Introductory Guide to Mathematics for Occupational Hygiene 2:

Workplace Air Monitoring Calculations for Exposures and Results

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Version 1.1

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This is the second in a series of introductory guides to the maths that underpins occupational hygiene calculations applied both in daily practice and in examinations.

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Disclaimer

Feedback

We welcome feedback on this guide.
Comments should be sent to BOHS at membership@bohs.org.

Version History

Version	Release date	Comments and amendments
Version 1	22 July 2026	Original version
Version 1.1	28 July 2026	Several numerical amendments in Sections 4 and 5.

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1. Introduction

One of the most basic competencies required by any occupational hygienist is the ability to provide data on the levels of airborne chemicals in the workplace air.

Measurement techniques result in the generation of the key analytical data required to calculate the corresponding exposure data. Basic calculations are often required to work out the airborne concentrations from the raw analytical data and correct into units comparable to the corresponding Occupational Exposure Limit (OEL).

The ability to perform these basic calculations is an absolute requirement for all levels of any occupational hygiene practitioner.

This guide provides examples of many of the key calculations which occupational hygienists are likely to require as well as providing an overview of the principles of Uncertainly of Measurement.

2. Air Monitoring Calculations

2.1 Useful formulae

Two essential formulae that all occupational hygienists should know:

Volume of air = Flowrate x Time

Concentration = Weight / Volume of air

These formulae may be swapped around depending on the component being calculated and terms may be interchanged.

For example, ***Volume of air = Weight / Concentration***

For example, **Weight** may be the analytical result or the Limit of Detection (LOD); **Concentration** may be the OEL in mg/m^3.

2.2 Check the units

There are a variety of different units which may be referred to, and it is essential that you are able to understand these and know how they all relate to one another. One of the key steps for any person performing calculations is to first check the base units of measurement:

Flowrates – usually recorded in litres per minute (l/min) or millilitres per minute (ml/min)**.**

Volumes – usually recorded in millilitres (ml), litres (l) or cubic metres (m^3).

Analysis results (Weights) – usually recorded and reported in milligrams (mg) or micrograms (µg).

2.3 Basic conversions

Volumes:

1 m^3 = 1000 litres = 1000 000 ml

1 litre = 0.001 m^3

To convert litres to m^3 you divide by 1000

To convert m^3 to litres you multiply by 1000

Weights:

1 mg = 1000 µg

1 ug = 0.001 mg

To convert µg to mg you divide by 1000

To convert mg to µg you multiply by 1000

Concentration:

µg /l is equivalent to mg/m^3

2.3.1 Questions and Solutions

Question

Convert 728 litres to m^3.

Solution

To convert litres to m^3, divide by 1000:

m^3 = 728/1000 = 0.728

Question

Convert 275 µg to mg.

Solution

To convert µg to mg, divide by 1000:

mg = 275/1000 = **0.275**

3. Sample Flowrates

Following on from the volume conversions shown above, **1 l/min = 1000 ml/min.**

As most OELs are reported in units of mg/m^3 or ppm it is necessary to convert the analytical data reported in µg or mg to either mg/m^3 or ppm.

3.1 Calculating air volumes from sample flowrates and sampling times

Using the equation:

Volume = Flowrate x Time

Whilst the units for **Time** are always Minutes (mins), the units for **Volume** may be in either Litres or ml and **Flowrate** may be either in l/min or ml/min.

For example:

For high flow sampling, flowrates are typically between 1-3 litres/min.

For low flow sampling, flowrates are < 1 litre/min and as such are referred to in ml/min. Typical flowrates are normally between 20 to 200 ml/min.

Most laboratories will ask for sample volumes in either Litres or ml.

3.1.1 Questions and Solutions

<u>Question</u>

A sample is taken for 6 hours and 53 minutes at 2.10 l/min. What is the air volume in litres?

<u>Solution</u>

The duration in mins = (6x60) + 53 mins = 360+53 = 413

Volume (l) = 2.1 l/min x 413 mins = **867.3 l**

4. Sample Results

4.1 To convert analytical results to a concentration in mg/m^3

Most results for high flow sampling (dusts and metals) are reported in milligrams (mg) or micrograms (µg) and the corresponding OELs are reported in mg/m^3.

You therefore need to correct your analytical result into mg/m^3 for direct comparison to the OEL.

Use the equation:

Concentration = Weight / Volume

and remember that **µg/l** is equivalent to **mg/m^3**

In this instance, **Weight** is the analytical result reported in µg or mg and **Volume** is the amount of air drawn through the sample, normally in litres but for the purpose of the calculation, converted into **m^3**.

Concentration in mg/m^3 = Analytical result reported in µg / Volume of air in litres

Or

Concentration in mg/m^3 = Analytical result reported in mg / Volume of air in m^3

4.1.1 Questions and Solutions

Question

Using the sample above with air volume of 867.3 l, the analytical result is 2.09 mg.

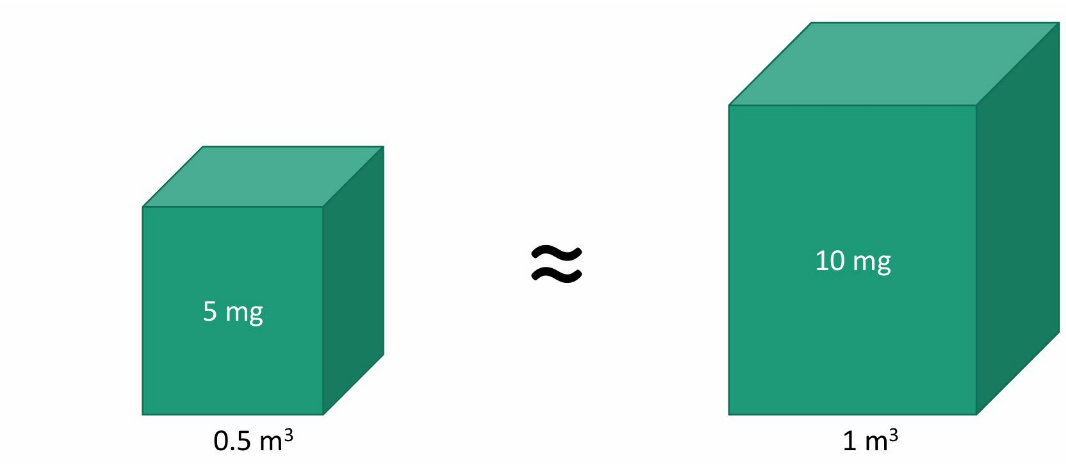
What is the concentration in mg/m^3?

Solution

The volume = 867.3 l = **0.8673 m^3**

Concentration = 2.09 / 0.8673 = **2.4 mg/m^3**

Equivalent mass per volume:



5 mg sampled in an air volume of 0.5 m^3 is equivalent to 10 mg in an air volume of 1 m^3.

4.2 To convert analytical results to a concentration in ppm

Most results for low flow sampling (hydrocarbons and chemicals) are reported in micrograms (µg) and the corresponding OELs are reported in parts per million (ppm).

Concentration (mg/m^3) = result (µg) / volume (ml) x 1000

You then need to convert the concentration in mg/m^3 into ppm.

To convert between ppm and mg/m^3:

ppm = mg/m^3 x 24.05526 / MW

mg/m^3 = ppm x MW / 24.05526

where:

- MW is the molecular weight of the substance being monitored;
- 24.05526 l.mol-1 is the molar volume of an ideal gas at 20ºC and 1 atmosphere pressure (760 mm mercury, 101325 Pa, 1.01325 bar) (HSE EH40, 2005).

To make calculations a little easier, 24.06 will be used throughout this document as the approximation to 4 significant figures of 24.05526, and 24.06 is generally used in practice.

Alternatively, you can refer to the NIOSH Pocket Guide to Chemical Hazards (NIOSH, 2020) to find conversion factors for each listed chemical. The NIOSH calculation works on an ideal gas at 25ºC, so the molar volume works out as 24.45 which leads to a small difference in the calculation outcome.

4.2.1 Questions and Solutions

<u>Question</u>

The analytical result for sample containing ammonia is 5.2 mg/m^3. The MW of ammonia is 17. What is the concentration of ammonia in ppm?

<u>Solution</u>

ppm = mg/m^3 x 24.06 / MW

Concentration in ppm = 5.2 x 24.06 / 17 = **7.36 ppm**

Using the NIOSH Pocket Guide to Chemical Hazards (NIOSH, 2020), the conversion factor for ammonia is 1 ppm = 0.70 mg/ m^3.

Concentration in ppm = 5.2 / 0.7 = **7.43 ppm**

4.3 Differences between Limit of Detection (LOD) & Limit of Quantification (LOQ)

In some cases the laboratory may report results as <LOD or <LOQ.

LOD is lowest quantity of an analyte that can be reliably detected from the specific analytical method. The **lowest concentration** of a substance (e.g., dust, metal, or chemical) that the analytical method can **reliably detect** as present — but **not necessarily quantify accurately**.

MDHS 14/4 (HSE MDHS14/4, 2014) states that in practice it is convenient for the LOD of the gravimetric analysis to be determined as three (3) times the standard deviation of the weight changes of the blank samples.

LOQ = The **lowest concentration** at which the method can **reliably detect** and quantify the substance with **accuracy and precision.**

5. Calculating Required Sampling Volumes to Achieve a Meaningful Limit of Detection

It is of no use to receive results from a laboratory for which the LOD only provides results which are greater than the OEL or required action level (e.g. 50% of the OEL). In such cases, you need to understand how to meet the LOD defined by the analytical method and/or the laboratory. This may be done by calculating either the amount of air to draw through a sample or the minimum required sampling time so the sample size is sufficient to meet the LOD.

Step 1

If the OEL of the substance being monitored is in ppm, convert this into mg/m^3.

Use the formula:

$mg/m^3 = ppm \times MW / 24.06$

Alternatively, use the NIOSH Pocket Guide to Chemical Hazards (NIOSH, 2020), conversion factor for the substance.

Step 2

Calculate the volume of air required to capture a representative amount of air.

For this step, you need the OEL in mg/m^3 and the LOD in µg.

Volume Required in litres = LOD in µg / OEL in mg/m^3

If you are using an action level (such as 50% of the OEL), substitute the 50% OEL value into the equation.

Step 3

Calculate the required flowrate.

For this step, you need to know the minimum duration for which you will be collecting your sample. The sample duration may be governed by the length of the activity being monitored.

Using the formula ***Volume = Flowrate x time***, swap this round so that ***Flowrate = Volume / time***

Flowrate = Volume / sampling time

Check that the flowrate is within the flowrate defined in the approved monitoring method.

5.1 Questions and Solutions

Question

You are monitoring a task which takes 15 minutes and involves exposure to mercury. Assuming you want to confirm whether exposure is below the Excursion Limit, what is the minimum sampling time required to meet the LOD, using a maximum flowrate of 0.25 l/min?

MW of mercury = 200.59

LOD = 0.05 ug

WEL 8-hr TWA = 0.02 mg/m^3

Excursion Limit (3 x 8hr TWA) = 0.06 mg/m^3

Answer

Volume required = LOD / OEL

Volume required = (0.05 ug x 10^{-3}) / 0.06 mg/m^3

Volume required = 0.00083 m^3 = 0.83 l

Volume = Flowrate x Time

Time = Volume / Flowrate

Minimum sampling time = 0.83 / 0.25 = **3.32 minutes**

6. The Uncertainty of Measurement

Every measurement is subject to some uncertainty. A measurement result is only complete if it is accompanied by a statement of the uncertainty in the measurement (Bell, 2001).

When undertaking any sampling there will be uncertainty at each stage of the sample collection, preparation/extraction and analysis.

Uncertainty of Measurement – Example – Aerosol Monitoring (MDHS 14/4) (HSE MDHS14/4, 2014)

In the instance of gravimetric sampling to MDHS 14/4, the following standard uncertainties would apply:

- the sampling equipment used to capture a defined volume of air;
- the capture efficiency of the sampling head/media;
- any losses of samples experienced during the post sample handling, transportation or storage;
- the analytical method used in terms of laboratory sample preparation and analysis.

	Expanded Uncertainty for a Measuring Procedure BS EN 13205-1:2014 Annex A	Source of Data	Set or Variable	Standard Uncertainty
A	***Sampling Efficiency*** Inhalable (IOM) head	**PD CEN/TR 15230:2005** BS EN 13205-1:2014 Clause 5.2	S	0.125
B	***Sampled Volume*** Flow rate measurement Pump flow stability Sampling time	**BS EN 482:2021 B.2** Flow meter test cert Pump conformity cert Clock timer cert	V V V	X X X
C	***Transport Losses – Filter*** 10-50% of WEL IOM cassette	**BS EN 13205-1:2014 Clause 5.2** Result dependent Validation data	V S	0.15 0.0001
D	***Analytical Method – MDHS 14/4*** 25mm IOM cassette	**BS ISO 15767:2009** Laboratory supplied	S	X

Uncertainty of measurement can be determined by:

1) Calculating the combined standard uncertainty using each individual standard uncertainty:

   Combined Standard Uncertainty (u_c) = $\sqrt{(A^2 + B^2 + C^2 + D^2)}$

2) Calculating the Expanded Uncertainty (k=2) which gives approximately 95% confidence:

   Expanded Uncertainty (U) = ku_c

3) The Expanded Uncertainty is given as a % so this needs to be multiplied against each calculated air sample result:

   Uncertainty of sample concentration = U/100 x Result Y

7. References

Bell S (2001) Good Practice Guide No. 11: A Beginner's Guide to Uncertainty of Measurement. Issue 2 with amendments. National Physical Laboratory. ISSN 1368-6550. https://www.npl.co.uk/resources/gpgs/beginners-guide-measurement-uncertainty-gpg11

BS EN 13205-1:2014 Workplace exposure. Assessment of sampler performance for measurement of airborne particle concentrations – General requirements. BSI. ISBN 978 0 580 78058 5.

BS EN 482:2021 Workplace exposure. Procedures for the determination of the concentration of chemical agents. Basic performance requirements. BSI. ISBN 978 0 539 06639 5.

BS ISO 15767:2009 Workplace atmospheres. Controlling and characterizing uncertainty in weighing collected aerosols. BSI. ISBN 978 0 580 58086 4.

HSE EH40 (2005) EH40/2005 Workplace exposure limits. Fourth edition 2020. ISBN 978 0 7176 6733 8 https://www.hse.gov.uk/pubns/priced/eh40.pdf

HSE MDHS 14/4 (2014) General methods for sampling and gravimetric analysis of respirable, thoracic and inhalable aerosols. June 2014. https://www.hse.gov.uk/pubns/mdhs/pdfs/mdhs14-4.pdf

NIOSH (2020) Pocket Guide to Chemical Hazards. Online version. Last reviewed February 2020. National Institute for Occupational Safety and Health. https://www.cdc.gov/niosh/npg/default.html

PD CEN/TR 15230:2005 Workplace atmospheres: Guidance for sampling of inhalable, thoracic and respirable aerosol fractions. BSI. ISBN 0 580 47338 4.

BOHS is a Chartered, science-based, charitable body that provides information, expertise and guidance in the recognition, evaluation, control and management of workplace health risks.

BOHS was founded in 1953: it is a learned society, publishing the world-renowned, scientific, peer-reviewed journal, Annals of Work Exposures and Health, and the only professional society representing qualified occupational hygienists in the UK. The Society supports, develops and connects its members with resources, guidance, events and training.

Its Faculty of Occupational Hygiene sets professional standards, promotes professional development and maintains the UK's only accredited Register of Occupational Hygiene Professionals.

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