Holcim
Emission and Monitoring
Guideline for Unit Conversion
of Continuous Measuring Devices

Version 2004-01 / January 2004

HGRS-CTS/MT
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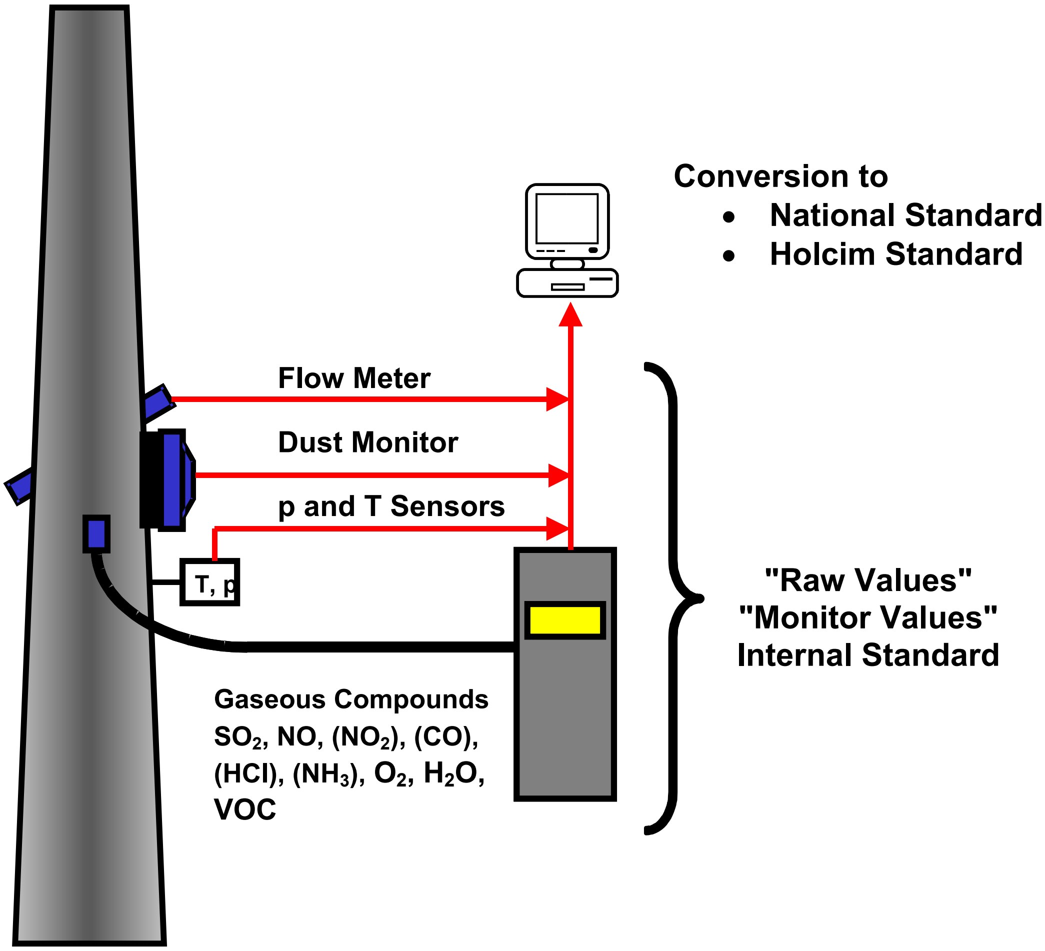
SYMBOL LIST

A	[m²]	Cross section area
c	[mg/m³]	Concentration
c_{dry}	[mg/m³]	Concentration, dry
$c_{dry,S}$	[mg/m³S]	Concentration, dry, standard condition
c_n, c_m	[mg/m³S]	Concentration, standard n or m
$c_{dry,S,ref}$	[mg/m³S]	Concentration, dry, standard condition, reference oxygen level
c_{Holcim}	[mg/m³N]	Concentration, dry, normal condition, reference oxygen level = 10 [%]
c_{wet}	[mg/m³]	Concentration, wet
f		Factor
h	[m]	Altitude (above sea level)
H_2O	[vol-%]	Water content of exhaust gas
M	[kg/kmol]	Molar mass
$\dot{m}$	[kg/s]	Mass flow
O_2	[vol-%]	Oxygen concentration (dry) in the stack
$O_{2,ref}$	[vol-%]	Reference oxygen level (dry)
p_S	[mbar]	Standard pressure (standard condition)
p_{Sn}, p_{Sm}	[mbar]	Standard pressure (standard condition n or m)
p_{Stack}	[mbar]	Stack pressure
T_S	[K]	Standard temperature (standard condition)
T_{S1}	[K]	Standard temperature (standard 1)
T_{S2}	[K]	Standard temperature (standard 2)
T_{S3}	[K]	Standard temperature (standard 3)
T_{Sn}, T_{Sm}	[K]	Standard temperature (standard n or m)
T_{Stack}	[K]	Stack temperature
$\dot{V}$	[m³/s]	Volume stream
$\dot{V}_{wet}$	[m³/s]	Volume stream, wet
$\dot{V}_{dry}$	[m³/s]	Volume stream, dry
$\dot{V}_{dry,S}$	[m³S/s]	Volume stream, dry, standard condition
$\dot{V}_n$, $\dot{V}_m$	[m³S/s]	Volume stream, dry, standard condition n or m
$\dot{V}_{dry,S,ref}$	[m³S/s]	Volume stream, dry, standard condition, reference oxygen level
$\dot{V}_{Holcim}$	[m³N/s]	Volume stream, dry, normal condition, reference oxygen level = 10 [%]
w	[m/s]	Velocity

1. "RAW VALUES" AND CONVERTED VALUES



1.1 "Raw Values" (or "Monitor Values")

The "Raw Values" are the values directly indicated on the instrument(s). These values are defined at certain standard ("internal standard") and generally not converted to a reference oxygen level. The supplier(s) of the instrument(s) must exactly defined these "Raw Values" and the definitions should be laid down in the reference manual.

1.2 Conversion to Standard Conditions

In an external computer the "Raw Values" must be converted to the National and Holcim standard. This conversion is explained in this Guideline.

2. THE STANDARDS

2.1 Holcim Standard

1. Emissions are expressed as concentration, mass of emitted substance per volume of the exhaust gas (e.g. in milligrams per cubic meter [mg/m^3]).

2. The emissions indicated as concentrations refer to the volume of exhaust gas under standard (normal) conditions (0 [°C], 1013 [mbar]) after subtraction of the moisture content (dry).

3. The measured emission concentrations shall be converted to a reference oxygen value of 10 [vol-%] (dry).

4. Nitrogen oxides NO_x (nitrogen monoxide NO and nitrogen dioxide NO_2) shall be expressed as nitrogen dioxide (NO_2).

5. Volatile Organic Compounds (VOC) shall be expressed as carbon [mgC/m^3_S]

2.2 National Standards

1. Generally emissions are expressed as concentration, mass of emitted substance per volume of the exhaust gas (e.g. in milligrams per cubic meter [mg/m^3]).

2. The emissions indicated as concentrations refer to the volume of exhaust gas under standard conditions (T_S, p_s) after subtraction of the moisture content (dry). Standard conditions are very different.
   Examples:
   - Standard 1[1]: p_s = 1013 [mbar], T_s = 0 [°C] (273.15 [K])
     European countries
   - Standard 2: p_s = 1013 [mbar], T_s = 20 [°C] (293.15 [K])
     USA
   - Standard 3: p_s = 1013 [mbar], T_s = 25 [°C] (298.15 [K])
     Mexico

3. Mostly the measured emission concentrations shall be converted to a reference oxygen value [vol-%] (dry). This value varies from country to country and lies between 7 and 11 [vol-%].
   Various countries have no reference oxygen value. In theses cases the governments state that the emission concentrations refer to the volume of exhaust gas, which is diluted no more than technology and operating conditions require.

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1 Standard 1 = so-called "normal conditions"

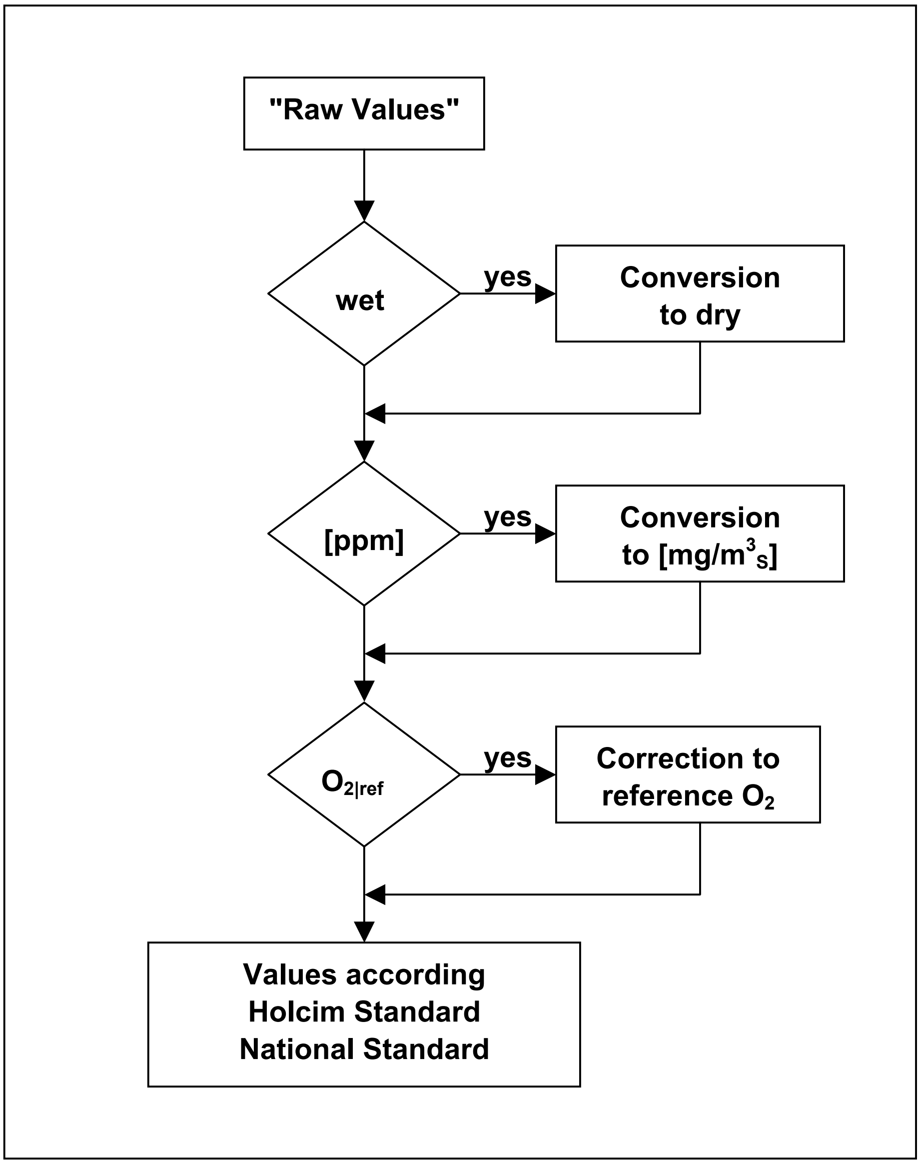
4. Generally nitrogen oxides NO_x (nitrogen monoxide NO and nitrogen dioxide NO_2) shall be expressed as nitrogen dioxide (NO_2).

5. Volatile Organic Compounds (VOC) shall be expressed as carbon [mgC/m^3_S]. In different countries (e.g. some US states) this emission shall be expressed as volume ratio ([ppm]) equivalent to methane or propane.

3. CONVERSION

3.1 Gaseous Compounds

3.1.1 Conversion Proceeding



3.1.2 "Raw Values"

The three continuous measuring devices, recommended by Holcim, as well as most of the other measuring devices indicate the "Raw Values" as follows:

Compound	**Possible Definitions**			
SO_2				
NO				2)
NO_2				
CO	[ppm]	[mg/m^3_S] 1)	dry or wet	
CO_2				
HCl				
NH_3				
H_2O	[%]		wet	
O_2	[%]		dry or wet	

1) m^3 defined at standard conditions (p_S, T_S)
Examples:
- Standard 1: p_S = 1013 [mbar], T_S = 0 [°C] (or 273.15 [K])
- Standard 2: p_S = 1013 [mbar], T_S = 20 [°C] (or 293.15 [K])
- Standard 3: p_S = 1013 [mbar], T_S = 25 [°C] (or 298.15 [K])

2) Generally the instruments indicate this component as [ppm] or as [mg] nitrogen monoxide (NO) per standard m^3 and not converted to nitrogen dioxide (NO_2).

Special Case: Volatile Organic Compounds (VOC)

- Flame ionization detectors (FID), measuring volatile organic compounds (VOC), are mostly calibrated with propane (C_3H_8); seldom with methane (CH_4).
- The flame ionization detector measures the emitted organic carbon at a temperature above 150 [°C]. Therefore the concentration is measured and also indicated in the wet gas state.
- It is possible that the signal of the flame ionization detector is directly integrated in the control unit of the continuous measuring device for gaseous compounds. There the values of the flame ionization detector can be converted to the dry gas state and indicated as "Raw Values".
- Possible indications are:
  - [ppm] equivalent to methane (CH_4)
  - [ppm] equivalent to propane (C_3H_8)
  - [mgC/m^3_S]

3.1.3 Conversion to Dry Gas Condition

First all values must be converted to dry gas state.

Remark: It is possible that the instrument(s) indicates some values in dry state and the others in wet.
Example: All components are converted internally to dry standard, except the oxygen measurement.

$$c_{dry}\left[\text{ppm or } \frac{mg}{m_S^3}\right] = c_{wet}\left[\text{ppm or } \frac{mg}{m_S^3}\right] \cdot \frac{1}{\left(1 - \frac{H_2O\,[\%]}{100}\right)}$$

3.1.4 Conversion from [ppm] to [mg/m^3_S]

If the "Raw Values" are indicated in [ppm] than the values must be converted as follows:

$$c_{dry,s}\left[\frac{mg}{m_S^3}\right] = f \cdot c_{dry}\,[\text{ppm}] \qquad f = \frac{M\left[\frac{kg}{kmol}\right]}{0.08206 \cdot T_S\,[K]}$$

Factor for Different Countries

Standard 1: $T_{S1} = 273.15\,[K] \rightarrow f = \frac{M\left[\frac{kg}{kmol}\right]}{22.41}$

Standard 2: $T_{S2} = 293.15\,[K] \rightarrow f = \frac{M\left[\frac{kg}{kmol}\right]}{24.06}$

Standard 3: $T_{S3} = 298.15\,[K] \rightarrow f = \frac{M\left[\frac{kg}{kmol}\right]}{24.47}$

Factors for Different Compounds

The factors for different compounds are indicated in the following table.

Component	M [kg/kmol]	Standard 1	Standard 2	Standard 3	
SO_2	64.07	2.86	2.66	2.62	
NO	30.01	1.34	1.25	1.23	
NO as NO_2	46.01	2.05	1.91	1.88	1)
NO_2	46.01	2.05	1.91	1.88	
CO	28.01	1.25	1.16	1.15	
HCl	35.46	1.58	1.47	1.45	
HF	20.01	0.89	0.83	0.82	
NH_3	17.03	0.76	0.71	0.70	
VOC	12.01	0.54	0.50	0.49	2)
	36.03	1.61	1.50	1.47	2)

1) Nitrogen monoxide NO expressed as nitrogen dioxide (NO_2).
2) Volatile organic compounds are indicated as emitted organic carbon per volume of the exhaust gas in milligrams per cubic meter [mgC/m^3]. Therefore the molar mass is the following:
   - Methane (CH_4) calibration: $M = 1 \cdot 12.01 \left[\frac{kg}{kmol}\right]$
   - Propane (C_3H_8) calibration: $M = 3 \cdot 12.01 \left[\frac{kg}{kmol}\right] = 36.03 \left[\frac{kg}{kmol}\right]$

3.1.5 Conversion to Reference Oxygen Content

$$c_{dry,s,ref}\left[\frac{mg}{m_S^3}\right] = c_{dry,s}\left[\frac{mg}{m_S^3}\right] \cdot \left(\frac{21 - O_{2,ref}}{21 - O_2}\right)$$

Holcim Standard [2]

$$c_{Holcim}\left[\frac{mg}{m_N^3}\right] = c_{dry,s}\left[\frac{mg}{m_N^3}\right] \cdot \left(\frac{21 - 10\,[\%]}{21 - O_2}\right) = c_{dry,s}\left[\frac{mg}{m_N^3}\right] \cdot \left(\frac{11}{21 - O_2}\right)$$

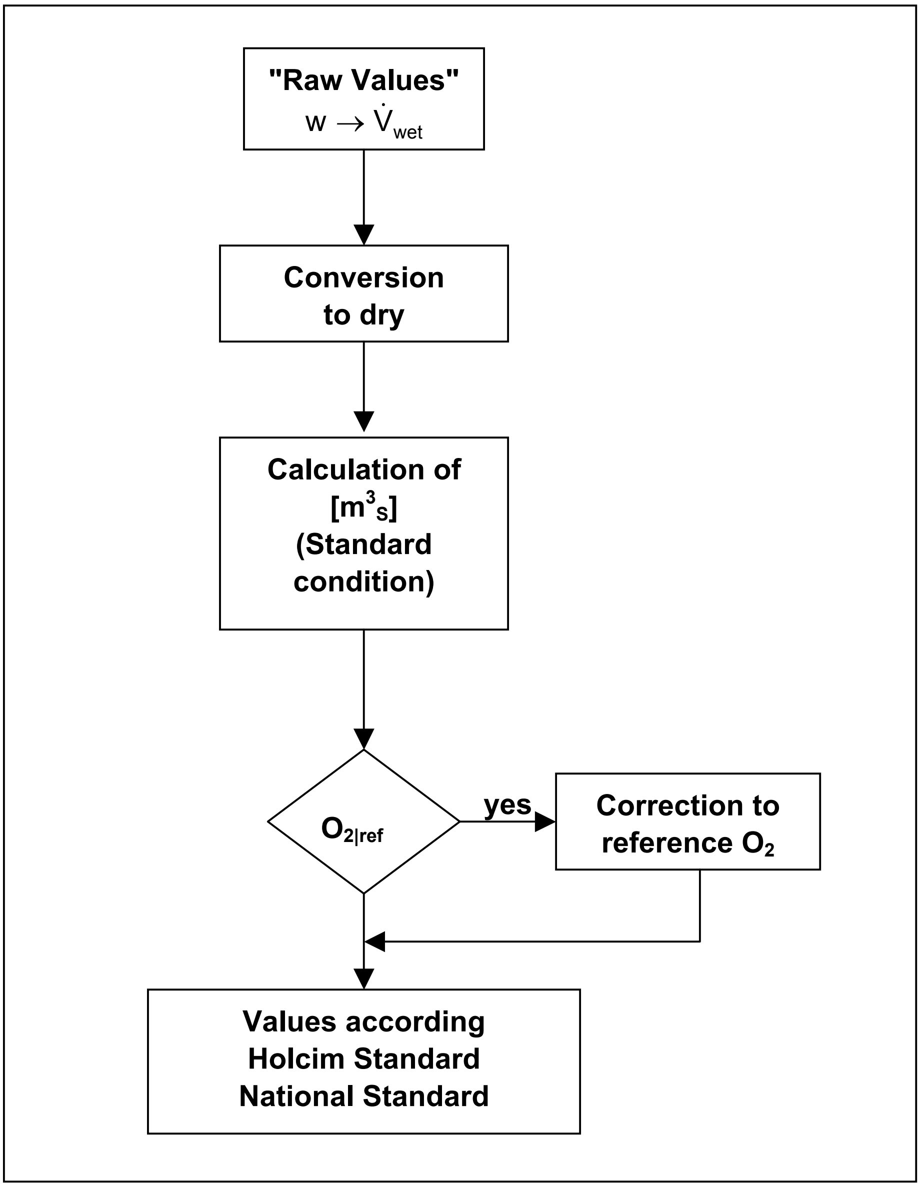
2 Standard 1: [m^3_S] = [m^3_N] → normal-m^3

3.2 Volume Stream

A flow meter measures the velocity w in the chimney at actual chimney conditions. The volume stream is product of the velocity and the cross section area.

$$\dot{V}_{wet} = A \cdot w$$

3.2.1 Conversion Proceeding



3.2.2 Conversion to Dry Gas Condition

$$\dot{V}_{dry}\left[\frac{m^3}{s}\right]=\dot{V}_{wet}\left[\frac{m^3}{s}\right]\cdot\left(1-\frac{H_2O\,[\%]}{100}\right)$$

3.2.3 Calculation of Volume Stream at Standard Conditions

$$\dot{V}_{dry,s}\left[\frac{m_s^3}{s}\right]=\dot{V}_{dry}\left[\frac{m^3}{s}\right]\cdot\left(\frac{p_{Stack}}{p_s}\right)\cdot\left(\frac{T_s}{T_{Stack}}\right)$$

Holcim Standard [3]

$$\dot{V}_{dry,N}\left[\frac{m_N^3}{s}\right]=\dot{V}_{dry}\left[\frac{m^3}{s}\right]\cdot\left(\frac{p_{Stack}\,[mbar]}{1013\,[mbar]}\right)\cdot\left(\frac{273.15\,[K]}{T_{Stack}\,[K]}\right)$$

Stack pressure

Very often in the stack only the temperature is measured and not the pressure. In first approximation the stack pressure is equal to the barometric pressure.

Approximate formula: $p_S\,[mbar]=1013-0.109\cdot h\,[m]$

3.2.4 Conversion to Reference Oxygen Content

$$\dot{V}_{dry,s,ref}=\dot{V}_{dry,s}\cdot\left(\frac{21-O_2}{21-O_{2,ref}}\right)$$

$$\dot{V}_{dry,s}\left[\frac{m_s^3}{s}\right]=\dot{V}_{dry}\left[\frac{m^3}{s}\right]\cdot\left(\frac{p_{Stack}}{p_s}\right)\cdot\left(\frac{T_s}{T_{Stack}}\right)\cdot\left(\frac{21-O_2}{21-O_{2,ref}}\right)$$

Holcim Standard [3]

$$\dot{V}_{dry,N,ref}=\dot{V}_{dry,N}\cdot\left(\frac{21-O_2}{11}\right)$$

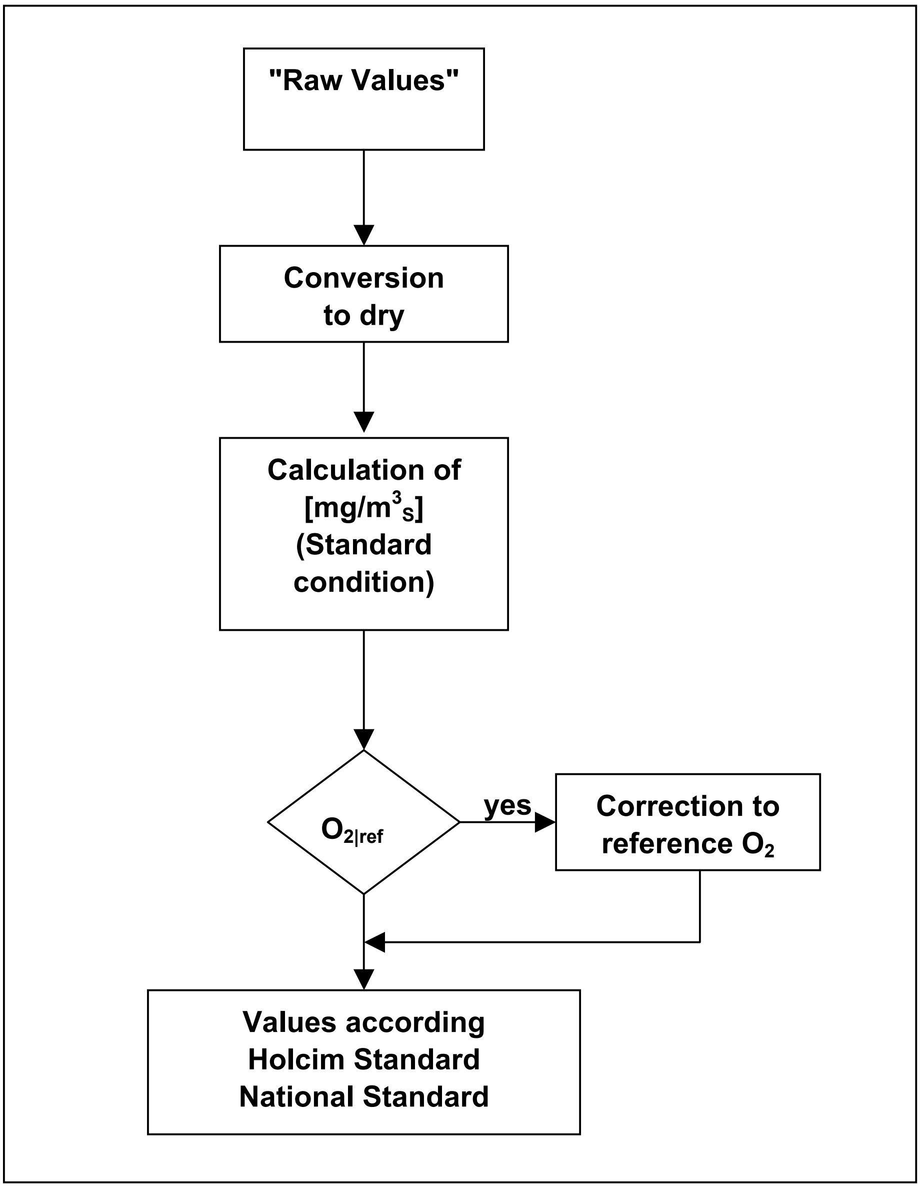
$$\dot{V}_{dry,N}\left[\frac{m_N^3}{s}\right]=\dot{V}_{dry}\left[\frac{m^3}{s}\right]\cdot\left(\frac{p_{Stack}\,[mbar]}{1013\,[mbar]}\right)\cdot\left(\frac{273.15\,[K]}{T_{Stack}\,[K]}\right)\cdot\left(\frac{21-O_2}{11}\right)$$

3 Standard 1: $[m^3_S] = [m^3_N]$ → normal-m^3

3.3 Dust Measurement

Dust monitors measure the concentration referred to the exhaust gas at stack conditions (temperature, pressure, wet).

3.3.1 Conversion Proceeding



3.3.2 Conversion to Dry Gas Condition

$$c_{dry}\left[\frac{mg}{m^3}\right] = c_{wet}\left[\frac{mg}{m^3}\right]\cdot\left(\frac{1}{1-\frac{H_2O\,[\%]}{100}}\right)$$

3.3.3 Calculation of Volume Stream at Standard Conditions

$$c_{dry,s}\left[\frac{mg}{m_S^3}\right] = c_{dry}\left[\frac{mg}{m_S^3}\right]\cdot\left(\frac{p_S}{p_{Stack}}\right)\cdot\left(\frac{T_{stack}}{T_S}\right)$$

Holcim Standard [4]

$$c_{dry,N}\left[\frac{mg}{m_N^3}\right] = c_{dry}\left[\frac{mg}{m_N^3}\right]\cdot\left(\frac{1013\,[mbar]}{p_{Stack}\,[mbar]}\right)\cdot\left(\frac{T_{Stack}\,[K]}{273.15\,[K]}\right)$$

Stack pressure

Approximate formula: $p_S\,[mbar] = 1013 - 0.109\cdot h\,[m]$

3.3.4 Conversion to Reference Oxygen Content

$$c_{dry,s,ref}\left[\frac{mg}{m_S^3}\right] = c_{dry,s}\left[\frac{mg}{m_S^3}\right]\cdot\left(\frac{21-O_{2,ref}}{21-O_2}\right)$$

Holcim Standard

$$c_{Holcim}\left[\frac{mg}{m_N^3}\right] = c_{dry,s}\left[\frac{mg}{m_N^3}\right]\cdot\left(\frac{21-10\,[\%]}{21-O_2}\right) = c_{dry,N}\left[\frac{mg}{m_N^3}\right]\cdot\left(\frac{11}{21-O_2}\right)$$

4 Standard 1: $[m^3_S] = [m^3_N]$ → normal-m^3

4. EMITTED MASS FLOW

General:

$$\dot{m}\left[\frac{kg}{s}\right] = \frac{1}{1000000}\cdot\left[\frac{mg}{kg}\right]\cdot c\left[\frac{mg}{m^3}\right]\cdot \dot{V}\left[\frac{m^3}{s}\right]$$

Rule: The concentration and the volume stream must be defined at the gas conditions (wet or dry, standard, oxygen)

- $\dot{m}\left[\frac{kg}{s}\right] = \frac{1}{1000000}\cdot\left[\frac{mg}{kg}\right]\cdot c_{wet}\left[\frac{mg}{m^3}\right]\cdot \dot{V}_{wet}\left[\frac{m^3}{s}\right]$
- $\dot{m}\left[\frac{kg}{s}\right] = \frac{1}{1000000}\cdot\left[\frac{mg}{kg}\right]\cdot c_{dry}\left[\frac{mg}{m^3}\right]\cdot \dot{V}_{dry}\left[\frac{m^3}{s}\right]$
- $\dot{m}\left[\frac{kg}{s}\right] = \frac{1}{1000000}\cdot\left[\frac{mg}{kg}\right]\cdot c_{dry,S}\left[\frac{mg}{m_S^3}\right]\cdot \dot{V}_{dry,S}\left[\frac{m_S^3}{s}\right]$
- $\dot{m}\left[\frac{kg}{s}\right] = \frac{1}{1000000}\cdot\left[\frac{mg}{kg}\right]\cdot c_{dry,S,ref}\left[\frac{mg}{m_S^3}\right]\cdot \dot{V}_{dry,S,ref}\left[\frac{m_S^3}{s}\right]$

5. REALATON BETWEEN DIFFERENT STANDARDS

Some Holcim Cement must report the kiln emissions to Holcim and to the local authorities. In various countries the Holcim standard is different from the National standard.

Example:

- Holcim standard (S_1): p_{S1} = 1013 [mbar], T_{S1} = 273.15 [K] (0 [°C]).
- National standard (S_2): p_{s2} = 1013 [mbar], T_{S2} = 293.15 [K] (20 [°C]).

The relation between the values of two different standards (n and m) is:

$$c_n\left[\frac{mg}{m^3_{Sn}}\right]=\left(\frac{T_{Sm}}{T_{Sn}}\right)\cdot\left(\frac{p_{Sn}}{p_{Sm}}\right)\cdot c_m\left[\frac{mg}{m^3_{Sm}}\right]\quad\rightarrow\quad c_n\left[\frac{mg}{m^3_{Sn}}\right]=\left(\frac{T_{Sm}}{T_{Sn}}\right)\cdot c_m\left[\frac{mg}{m^3_{Sm}}\right]$$

$$\dot{V}_n\left[\frac{m^3_{Sn}}{s}\right]=\left(\frac{T_{Sn}}{T_{Sm}}\right)\cdot\left(\frac{p_{Sm}}{p_{Sn}}\right)\cdot\dot{V}_m\left[\frac{m^3_{Sm}}{s}\right]\quad\rightarrow\quad\dot{V}_n\left[\frac{m^3_{Sn}}{s}\right]=\left(\frac{T_{Sn}}{T_{Sm}}\right)\cdot\dot{V}_m\left[\frac{m^3_{Sm}}{s}\right]$$

Example:

- $c_1\left[\frac{mg}{m^3_{S1}}\right]=\left(\frac{T_{S2}}{T_{S1}}\right)\cdot c_2\left[\frac{mg}{m^3_{S2}}\right]=\left(\frac{293.15}{273.15}\right)\cdot c_2\left[\frac{mg}{m^3_{S2}}\right]=1.073\cdot c_2\left[\frac{mg}{m^3_{S2}}\right]$
- $\dot{V}_1\left[\frac{m^3_{S1}}{s}\right]=\left(\frac{T_{S1}}{T_{S2}}\right)\cdot\dot{V}_2\left[\frac{m^3_{S2}}{s}\right]=\left(\frac{273.15}{293.15}\right)\cdot\dot{V}_2\left[\frac{m^3_{S2}}{s}\right]=0.932\cdot\dot{V}_2\left[\frac{m^3_{S2}}{s}\right]$