhouse gas i in the gaseous stream in a time interval t on a dry basis (m^3 gas i/m^3 dry gas)
$\rho_{i,t}$	=	Density of greenhouse gas i in the gaseous stream in time interval t (kg gas i/m^3 gas i)
P_t	=	Absolute pressure of the gaseous stream in time interval t (Pa)
MM_i	=	Molecular mass of greenhouse gas i (kg/kmol)
R_u	=	Universal ideal gases constant (Pa.m^3/kmol.K))
T_t	=	Temperature of the gaseous stream in time interval t (K)

Option B

The mass flow of greenhouse gas i ($F_{i,t}$) is determined using equations (5) and (6). The volumetric flow of the gaseous stream in time interval t on a dry basis ($V_{t,db}$) is determined by converting the measured volumetric flow from wet basis to dry basis as follows:

$$V_{t,db} = V_{t,wb} / (1+v_{H2O,t,db}) \qquad \text{Equation (7)}$$

Where:

$V_{t,db}$	=	Volumetric flow of the gaseous stream in time interval t on a dry basis (m^3 dry gas/h)
$V_{t,wb}$	=	Volumetric flow of the gaseous stream in time interval t on a wet basis (m^3 wet gas/h)
$v_{H2O,t,db}$	=	Volumetric fraction of H_2O in the gaseous stream in time interval t on a dry basis (m^3 H_2O/m^3 dry gas)

1) The volumetric fraction of H_2O in time interval t on a dry basis ($v_{H2O,t,db}$) is estimated according to equation (8).

$$v_{H2O,t,db} = \frac{m_{H2O,t,db} \times MM_{t,db}}{MM_{H2O}} \qquad \text{Equation (8)}$$

Where;

$v_{H2O,t,db}$	=	Volumetric fraction of H_2O in the gaseous stream in time interval t on a dry basis (m^3 H_2O/m^3 dry gas)
$m_{H2O,t,db}$	=	Absolute humidity in the gaseous stream in time interval t on a dry basis (kg H_2O/kg dry gas)
$MM_{t,db}$	=	Molecular mass of the gaseous stream in time interval t on a dry basis (kg dry gas/kmol dry gas)
MM_{H2O}	=	Molecular mass of H_2O (kg H_2O/kmol H_2O)

2) The absolute humidity of the gaseous stream ($m_{H2\,O,t,db}$) is determined using either option 1 or 2 specified in the determination of the absolute humidity of the gaseous stream section of the tool and the molecular mass of the gaseous stream ($MM_{t,db}$) is determined using equation (3).

Option C The mass flow of greenhouse gas i ($F_{i,t}$) is determined as follows:

$$F_{i,t} = V_{t,wb,n} \times v_{i,t,wb} \times \rho_{i,n} \qquad \text{Equation (9)}$$

With:

$$\rho_{i,n} = \frac{P_n \times MM_i}{R_u \times T_n} \qquad \text{Equation (10)}$$

Where:

$F_{i,t}$	=	Mass flow of greenhouse gas i in the gaseous stream in time interval t (kg gas/h)
$V_{t,wb,n}$	=	Volumetric flow of the gaseous stream in time interval t on a wet basis at normal conditions (m^3 wet gas/h)
$v_{i,t,wb}$	=	Volumetric fraction of greenhouse gas i in the gaseous stream in time interval t on a wet basis (m^3 gas i/m^3 wet gas)
$\rho_{i,n}$	=	Density of greenhouse gas i in the gaseous stream at normal conditions (kg gas i/m^3 wet gas i)
P_n	=	Absolute pressure at normal conditions (Pa)
T_n	=	Temperature at normal conditions (K)
MM_i	=	Molecular mass of greenhouse gas i (kg/kmol)
R_u	=	Universal ideal gases constant ($Pa \cdot m^3$ /kmol-K)

The following equation should be used to convert the volumetric flow of the gaseous stream from actual conditions to normal conditions of temperature and pressure:

$$\mathbf{V_{t,wb,n} = V_{t,wb} \times [(T_n/T_t) \times (P_t/P_n)]} \qquad \text{Equation (11)}$$

Where;

$V_{t,wb,n}$	=	Volumetric flow of the gaseous stream in a time interval t on a wet basis at normal conditions (m^3 wet gas/h)
$V_{t,wb}$	=	Volumetric flow of the gaseous stream in time interval t on a wet basis (m^3 wet gas/h)
P_t	=	Pressure of the gaseous stream in time interval t (Pa)
T_t	=	Temperature of the gaseous stream in time interval t (K)
P_n	=	Absolute pressure at normal conditions (Pa)
T_n	=	Temperature at normal conditions (K)

Option D

Flow measurement on a dry basis is not doable for a wet gaseous stream. Therefore, it is necessary to demonstrate that the gaseous stream is dry to use this option. There are two ways to do this:

(a) Measure the moisture content of the gaseous stream ($C_{H2O,t,db,n}$) and demonstrate that this is less or equal to 0.05 kg H_2O/m^3 dry gas; or

(b) Demonstrate that the temperature of the gaseous stream (Tt) is less than 60 °C (333.15 K) at the flow measurement point.

If it cannot be demonstrated that the gaseous stream is dry, then the flow measurement should be assumed to be on a wet basis and the corresponding option from Table 2 should be applied instead. The mass flow of greenhouse gas i ($F_{i,t}$) is determined using equations (5) and (6). The volumetric flow of the gaseous stream in time interval t on a dry basis ($V_{t,db}$) is determined by converting the mass flow of the gaseous stream to a volumetric flow as follows:

$$V_{t,db} = M_{t,db} / \rho_{t,db}$$ Equation (12)

Where;

$V_{t,db}$ = Volumetric flow of the gaseous stream in time interval t on a dry basis (m^3 dry gas/h)

$M_{t,db}$ = Mass flow of the gaseous stream in time interval t on a dry basis (kg/h)

$\rho_{t,db}$ = Density of the gaseous stream in time interval t on a dry basis (kg dry gas/m^3 dry gas)

1) The density of the gaseous stream ($\rho_{t,db}$) should be determined as follows:

$$\rho_{t,db} = \frac{P_t \times MM_{t,db}}{R_u \times T_t}$$ Equation (13)

Where;

$\rho_{t,db}$ = Density of the gaseous stream in a time interval t on a dry basis (kg dry gas/m^3 dry gas)

$MM_{t,db}$ = Molecular mass of the gaseous stream in a time interval t on a dry basis (kg dry gas/kmol dry gas)

P_t = Pressure of the gaseous stream in time interval t (Pa)

T_t = Temperature of the gaseous stream in time interval t (K)

2) The molecular mass of the gaseous stream ($MM_{t,db}$) is estimated using equation (3).

Option E

The mass flow of greenhouse gas i ($F_{i,t}$) is determined using equations (5) and (6). The volumetric flow of the gaseous stream in time interval t on a dry basis ($V_{t,db}$) is determined in two steps. First the mass flow of the gaseous stream in time interval t on a wet basis ($M_{t,wb}$) is converted from wet basis to dry basis as follows:

$$M_{t,db} = M_{t,wb}/(1+m_{H2O,t,db}) \quad \text{Equation (14)}$$

Where

$M_{t,db}$	=	Mass flow of the gaseous stream in time interval t on a dry basis (kg/h)
$M_{t,wb}$	=	Mass flow of the gaseous stream in time interval t on a wet basis (kg/h)
$m_{H2O,t,db}$	=	Absolute humidity of H_2O in the gaseous stream in a time interval t on a dry basis (kg H_2O/kg dry gas)

1) Then, the mass flow of the gaseous stream in time interval t on a dry basis ($M_{t,db}$) is converted to the volumetric flow of the gaseous stream in time interval t on a dry basis ($V_{t,db}$) using equation (12)

2) The absolute humidity of the gaseous stream ($m_{H2O,t,db}$) is determined using either Option 1 or 2 specified in the determination of the absolute humidity of the gaseous stream at section of the tool.

Option F

The mass flow of greenhouse gas i ($F_{i,t}$) is determined using equations (9), (10), and the following equations:

$$V_{t,wb,n} = M_{t,wb} / \rho_{t,wb,n} \quad \text{Equation (15)}$$

and

$$\rho_{t,wb,n} = \frac{P_n \times MM_{t,wb}}{R_u \times T_n} \quad \text{Equation (16)}$$

Where;

$V_{t,wb,n}$	=	Volumetric flow of the gaseous stream in time interval t at normal conditions on a wet basis (m^3 wet gas/h)

$v_{i,t,wb}$	=	Volumetric fraction of greenhouse gas i in the gaseous stream in time interval t on a wet basis (m^3 gas i/m^3 wet gas)
$M_{t,wb}$	=	Mass flow of the gaseous stream in time interval t on a wet basis (kg/h)
$\rho_{t,wb,n}$	=	Density of the gaseous stream in time interval t on a wet basis at normal conditions (kg wet gas/m^3 wet gas)
P_n	=	Absolute pressure at normal conditions (Pa)
T_n	=	Temperature at normal conditions (K)
$MM_{t,wb}$	=	Molecular mass of the gaseous stream in time interval t on a wet basis (kg wet gas/kmol wet gas)
R_u	=	Universal ideal gases constant (Pa·m^3 /kmol-K)

1) The determination of the molecular mass of the gaseous stream ($MM_{t,wb}$) requires measuring the volumetric fraction of all gases (k) in the gaseous stream. However as a simplification, the volumetric fraction of only the gases k that are greenhouse gases and are considered in the emission reduction calculation in the underlying methodology must be monitored and the difference to 100% may be considered as pure nitrogen. The simplification is not acceptable if it is differently specified in the underlying methodology. The molecular mass of the gaseous stream ($MM_{t,wb}$) is determined as follows:

$$\mathbf{MM_{t,wb} = \sum_{k}(v_{k,t,wb} \times MM_k)} \qquad \text{Equation (17)}$$

Where;

$MM_{t,wb}$	=	Molecular mass of the gaseous stream in time interval t on a wet basis (kg wet gas/kmol wet gas)
$v_{k\ t,wb}$	=	Volumetric fraction of gas k in the gaseous stream in time interval t on a wet basis (m^3 gas k/m^3 wet gas)
MM_k	=	Molecular mass of gas k (kg/kmol)
k	=	All gases contained in the gaseous stream (such as N_2, CO_2, O_2, CO, H_2, CH_4, N_2O, NO, NO_2, SO_2, SF6 และ PFC and H_2O in vapor phase)

5. Monitoring Plan

5.1 Monitoring methodology

1) The project developer explains and specifies the steps for monitoring the project activity data (Activity data) or verify all measurement results in the project proposal document. including the type of measuring instruments used Person responsible for monitoring results and verifying information Calibration of measuring instruments (if any) and procedures for warranty and quality control Where methods have different options, such as using default values or on-site measurements The project developer must specify which option to use. In addition, the installation, maintenance, and calibration of measuring instruments should be carried out in accordance with the instructions of the equipment manufacturer and in accordance with national standards. or international standards such as IEC, ISO

2) All data collected as part of the greenhouse gas reduction monitoring. The data should be stored in electronic file format and the retention period is in accordance with the guidelines set by the Administrative Organization or the organization's quality system, but the period of time is not less than that specified by the TGO. Must follow the follow-up methods specified in the follow-up parameters specified in Table 5.2.

5.2. Data and parameters to be monitored

Parameter:	$V_{t,wb}$
Data unit:	m^3 wet gas/h
Description:	Volumetric flow of the gaseous stream in time interval t on a wet basis
Source of data:	
Measurement procedures:	Volumetric flow measurement should always refer to the actual pressure and temperature. Instruments with recordable electronic signal (analogical or digital) are required
Monitoring frequency:	Continuous if not specified in the underlying methodology
QA/QC procedures:	Periodic calibration against a primary device provided by an independent accredited laboratory is mandatory for all projects applying large scale methodology(ies). Calibration and frequency of calibration is according to manufacturer's specifications
Any comment:	This parameter will be monitored in Options B and C

Parameter:	$V_{t,db}$
Data unit:	m³ dry gas/h
Description:	Volumetric flow of the gaseous stream in time interval t on a dry basis
Source of data:	-
Measurement procedures:	Volumetric flow measurement should always refer to the actual pressure and temperature. Calculated based on the wet basis flow measurement plus water concentration measurement
Monitoring frequency:	Continuous if not specified in the underlying methodology
QA/QC procedures:	Periodic calibration against a primary device provided by an independent accredited laboratory is mandatory for all projects applying large scale methodology(ies). Calibration and frequency of calibration is according to manufacturer's specifications
Any comment:	This parameter will be monitored in Options A

Parameter:	$V_{i,t,db}$
Data unit:	m³ dry gas/h
Description:	Volumetric fraction of greenhouse gas i in a time interval t on a dry basis
Source of data:	
Measurement procedures:	Continuous gas analyzer operating in dry basis. Volumetric flow measurement should always refer to the actual pressure and temperature
Monitoring frequency:	Continuous if not specified in the underlying methodology
QA/QC procedures:	Calibration should include zero verification with an inert gas (e.g. N_2) and at least one reading verification with a standard gas (single calibration gas or mixture calibration gas). All calibration gases must have a certificate provided by the manufacturer and must be under
Any comment:	This parameter will be monitored in Options B and E and may be monitored in Options A and D

parameter:	$V_{i,t,wb}$
Data unit:	m³ gas i/m³ wet gas
Description:	Volumetric fraction of greenhouse gas i in a time interval t on a wet
Source of data:	-
Measurement procedures:	Calculated based on the dry basis analysis plus water concentration measurement or continuous in-situ analyzers if not specified in the underlying methodology
Monitoring frequency:	Continuous if not specified in the underlying methodology

QA/QC procedures:	Calibration should include zero verification with an inert gas (e.g. N_2) and at least one reading verification with a standard gas (single calibration gas or mixture calibration gas). All calibration gases must have a certificate provided by the manufacturer and must be under their validity period.
Any comment:	This parameter will be monitored in Options C and F and may be monitored in Options A and D

Parameter:	$M_{t,wb}$
Data unit:	kg/hr
Description:	Mass flow of the gaseous stream in time interval t on a wet basis
Source of data:	-
Measurement	Instruments with recordable electronic signal (analogical or digital)
Monitoring frequency:	Continuous if not specified in the underlying methodology
QA/QC procedures:	Periodic calibration against a primary device provided by an independent accredited laboratory is mandatory. Calibration and frequency of calibration is according to manufacturer's specifications
Any comment:	This parameter will be monitored in Options E and F

Parameter:	$M_{t,db}$
Data unit:	kg/hr
Description:	Mass flow of the gaseous stream in time interval t on a dry basis
Source of data:	
Measurement procedures:	Calculated based on the wet basis flow measurement plus water concentration measurement
Monitoring frequency:	Continuous if not specified in the underlying methodology
QA/QC procedures:	Calibration and frequency of calibration is according to manufacturer's
Any comment:	This parameter will be monitored in Option D

Parameter:	$C_{H2O,t,db,n,}$
Data unit:	mg H_2O/m^3dry gas
Description:	Moisture content of the gaseous stream at normal conditions, in time interval t
Source of data:	Measurements according to the USEPA CF42 method 4 –Gravimetric determination of water content
Measurement	Discrete measurement procedure

Monitoring frequency:	The mean value among three consecutive measurements performed in the same day (at least 2 hours each) shall be considered. Measurements should coincide with the Annual Surveillance Test (associated with requirements of the EN 14181 standard) or the calibration of the flow meter for the gaseous stream
QA/QC procedures:	According to the USEPA CF42 method 4
Any comment:	Monitoring is required if Option 1 described in the "Determination of the absolute humidity of the gaseous stream" section of the tool is applied, or as one of the ways of proving that the gaseous stream is dry (necessary for Options A or D)

Parameter:	T_t
Data unit:	K
Description:	Temperature of the gaseous stream in time interval t
Source of data:	
Measurement procedures:	Instruments with recordable electronic signal (analogical or digital) are required for examples thermocouples, thermo resistance, etc
Monitoring frequency:	Continuous unless differently specified in the underlying methodology
QA/QC procedures:	Periodic calibration against a primary device provided by an independent accredited laboratory is mandatory. Calibration and frequency of calibration is according to manufacturer's specifications
Any comment:	Provided all parameters are converted to normal conditions during the monitoring process, this parameter may not be needed except for moisture content determination and therefore it should be metered only when performing such measurements (with same frequency). However, if the applicability condition related to the gaseous stream flow temperature being below 60 ºC is adopted, this parameter must be monitored continuously to assure the applicability condition is met.

Parameter:	P_t
Data unit:	Pa (N/m^2)
Description:	Pressure of the gaseous stream in time interval t
Source of data:	
Measurement procedures:	Instruments with recordable electronic signal (analogical or digital) are required. Examples include pressure transducers, etc
Monitoring frequency:	Continuous unless differently specified in the underlying methodology

QA/QC procedures:	Periodic calibration against a primary device must be performed periodically and records of calibration procedures must be kept available as well as the primary device and its calibration certificate. Pressure transducers (either capacitive or resistive) must be calibrated monthly
Any comment:	Provided all parameters are converted to normal conditions during the monitoring process, this parameter may not be needed except for moisture content determination and therefore it should be metered only when performing such measurements (with same frequency)

Parameter:	$p_{H20,t,sat}$
Data unit:	Pa (N/m^2)
Description:	Saturation pressure of H_2O at temperature T_t
Source of data:	
Measurement procedures:	This parameter is solely a function of the gaseous stream temperature T_t and can be found at reference [1] for a total pressure equal to 101,325 Pa.
Monitoring frequency:	
QA/QC procedures:	
Any comment:	[1] Fundamentals of Classical Thermodynamics; Gordon J. Van Wylen, Richard E. Sonntag and Borgnakke; 4° Edition 1994, John Wiley & Sons, Inc.

Parameter:	$V_{k,t,db}$
Data unit:	mg H_2O/m^3 dry gas
Description:	Volumetric fraction of gas k in the gaseous stream in time interval t on a dry basis
Source of data:	
Measurement	Continuous gas analyzer operating in dry-basis
Monitoring frequency:	Continuous if not specified in the underlying methodology/tool
QA/QC procedures:	Calibration should include zero verification with an inert gas (e.g. N2) and at least one reading verification with a standard gas (single calibration gas or mixture calibration gas). All calibration gases must have a certificate provided by the manufacturer and must be under their validity period.
Any comment:	

Parameter:	$v_{k,t,wb}$
Data unit:	m^3 gas k/m^3 wet gas
Description:	Volumetric fraction of gas k in the gaseous stream in time interval t on a wet basis
Source of data:	

Measurement procedures:	Calculated based on the dry basis analysis plus water concentration measurement or continuous in-situ analyzers if not specified in the underlying methodology/tool
Monitoring frequency:	Continuous if not specified in the underlying methodology
QA/QC procedures:	Calibration should include zero verification with an inert gas (e.g. N_2) and at least one reading verification with a standard gas (single calibration gas or mixture calibration gas). All calibration gases must have a certificate provided by the manufacturer and must be under their validity period
Any comment:	

Parameter:	Status of biogas destruction device
Data unit:	-
Description:	Operational status of biogas destruction devices
Source of data:	
Measurement procedures:	Monitoring and documenting may be undertaken by recording the energy production from methane captured or the operation of the flare by means of a flame detector to demonstrate the actual destruction of methane unless a different method is specified in the underlying methodology/tool. Emission reductions will not accrue for periods in which the destruction device is not operational.
Monitoring frequency:	Continuous if not specified in the underlying methodology/tool
QA/QC procedures:	
Any comment:	For flame detector devices refer to the TVER-TOOL-02-04 "Tool to calculate project emissions from flaring"

5.3. Data and parameters not monitored

Parameter:	R_U
Data unit:	Pa·m^3/kmol-K
Description:	Universal ideal gases constant
Value to be applied:	8,314
Any comment:	

Parameter:	MM_i
Data unit:	kg/kmol
Description:	Molecular mass of greenhouse gas i

Value to be applied:	
	(table below)
Any comment:	

Compound	Structure	Molecular mass (kg / kmol)
Carbon dioxide	CO_2	44.01
Methane	CH_4	16.04
Nitrous oxide	N_2O	44.02
Sulfur hexafluoride	SF_6	146.06
Perfluoromethane	CF_4	88.00
Perfluoroethane	C_2F_6	138.01
Perfluoropropane	C_3F_8	188.02
Perfluorobutane	C_4F_{10}	238.03
Perfluorocyclobutane	$c\text{-}C_4F_8$	200.03
Perfluoropentane	C_5F_{12}	288.03
Perfluorohexane	C_6F_{14}	338.04
Carbon dioxide	CO_2	44.01

Parameter:	MM_k
Data unit:	kg/kmol
Description:	Molecular mass of gas k
Value to be applied:	(table below)
Any comment:	

Compound	Structure	Molecular mass (kg / kmol)
Nitrogen	N_2	28.01
Oxygen	O_2	32.00
Carbon monoxide	CO	28.01
Hydrogen	H_2	2.02
Nitric oxide	NO	30.01
Nitrogen dioxide	NO_2	46.01
Sulfur dioxide	SO_2	64.06

Parameter:	MM_{H2O}
Data unit:	kg/kmol
Description:	Molecular mass of water

Value to be applied:	18.0152
Any comment:	

Parameter:	P_n
Data unit:	Pa
Description:	Total pressure at normal conditions
Value to be applied:	101,325
Any comment:	

parameter:	T_n
Data unit:	K
Description:	Temperature at normal conditions
Value to be applied:	273.15
Any comment:	

6. Reference

CDM Methodological tool:

TOOL08: Tool to determine the mass flow of a greenhouse gas in a gaseous stream Version 03.0

Appendix 1

Additional data handling and monitoring guidance for determining the mass flow of methane in biogas

This appendix is applicable small-scale and large-scale project activities to the determination of mass flow of methane in biogas from waste treatment and landfill gas.

1. Data substitution for methane content or biogas flow

If missing data are encountered in the course of determining the methane mass flow, it may be substituted with conservative data sets (see below) from specific periods. However, data substitution shall only be applied to either the methane concentration or the biogas volumetric flow readings, but not to both simultaneously. If data is missing for both parameters during a given period of time, no data substitution shall be allowed for that period. Substitution as outlined in Table 1 below may be undertaken only if the following conditions are met:

(a) For methane concentration, biogas flow rates during the period where data gap occurred (data gap period) shall be consistent with normal operation (i.e. the average flow rates during the gap period shall not deviate from the average flow rates of the period taken for data substitution (data substitution period)1 by more than +/- 20%); and

(b) For biogas flow rate, methane concentration during the data gap period shall be consistent with the methane concentration observed during normal operations (i.e. the average methane concentration during the data gap period shall not deviate from the average methane concentration of the data substitution period by more than +/- 20%); and

(c) Project participants shall demonstrate that the methane is being destroyed during the period of the data gap. If corroborating parameters fail to demonstrate any of these requirements, no substitution shall be allowed.

Table 1 Data substitution procedure

Duration of missing data	Data substitution procedure
Less than six hours	Use the weighted average of the four hours period immediately before and four hours period immediately after the outage

Duration of missing data	Data substitution procedure
6 to 24 hours	Use the upper bound or lower bound of 95% confidence interval of the data spanning 24 hours prior to and 24 hours after the outage, whichever results in more conservative estimate of emission reductions.
1 to 7 days	Use the upper bound or lower bound of 95% confidence interval of the data spanning 72 hours prior to and 72 hours after the outage, whichever results in more conservative estimate of emission reductions
Greater than one week	No data may be substituted

2. Use of a single flow meter for multi-use of recovered biogas

If the biogas recovery (e.g. landfill gas) is used for multiple purposes (e.g. flaring or energy generation), and all methane destruction devices are verified to be operational (e.g. by means of flame detectors records, energy generated), a single flow meter may be used to record the flow into multiple destruction devices. The destruction efficiency of the least efficient among the destruction devices shall be used as the destruction efficiency for all destruction devices monitored by this flow meter.

If there are any periods for which one or more destruction devices are not operational, emission reductions from methane destruction for these periods may be claimed referred to verification that confirms the fulfilment of all the following conditions indicated below. In such a case, the destruction efficiency of the least efficient destruction device in operation shall be used as the destruction efficiency for all destruction devices monitored by this single flow meter:

(a) All destruction devices are either equipped with valves on the input gas line that close automatically (e.g., normally closed valves) if the device becomes non-operational (i.e., requiring no manual intervention), or designed in such a manner that it is physically impossible for the gas to pass through and into the atmosphere while the device remains non-operational; and

(b) For any period where one or more destruction devices within this arrangement are not operational, it shall be demonstrated that the remaining operational devices have the capacity to destroy the actual gas flow recorded during the period. For devices other than flares, it shall be shown that the output corresponds to the flow of gas (e.g., through mass and/or energy balance).

Measurement of methane content shall be conducted immediately downstream of the flow meter, while respecting the installation requirements of the flow meter.

3. Use of a sampling method for methane content of landfill gas

Methane content of landfill gas can be monitored by sampling, provided that the following conditions are met:

(a) The maximum waste treatment capacity of the landfill is 200 tonnes waste per day;

(b) The sample vehicles are statistically randomly selected using Taro Yamane's table with a 95% confidence level and a 10% error, detailed in Annex 2.

(c) National or international protocols for measuring methane content of biogas by a semi-continuous analysis shall be followed; otherwise, meter reading can only be collected when the methane content has reached stabilization for at least 3 minutes. Orsat analysis is not eligible; and

(d) The biogas flow rate is monitored continuously. The methane content measured by sampling for a given period can be used directly only if the average flow rate during the following week does not fluctuate by more than +/- 20% as compared to the mean value of the flow rates for the period during which the methane content is measured by sampling. Otherwise, a conservative adjustment shall be applied to the measured methane content, i.e. by applying the observed deviation as a discounting factor.

Appendix 2

Taro Yamane Sample Determination

Formula for finding the number of samples of Taro Yamane (Taro Yamane, 1973) according to Equation (1).

$$n = \frac{N}{1+Ne^2} \qquad \text{Equation (1)}$$

Where n = number of samples

N = population

e = Tolerance

Table 2 Taro Yamane sample size at 95% confidence level and various discrepancies

Population	Sample size at the tolerance level (e)					
	± 1%	± 2%	± 3%	± 4%	± 5%	± 10%
500	*	*	*	*	222	83
1,000	*	*	*	385	286	91
1,500	*	*	638	441	316	94
2,000	*	*	714	476	333	95
2,500	*	1,250	769	500	345	96
3,000	*	1,364	811	517	353	97
3,500	*	1,458	843	530	359	97
4,000	*	1,538	870	541	364	98
4,500	*	1,607	891	549	367	98
5,000	*	1,667	909	556	370	98
6,000	*	1,765	938	566	375	98
7,000	*	1,842	959	574	378	99
8,000	*	1,905	976	580	381	99
9,000	*	1,957	989	584	383	99
10,000	5,000	2,000	1,000	588	385	99
15,000	6,000	2,143	1,034	600	390	99
20,000	6,667	2,222	1,053	606	392	100
25,000	7,143	2,273	1,064	610	394	100
50,000	8,333	2,381	1,087	617	397	100
100,000	9,091	2,439	1,099	621	398	100
∞	10,000	2,500	1,111	625	400	100

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