Technical Note

Estimation of pollutant concentration from stack parameters

This document provides guidance on estimation of pollutant concentrations based on mass emission rates and designed stack parameters (Departmental internal use only).

1   Introduction

This technical note can be used for reviewing stack monitoring reports, setting air emission limits, or assessing compliance. It provides guidance for on how to estimate pollutant concentrations based on mass emission rates and designed stack parameters. Stack emissions in term of concentration and/or mass emissions are considered for compliance purpose, assessing licence applications for new development, or amending the existing licence conditions. Sometimes this information is not provided in the same format as required by the Department. For example, the data may be provided in terms of mass emissions. However, the limits are specified in terms of concentration or vice versa. To assess compliance, the assessing officer needs to calculate the emissions data as required by the licence. The Department can also use emissions monitoring data to assess pollution control device efficiency and to determine impacts on the receiving environment.

The officers may be required to estimate the pollutant concentration for the following scenarios:

Assessment officer reviewing potential impacts from new development proposals:
The applicant is required to demonstrate compliance not only with the best practice emission standards but also with the ambient air quality standards (e.g. EPP (Air) objectives). The applicant estimated the mass emission rates based on the manufacture specifications and designed stack gas volume flow rate which is a function of exit velocity, stack diameter, stack temperature and moisture content. Please note dispersion modelling require stack parameters such as pollutant mass emission rate, exit velocity, stack height, and stack temperature. The assessment officer would like to check that the mass emission rate entered in the model represents the best practice concentration limit and the designed stack parameters.

Compliance officer reviewing lab report to determine compliance with EA condition:
Stack emissions monitoring is an important part of air pollution management system. Monitoring demonstrates compliance with the air emission limits specified in the Environmental Authority (EA). The compliance officer may need to review a lab report submitted by the client. The EA condition has both concentration and mass emission limits. The compliance officer can check that the emission rate is calculated accurately using the stack parameters such as the measured exit velocity, stack diameter, stack temperature, moisture content and in some situation oxygen content to demonstrate compliance with both concentration and mass emission limits.

2   Estimation of pollutant concentrations

The following procedure is used for the estimation of stack's pollutant concentrations:

Step 1: Calculate actual volume flow rate (**Q**) based on the exit velocity of the flue gas passing through the stack using the formula:

$$Q = π \times (D ÷ 2)^2 \times V$$

Where,

Q – is the actual volume flow rate (m^3/sec),

D - is the stack diameter (m), and

V – is the gas exit velocity (m/sec).

Step 2: Calculate normal volume flow rate by applying temperature and pressure correction.

Normal volume flow rate after temperature correction (Q_T):

$$Q_T = Q \times [273 ÷ (273+T)]$$

Where,

Q_T - is normal volume flow rate after temperature correction (Nm^3/sec (wet)), and

T – is the stack temperature (^{o}C).

Normal volume flow rate after pressure correction (Q_P):

$$Q_P = Q_T \times (P ÷ 101.3)$$

Where,

Q_P – is normal volume flow rate after pressure correction (Nm^3/sec (wet)), and

P – is the stack gas pressure (kPa).

Step 3: Calculate normal volume flow rate on dry basis by applying moisture correction.

Normal volume flow rate after moisture correction (Q_D):

$$Q_D = Q_P \times [1 − (M ÷ 100)]$$

Where,

Q_D – is the normal volume flow rate at standard temperature and pressure on dry basis (Nm^3/sec (dry)), and

M – is the moisture content of flue gas (%).

The above normal gas volume flow rate (Q_D) gives the pollutant volume of gas sampled at the test conditions (i.e. temperature, pressure, and moisture content). The modelled/measured mass emission rate can be divided by the normal volume flow rate (Q_D) to calculate the concentration value. For the fuel burning equipment, since the concentration limit is specified at an oxygen reference level, the normal volume flow rate must be calculated at the same oxygen reference level. For example, in the case of gas-fired boiler, nitrogen dioxide concentration is presented in terms of 3% oxygen reference level. In this situation, the volume flow rate must be calculated at the same oxygen reference level as specified in the concentration limit (see Step 4 below).

Step 4: For fuel burning equipment, calculate normal volume flow rate at oxygen reference level as specified in the concentration limit.

Normal volume flow rate (Q_{O2}) at oxygen reference level (O_2):

$$Q_{O2} = Q_D \times [(20.9 − O_1) ÷ (20.9 − O_2)]$$

Where,

Q_{O2} – is the normal volume flow rate at oxygen reference level (Nm^3/sec (dry)),

O_1 – is the measured oxygen content in the flue gas (%), and

O_2 – is the required oxygen reference level (%).

It is common for the Department to regulate emissions of fuel burning equipment to certain referenced conditions. The best practice source emission standards for the fuel burning equipment are also specified to

certain oxygen reference level. Please note different type of fuel burning equipment use different reference levels. For example, coal fired boiler emissions referenced to 7% O_2, gas/liquid fired boiler emissions referenced to 3% O_2 while the gas turbine emissions referenced to 15% O_2. For instance, the standard states that NOx must be limited to 350 mg/Nm^3 (dry) at 3% O_2. But the stack measurement may be greater than 3% O_2 or the data from a manufacture might show the O_2 level after combustion is 5.5% O_2. Then a conversation of normal volume flow rate to the reference level must be applied.

Step 5: **Estimation of pollutant concentration**
Pollutant concentration at standard temperature and pressure on dry basis (**C**) can be calculated by dividing the pollutant mass emission rate (**M**) with gas volume flow rate (**Q$_D$** for non-fuel burning equipment, or **Q$_{O2}$** for fuel burning equipment), as follows:

$$C = M \div Q_D \qquad \text{or} \qquad C = M \div Q_{O2}$$

Where,

> **C** – is the pollutant concentration at standard temperature and pressure on dry basis (mg/Nm^3 (dry)),
>
> **M** – is the mass of the pollutant in the flue gas (mg/sec), and
>
> **Q$_D$** and **Q$_{O2}$** – are as defined in Step 3 and Step 4, respectively.

For the calculation of pollutant concentration, it is important to note how the concentration limit is specified in the source emission standard or EA. For example, if it is specified at standard temperature and pressure without any oxygen reference level then the gas volume flow rate must be also based on standard temperature and pressure without any oxygen reference level. For the fuel burning equipment oxygen reference level is always applied. However, in some situation such as a drum dryer where the hot flue gas inside the drum is exposed to ambient air, oxygen reference level cannot be applied to stack concentration limit.

3   Calculation tool and worked example

A Microsoft excel calculation tool (file name: *Estimation of concentration calculator)* has been developed to assist with calculations.

The worked examples for the calculation of stack concentrations using the calculator is provided as the default values in the excel calculator. The default calculator values are based on the following scenarios:

Non-fuel burning source:
The stack parameters of a non-fuel burning equipment assumed for this exercise are as follows:

- Stack diameter = 0.5 m
- Stack exit velocity = 10 m/sec
- Stack temperature = 40°C
- Stack moisture content = 8%
- Stack gas pressure assumed same as atmospheric pressure.
- Since emission source is not a fuel burning equipment, oxygen correction is not applicable.
- The pollutant mass emission rates modelled in the impact assessment based on the manufacture specification are:
  - ➢ TSP = 4.5 g/min
  - ➢ Total heavy metals = 0.03 g/min
  - ➢ Total VOCs = 1.5 g/min

Pollutants concentration values are calculated as:

- TSP = 47.602 mg/Nm^3 (dry)
- Total heavy metals = 0.317 mg/Nm^3 (dry)
- Total VOCs = 15.867 mg/Nm^3 (dry)

The above concentration values are below the best practice source emission standard. This indicates that mass emission rates which are based on the manufacture specifications and used in the dispersion modelling for impact assessment comply with the best practice source emission standard.

Fuel burning source:
The stack parameters of a gas fired boiler assumed for this exercise are as follows:

- Stack diameter = 0.5 m
- Stack exit velocity = 10 m/sec
- Stack temperature = 140°C
- Stack moisture content = 8%
- Oxygen concentration = 5.5%
- Stack gas pressure assumed same as atmospheric pressure.
- Since emission source is a fuel burning equipment, oxygen correction is applicable.
- The pollutant mass emission rates based on manufacturer specification:
  - ➢ NOx as NO$_2$ = 20 g/min
  - ➢ CO = 7.5 g/min
  - ➢ Total VOCs = 1.5 g/min

Pollutants concentration values are calculated as:

- NOx as NO$_2$ = 324.474 mg/Nm^3 (dry) at 3% O$_2$
- CO = 121.678 mg/Nm^3 (dry) at 3% O$_2$
- Total VOCs = 24.336 mg/Nm^3 (dry) at 3% O$_2$

The above concentration values are below the best practice source emission standard. This indicates that mass emission rates which are based on the manufacture specifications and used in the dispersion modelling for impact assessment comply with the best practice source emission standard.

Officers can enter their own stack parameters and mass emission rate in the spreadsheet to calculate the concentration values for their particular situation.

4   Definitions and abbreviations

Nm^3 Normal cubic metre means the volume of dry gaseous contaminant which occupies 1 cubic metre at a standard temperature of zero degrees Celsius (273 K) and 1 atmosphere pressure (101.3 kilopascals).

^{o}C   Degrees Celsius

m   Meters

m^3 Gas volume in cubic metres

mg   Milligrams

sec   Second

min   minute (equal to 60 sec)

π   Pi - constant of 3.14159…