National Pollutant Inventory

Emission Estimation Technique Manual

for

Malting Processes

Version 1.0 - First Published 10 July 2000

EMISSION ESTIMATION TECHNIQUES
FOR
MALTING PROCESSES

TABLE OF CONTENTS

EMISSION ESTIMATION TECHNIQUE MANUAL FOR MALTING PROCESSES

LIST OF FIGURES, TABLES AND EXAMPLES

1.0   Introduction

The purpose of Emission Estimation Technique (EET) Manuals in this series is to assist Australian manufacturing, industrial and service facilities to report emissions of listed substances to the National Pollutant Inventory (NPI). This Manual describes the procedures and recommended approaches for estimating emissions from facilities engaged in malting processes.

The malt manufacturing activities covered in this Manual apply to facilities primarily engaged in the manufacture of malt mainly used as a feed source for the beer brewing industry.

    EET MANUAL: Malting Processes

    HANDBOOK: Beer and Malt Manufacturing

    ANZSIC CODES: 2182

This Manual was drafted by C. M. Dudgeon, on behalf of the NPI Unit of Environment Australia. It has been developed through a process of national consultation involving State and Territory environmental authorities and key industry stakeholders.

The scope of this manual is presented diagrammatically in Figure 1.
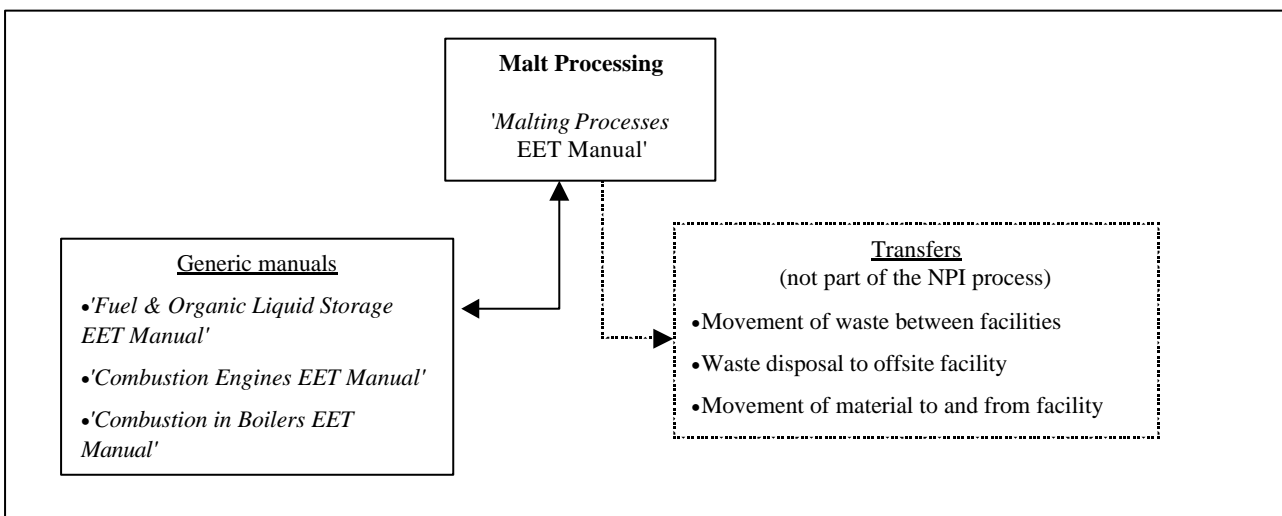
Figure 1   Scope of the *Malting Processes EET Manual* and its Relationship with Other EET Manuals

1.1 Manual Structure

This manual is structured to allow facilities to work through it and address issues in a structured and coherent manner.

Section 1   **Introduction** provides general information about this manual.

Section 2   **Processes and Emissions** discusses likely emissions from facilities and environments where emissions may enter.

Section 3   **Reporting Thresholds** provides a brief overview of each NPI category and gives reporting threshold values for each category.

Section 4   **References** provides a list of references utilised in the compilation of this Manual.

Appendix A **Emission Estimation Techniques** addresses the EETs likely to be used by the industry. This approach has been adopted in order to demonstrate how an EET may be applied to estimating emissions of a substance and may be supported by other EETs. For example, some industries and facilities may choose to use a variety of mass balance approaches to their estimation of specific chemical emissions. However, the mass balance EET is likely to be supported by direct monitoring data and emission factors.

Appendix B **Emission Estimation Techniques: Acceptable Reliability and Uncertainty** addresses the reliability of each estimation method present in Appendix A.

Appendix C **List of Variables and Symbols** presents a complete list of variables and symbols used within this Manual.

Appendix D **Glossary** gives a glossary of terms and acronyms used in this Manual.

1.2 Manual Application

Context and use of the Manual

This NPI manual provides a "how to" guide for the application of various methods to estimate emissions as required by the NPI. It is recognised that the data that is generated in this process will have varying degrees of accuracy with respect to the actual emissions from malt processing facilities. In some cases there will necessarily be a large potential error due to inherent assumptions in the various emissions estimation techniques (EETs) and/or a lack of available information of chemical processes.

EETs should be considered as 'points of reference'

The EETs and generic emission factors presented in the manual should be seen as 'points of reference' for guidance purposes only. Each has associated error bands that are potentially quite large. Appendix B discusses the general reliability associated with the various methods. The potential errors associated with the different EET options should be considered on a case-by-case basis as to their suitability for a particular facility. Facilities may use EETs that are not outlined in this document. They must, however, seek the consent of their relevant environmental authority to determine whether any 'in house' EETs are suitable for meeting their NPI reporting requirements.

Hierarchical approach recommended in applying EETs

This manual presents a number of different EETs, each of which could be applied to the estimation of NPI substances. The range of available methods should be viewed as a hierarchy of available techniques in terms of the error associated with the estimate. Each substance needs to be considered in terms of the level of error that is acceptable or appropriate with the use of the various estimation techniques. Also the availability of pre-existing data and the effort required to decrease the error associated with the estimate will need to be considered. For example, if emissions of a substance are clearly very small no matter which EET is applied, then there would be little gained by applying an EET which required significant additional sampling.

The steps in meeting the reporting requirements of the NPI can be summarised as follows:

- for Category 1 and 1a substances identify which reportable NPI substances are used, produced or stored, if any and determine whether the amounts used or handled are above the "threshold" values and therefore trigger reporting requirements;

- for Category 2a and 2b substances determine the amount and rate of fuel (or waste) burnt each year, the annual power consumption and the maximum potential power consumption, and assess whether the threshold limits are exceeded;

- for Category 3 substances determine the annual emissions to water and assess whether the threshold limits are exceeded; and

- for those substances above the threshold values, examine the available range of EETs and determine emission estimates using the most appropriate EET.

Generally it will be appropriate to consider various EETs as alternative options whose suitability should be evaluated in terms of:

- the associated reliability or error bands; and
- the cost/benefit of using a more reliable method.

The accuracy of particular EETs is discussed in Appendix B.

NPI emissions in the environmental context

It should be noted that the NPI reporting process generates emission estimates only. It does not attempt to relate emissions to potential environmental impacts, bioavailability of emissions or natural background levels.

Facilities may undertake 'Ancillary Activities', such as the production of hydrochloric acid or ammonium sulfate, either as a process input or through processing of waste streams. When estimating emissions a facility should ensure that emissions are not 'double counted' (See Appendix B) and process maps should be used to minimise the potential for this.

2.0   Processes and Emissions

The following section presents a brief description of the Malt Manufacturing Industry and identifies likely sources of emissions.

2.1   Process Description

Malt, primarily barley malt, is the main constituent in the process for beer manufacturing. Malt manufacturing processes raw barley grain into barley malt utilising five (5) main operations: storage, steeping, germination, kilning and polishing. Figure 2 illustrates typical malthouse operations with likely emissions points.
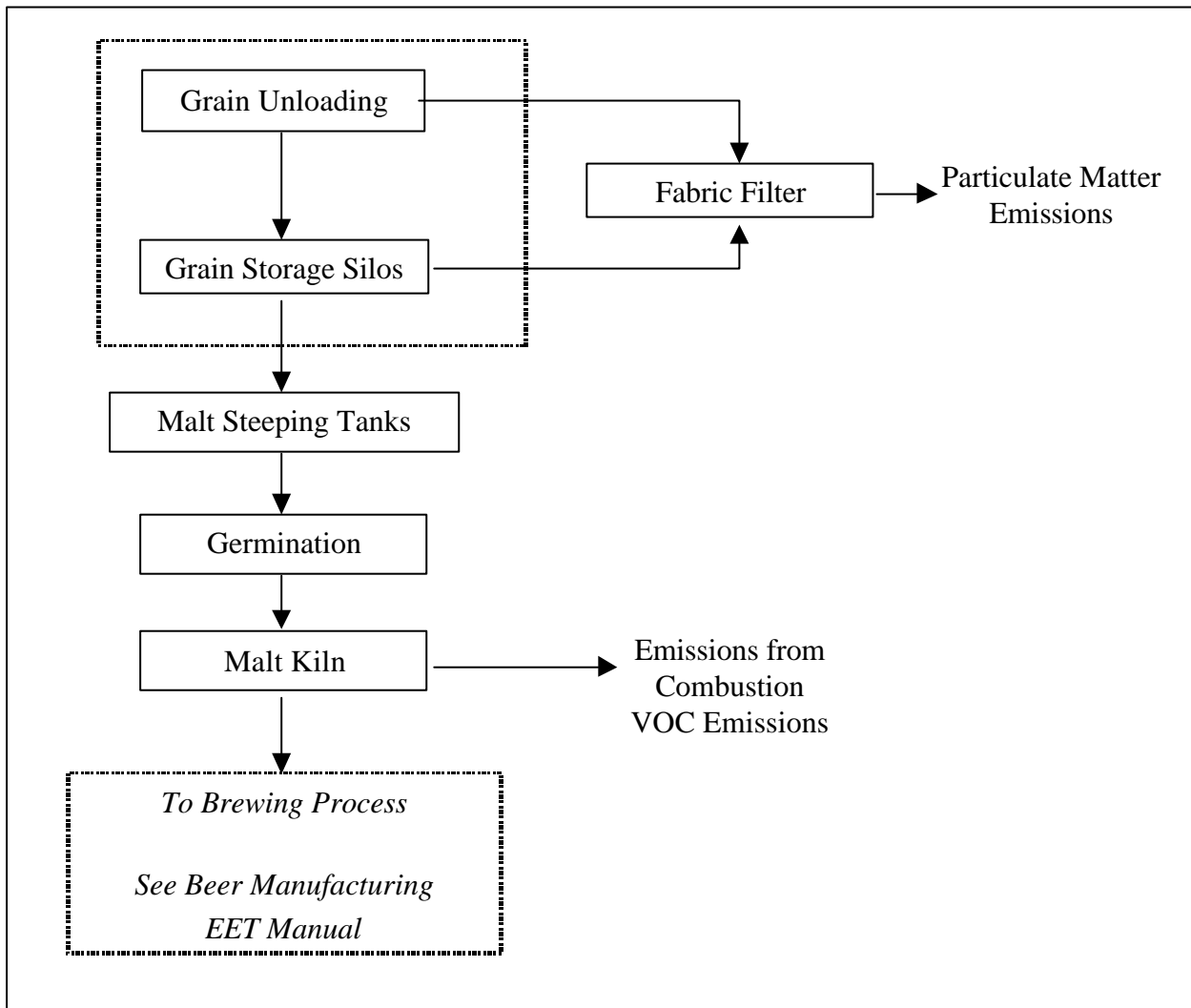

Figure 2   Malthouse Operations: Process Inputs and Emissions

2.2 Emission Sources and Control Technologies

2.2.1 Emissions to Air

Air emissions may be categorised as:

Fugitive Emissions

These are emissions that are **not** released through a vent or stack. Examples of fugitive emissions include dust from stockpiles, volatilisation of vapour from vats, open vessels or spills, and materials handling. Emissions emanating from ridgeline roof-vents, louvres, and open doors of a building as well as equipment leaks, and leaks from valves and flanges are also examples of fugitive emissions. Emission factor EETs are the usual method for determining losses through fugitive emissions.

Fugitive emissions may be present within the malt manufacturing industry. These emissions generally include equipment leaks, emissions from barley and malt transfer operations, windblown dust and of other industrial processes. For guidance on the estimation of emissions from fugitive sources, refer to the Emission Estimation Technique Manual for Fugitive Emissions.

Point Source Emissions

These emissions are exhausted into a vent (excluding roof vents) or stack, and emitted through point sources into the atmosphere. For malt manufacturing operations, main point sources include:

- Emissions from natural gas combustion processes.
- Volatile organic compounds (VOCs) such as aldehydes and carboxylic acids.
- Particulate emissions from filters and stacks.

Particulate Matter (PM_{10}) emissions from operations such as barley transfer operations and silo filling are **NOT** reportable under NPI legislation, unless the facility triggers the fuel consumption threshold (see Emissions Estimation Technique Manual for Combustion in Boilers). Guidance on calculating particulate emissions from these operations is given in Section A.4 of this Manual.

A study in Europe (Passant, Richardson, Swannell, Gibson, Woodfield, 1993) indicates that extremely low concentration VOCs are released during the malting process. A specific example on calculating this concentration is given in Appendix A.4.1 of this Manual. It is expected that most malt manufacturers will have emissions that are below the threshold NPI reporting value (25 tonnes) for VOCs.

For guidance on the estimation of emissions from natural gas combustion processes, please refer to the Emission Estimation Technique Manual for Combustion in Boilers (Section 3.4.2).

Table 1 illustrates likely air emissions from typical Malthouse processes.

Table 1   Likely Air Emissions during Malting Operations

Activity	Constituent	NPI Category	Comments
Malting Operations	Volatile Organic Compounds (VOCs)	1a	Use Emission Factor
Fuel Burning - Kiln	Carbon Monoxide Fluoride Compounds Hydrochloric Acid Particulate Matter (PM$_{10}$) Polycyclic Aromatic Hydrocarbons (PAHs) Sulfur Dioxide Total Volatile Organic Compounds (VOCs)	2a	See Emission Estimation Technique Manual for Combustion in Boilers (Section 3.4.2)
Fuel Burning - Kiln	Arsenic & compounds Beryllium & compounds Cadmium & compounds Chromium (III) & Compounds Chromium (VI) & compounds Copper & compounds Lead & compounds Magnesium Oxide Fume Manganese & compounds Mercury & compounds Nickel & compounds Nickel Carbonyl Nickel Subsulfide Polychlorinated Dioxins & Furans **PLUS all Category 2a substances (above)**	2b	See Emission Estimation Technique Manual for Combustion in Boilers (Section 3.4.2)
Grain Storage & Transfer Operations	Particulate Matter (PM$_{10}$)	2a	Use Emission Factor

Air emission control technologies, such as electrostatic precipitators, fabric filters or baghouses, and wet scrubbers, are commonly installed to reduce the concentration of substances in venting air streams prior to emission. Where such emission abatement equipment has been installed, and where emission factors from uncontrolled sources have been used in emission estimation, the collection efficiency of the abatement equipment needs to be considered. The NPI substance most commonly impacted by this equipment is the PM$_{10}$ emissions (particulate matter with an equivalent aerodynamic diameter of 10 micrometres or less i.e. $\leq 10 \mu m$). Collection efficiency is different for different substances. Guidance on applying collection efficiencies to emission factor equations is provided in Appendix B.4.

With regards to emission controls for PM$_{10}$ emissions in the absence of measured data or knowledge of the collection efficiency for a particular piece of equipment, an efficiency of 90% should be used in the emission factor equation to calculate actual mass emissions. This default should only be used if there is no other available control efficiency with literature or other sources.

2.2.2   Emissions to Water

For malt manufacturing operations it is expected that all process liquid effluent and wastewater will be:

- Sent to sewer;
- Treated on-site, then sent to sewer;

- Sent offsite for treatment, recycling or recovery; or
- Recycled or reused through the process.

Emissions of substances to water which must be reported under NPI legislation can be categorised as discharges to:

- Surface waters (e.g. lakes, rivers, dams, and estuaries);
- Coastal or marine waters; and
- Stormwater.

Therefore, malt manufacturing facilities are not expected to be required to report for their emissions to water. However, because of the significant environmental hazards posed by emitting toxic substances to water, most facilities emitting NPI-listed substances to waterways are required by their relevant State or Territory environment agency to closely monitor and measure these emissions. Existing sampling data can be used to calculate annual emissions of NPI pollutants.

2.2.3   Emissions to Land

Emissions of substances on land within the facility include solid wastes, slurries, sediments, spills and leaks, storage and distribution of liquids. Such emissions may contain listed substances. Within the malting industry it is expected that substances will be either sent to sewer or sent off-site for landfill, recycling or treatment and in these cases, there is no reporting requirement under NPI legislation.

Therefore, the only emissions to land which will be reportable are spills and leaks or in the practice of on-site disposal. Refer to the *Emission Estimation Technique Manual for Organic Chemical Processing Industries* (Sections 9.1 and 9.2) for guidance in estimating releases due to spills/leaks or other releases to groundwater.

3.0   Reporting Thresholds

For in-depth information of reporting thresholds, refer to *The NPI Guide* provided within the Industry Handbook.

3.1   Category 1

The Category 1 reporting threshold is triggered if a facility handles, manufactures, imports, processes or uses a total of ten (10) tonnes or more of a Category 1 substance. A complete list of NPI Category 1 substances are listed in *The NPI Guide*. With Category 1 substances, a facility is only required to report those substances that each individually trigger the reporting threshold. It is not expected that a facility which is only involved in malting processes (and not brewing operations) will trigger the threshold for any of the Category 1 substances.

3.2   Category 1a

The Category 1a threshold is triggered if the facility either:

- Uses, produces, imports, processes or emits more than 25 tonnes of Volatile Organic Compounds (VOCs) in a year; or
- Has bulk storage facilities with a design capacity greater than 25 kilotonnes.

3.3   Category 2a

Both Categories 2a and 2b are based on energy consumption or fuel usage. The category 2a reporting threshold is triggered if a facility:

- Burns 400 tonnes or more of fuel or waste per year; or
- Burns 1 tonne or more of fuel or waste in an hour at any time during the reporting year.

3.4   Category 2b

Category 2b deals with a range of trace metals which are emitted when large quantities of fuel are consumed. A facility must report emissions under Category 2b if that facility:

- Burns 2 000 tonnes or more of fuel or waste in a year;
- Consumes 60 000 megawatt hours of energy in a year; or
- If the maximum potential power consumption of the facility at any time in the year is rated at 20 megawatts or more.

3.5   Category 3

A facility must report its emissions of Total Nitrogen and/or Total Phosphorus if its annual emissions to water are at, or above:

- 15 tonnes per year for Total Nitrogen (excluding emissions to groundwater and sewer); or
- 3 tonnes per year for Total Phosphorus (excluding emissions to groundwater and sewer).

4.0   References

Passant, N., Richardson, S., Swannell, R., Gobson, N., Woodfield, M. (1993) 'Emissions of Volatile Organic Compounds (VOCs) from the Food and Drink industries of the European Community', *Atmospheric Environment*, Vol. 27A, No. 16,pp.2555-2566.

US EPA, Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources, AP-42 Section 9.12.1 Malt Beverages, United States Environmental Protection Agency. Accessed online: 3 December 1999 and 4 January 2000,
URL: http://www.epa.gov/ttn/chief/ap42pdf/c9s12-1.pdf

US EPA, Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources Backup Documentation, AP-42 Section 9.9.1 Grain Handling, United States Environmental Protection Agency. Accessed online: 23 May 2000,
URL: http://www.epa.gov/ttn/chief/fbgdocs/b09s09-1.pdf

The following Emission Estimation Technique Manuals are available at the NPI Homepage (http://www.npi.gov.au), and from your local Environmental Protection Authority:

- *Emission Estimation Technique Manual for Combustion in Boilers*
- *Emission Estimation Technique Manual for Fugitive Emissions*
- *Emission Estimation Technique Manual for Organic Chemical Processing Industries*

Appendix A - Emission Estimation Techniques

Estimates of emissions of NPI-listed substances to air, water and land should be reported for each substance that triggers a threshold. The reporting list and detailed information on thresholds are contained in *The NPI Guide* at the front of this Handbook.

In general, there are four types of emission estimation techniques (EETs) that may be used to estimate emissions from your facility.

The four types described in *The NPI Guide* are:

- sampling or direct measurement;
- mass balance;
- fuel analysis or other engineering calculations; and
- emission factors.

Select the EET, (or mix of EETs), that is most appropriate for your purposes. For example, you might choose to use a mass balance to best estimate fugitive losses from pumps and vents, direct measurement for stack and pipe emissions, and emission factors when estimating losses from storage tanks and stockpiles.

If you estimate your emission by using any of these EETs, your data will be displayed on the NPI database as being of 'acceptable reliability'. Similarly, if your relevant environmental authority has approved the use of EETs that are not outlined in this handbook, your data will also be displayed as being of 'acceptable reliability'.

This Manual seeks to provide the most effective emission estimation techniques for the NPI substances relevant to this industry. However, the absence of an EET for a substance in this handbook does not imply that an emission should not be reported to the NPI. The obligation to report on all relevant emissions remains if reporting thresholds have been exceeded.

> **You are able to use emission estimation techniques that are not outlined in this manual. You must, however, seek the consent of your relevant state or territory environmental authority. For example, if your company has developed site-specific emission factors, you may use these if approved by your relevant environmental authority.**

You should note that the EETs presented in this manual relate principally to average process emissions. Emissions resulting from non-routine events are rarely discussed in the literature, and there is a general lack of EETs for such events. However, it is important to recognise that emissions resulting from significant operating excursions and/or accidental situations (e.g. spills) also need to be estimated. Emissions to land, air and water from spills must be estimated and added to process emissions when calculating total emissions for reporting purposes. The emission resulting from a spill is the net emission, i.e. the quantity of the NPI reportable substance spilled, less the quantity recovered or consumed during clean up operations.

The **usage**[a] of each of the substances listed as Category 1 and 1a under the NPI must be estimated to determine whether the 10 tonnes (or 25 tonnes for VOCs) reporting threshold is exceeded. If the threshold is exceeded, **emission** of these Category 1 and 1a substances must be reported for all operations/processes relating to the facility, even if the actual emissions of the substances are very low or zero.

[a]Usage is defined as meaning the handling, manufacture, import, processing, coincidental production or other uses of the substances.

A list of the variables and symbols used in this Manual is in Appendix C.

A.1   Direct Measurement

You may wish to undertake direct measurement in order to report to the NPI, particularly if you already do so in order to meet other regulatory requirements. However, the NPI does not require you to undertake additional sampling and measurement. For the sampling data to be adequate and able to be used for NPI reporting purposes, it would need to be collected over a period of time, and to be representative of operations for the whole reporting period.

A.1.1   Sampling Data

Stack sampling test reports often provide emissions data in terms of kg per hour or grams per cubic metre (dry). Annual emissions for NPI reporting can be calculated from this data. Stack tests for NPI reporting should be performed under representative (i.e. normal) operating conditions. You should be aware that some tests undertaken for a State or Territory license condition may require the test be taken under maximum emissions rating, where emissions are likely to be higher than when operating under normal operating conditions. It may not be valid to use the maximum emission levels to estimate emissions for NPI reporting.

An example of test results is summarised in Table 2. The table shows the results of three different sampling runs conducted during one test event. The source parameters measured as part of the test run include gas velocity and moisture content, which are used to determine exhaust gas flow rates in m^3/s. The filter weight gain is determined gravimetrically and divided by the volume of gas sampled, as shown in Equation 1 to determine the PM concentration in grams per m^3. Note that this example does not present the condensable PM emissions.

Pollutant concentration is then multiplied by the volumetric flow rate to determine the emission rate in kilograms per hour, as shown in Equation 2 and Example 1.

Equation 1

$$C_{PM} \quad = \quad C_f / V_{m, STP}$$

where:

C_{PM} =   concentration of PM or gram loading, g/m^3
C_f =   filter catch, g
$V_{m,STP}$ =   metered volume of sample at STP, m^3

Equation 2

$$E_{PM} \quad = \quad C_{PM} * Q_d * 3.6 * [273 / (273 + T)]$$

where:

E_{PM}	=	hourly emissions of PM, kg/hr
C_{PM}	=	concentration of PM or gram loading, g/m^3
Q_d	=	stack gas volumetric flow rate, m^3/s, dry
3.6	=	3600 seconds per hour multiplied by 0.001 kilograms per gram
T	=	stack gas temperature, °C

Table 2   Stack Sample Test Results

Parameter	Symbol	Test 1	Test 2	Test 3
Total sampling time (sec)		7 200	7 200	7 200
Moisture collected (g)	g_{MOIST}	395.6	372.6	341.4
Filter catch (g)	C_f	0.0851	0.0449	0.0625
Average sampling rate (m^3/s)		$1.67 * 10^{-4}$	$1.67 * 10^{-4}$	$1.67 * 10^{-4}$
Standard metered volume (m^3)	$V_{m, STP}$	1.185	1.160	1.163
Volumetric flow rate (m^3/s), dry	Q_d	8.48	8.43	8.45
Concentration of particulate (g/m^3)	C_{PM}	0.0718	0.0387	0.0537
Queensland Department of Environment and Heritage 1998				

Example 1   Using Stack Sampling Data

Determine the particulate matter emissions from test 1 data in table 2.

From Equation 2 and the stack sampling data for Test 1 in Table 2 with a stack gas temperature of 150°C, the PM emissions are estimated as shown below.

C_{PM}	=	C_f / $V_{m, STP}$
	=	0.0851 / 1.185
	=	0.072 g/m^3

E_{PM}	=	$C_{PM} * Q_d * 3.6 * [273/(273+T)]$
	=	$0.072 * 8.48 * 3.6 * [273/(273 + 150)]$
	=	1.42 kg/hr

The information from some stack tests may be reported in grams of particulate per cubic metre of exhaust gas (wet). Use
Equation 3 to calculate particulate emissions in kg/hr on a dry gas basis.

Equation 3

$$E_{PM} = Q_w * C_{PM} * 3.6 * (1 - moist_R/100) * [273 / (273 + T)]$$

where:

E_{PM}	=	hourly emissions of PM in kilograms per hour, kg/hr
Q_w	=	wet cubic metres of exhaust gas per second, m^3/s
C_{PM}	=	concentration of PM or gram loading, g/m^3
3.6	=	3600 seconds per hour multiplied by 0.001 kilograms per gram
$moist_R$	=	moisture content, wt%
273	=	273 K (0°C)
T	=	stack gas temperature, °C

Total suspended particulates (TSP) are also referred to as total particulate matter (total PM). To determine PM_{10} from total PM emissions, a size analysis may need to be undertaken. The mass of PM_{10} fraction can then be multiplied by the total PM emission rate to produce PM_{10} emissions. Alternatively, assume that 100% of PM emissions are PM_{10}; i.e. assume that all particulate matter emitted to air has an equivalent aerodynamic diameter of 10 micrometres or less i.e. $\leq 10 \mu m$.

To calculate moisture content use Equation 4.

Equation 4

Moisture content   =   100 % * weight of water vapour per specific
                                       volume of stack gas divided by total weight of the
                                       stack gas in that volume.

$$ moist_R = \frac{100\% * \dfrac{g_{moist}}{(1000 * V_{m,STP})}}{\dfrac{g_{moist}}{(1000 * V_{m,STP})} + r_{STP}} $$

where

$moist_R$	=	moisture content, wt%
g_{moist}	=	moisture collected, g
$V_{m,STP}$	=	metered volume of sample at STP, m^3
ρ_{STP}	=	dry density of stack gas sample, kg/m^3 at STP (if the density is not known a default value of 1.62 kg/m^3 may be used. This assumes a dry gas composition of 50 vol% air and 50 vol% CO_2)

Example 2   Calculating Moisture Percentage

A 1.2m^3 sample (at STP) of gas contains 410g of water. To calculate the moisture content use Equation 4.

$$ moist_R = \frac{100\% * \dfrac{g_{moist}}{(1000 * V_{m,STP})}}{\dfrac{g_{moist}}{(1000 * V_{m,STP})} + r_{STP}} $$

$g_{MOIST}/1000 * V_{m,STP}$	=	410 / (1000 * 1.2)
	=	0.342
$moist_R$	=	100 * 0.342/(0.342 + 1.62)
	=	17.4 wt%

A.1.2   Continuous Emission Monitoring System (CEMS) Data

A continuous emission monitoring system (CEMS) provides a continuous record of emissions over time, usually by reporting pollutant concentration. Once the pollutant concentration is known, emission rates are obtained by multiplying the pollutant concentration by the volumetric gas or liquid flow rate of that pollutant.

Although CEMS can report real-time hourly emissions automatically, it may be necessary to estimate annual emissions from hourly concentration data manually. This Section describes how to calculate emissions for the NPI from CEMS concentration data. The selected CEMS data should be

representative of operating conditions. When possible, data collected over longer periods should be used.

It is important to note that prior to using CEMS to estimate emissions, you should develop a protocol for collecting and averaging the data in order that the estimate satisfies the local environmental authority's requirement for NPI emission estimations.

To monitor SO_2, NO_x, VOC, and CO emissions using a CEMS, you use a monitor that measures the concentration in parts per million by volume dry gas (ppm$_{vd}$ = volume of pollutant gas/10^6 volumes of dry gas). Flow rates should be measured using a volumetric flow rate monitor. Flow rates estimated based on heat input using fuel factors may be inaccurate because these systems typically run with high excess air to remove the moisture out of the kiln. Emission rates (kg/hr) are then calculated by multiplying the stack gas concentrations by the stack gas flow rates.

Table 3 presents example CEM data output over three periods for a hypothetical kiln. The output includes pollutant concentrations in parts per million dry basis (ppm$_{vd}$), diluent (O_2 or CO_2) concentrations in percent by volume dry basis (%v, d) and gas flow rates; and may include emission rates in kilograms per hour (kg/hr). This data represents a snapshot of a hypothetical kiln operation. While it is possible to determine total emissions of an individual pollutant over a given time period from this data, assuming the CEM operates properly all year long, an accurate emission estimate can be made by adding the hourly emission estimates if the CEMS data is representative of typical operating conditions.

Table 3   Example CEMS Output for a Hypothetical Kiln Firing Waste Fuel Oil

Time	O_2 Content	Concentration (ppm$_{vd}$)				Gas Flow Rate (Q)	Production Rate of Product (A)
		SO_2 (ppm$_{vd}$)	NO_x (ppm$_{vd}$)	CO (ppm$_{vd}$)	VOC (ppm$_{vd}$)		
	(vol%)					(m^3/s)	(tonnes/ hour)
1	10.3	150.9	142.9	42.9	554.2	8.52	290
2	10.1	144.0	145.7	41.8	582.9	8.48	293
3	11.8	123.0	112.7	128.4	515.1	8.85	270

Hourly emissions can be based on concentration measurements as shown in Equation 5.

Equation 5

$$E_i \quad = \quad (C_i * MW_i * Q * 3600) / [22.4 * (T + 273/273) * 10^6]$$

where:

E_i	=	emissions of pollutant i, kg/hr
C_i	=	pollutant concentration, ppm$_{v,d}$
MW_i	=	molecular weight of the pollutant, kg/kg-mole
Q	=	stack gas volumetric flow rate, m^3/s
3600	=	conversion factor, s/hr
22.4	=	volume occupied by one mole of gas at standard temperature and pressure (0°C and 101.3 kPa), m^3/kg-mole
T	=	stack gas temperature, °C

Actual annual emissions can be calculated by multiplying the emission rate in kg/hr by the number of actual operating hours per year (OpHrs) as shown in Equation 6 for each typical time period and summing the results.

Equation 6

$$E_{kpy,i} \quad = \quad \Sigma \, (E_i * OpHrs)$$

where:

$E_{kpy,i}$ = annual emissions of pollutant i, kg/yr
E_i = emissions of pollutant i, kg/hr (from Equation 5)
OpHrs = operating hours, hr/yr

Emissions in kilograms of pollutant per tonne of clinker produced can be calculated by dividing the emission rate in kg/hr by the production rate (tonnes/hr) during the same period from Equation 7.

It should be noted that the emission factor calculated below assumes that the selected time period (i.e. hourly) is representative of annual operating conditions and longer time periods should be used for NPI reporting where they are available. Use of the calculation is shown in Example 3.

Equation 7

$$E_{kpt,i} \quad = \quad E_i \, / \, A$$

where:

$E_{kpt,i}$ = emissions of pollutant i per tonne of clinker produced, kg/t
E_i = hourly emissions of pollutant i, kg/hr
A = production rate, t/hr

Example 3 illustrates the application of Equation 5, Equation 6 and Equation 7.

Example 3   Using CEMS Data

This example shows how SO_2 emissions can be calculated using Equation 5 based on the CEMS data for Time Period 1 shown in Table 3, and an exhaust gas temperature of 150°C (423 K).

$E_{SO2,1}$ = $(C_i * MW_i * Q * 3600) / [(22.4 * (T + 273/273) * 10^6]$
 = $(150.9 * 64 * 8.52 * 3600) / [22.4 * (423/273) * 10^6]$
 = 296 217 907 / 34 707 692
 = 8.53 kg/hr

For Time Period 2, also at 150°C
$E_{SO2,2}$ = 8.11 kg/hr

For Time Period 3, also at 150°C
$E_{SO2,3}$ = 7.23 kg/hr

The duration of periods of representative operating conditions are:

Period 1 = 1 500 hr
Period 2 = 2 000 hr
Period 3 = 1 800 hr

Total emissions for the year are calculated by adding the results of the three Time Periods using Equation 6:

$$
\begin{aligned}
E_{kpy,SO2} &= E_{SO2,1} * OpHrs + E_{SO2,2} * OpHrs + E_{SO2,3} * OpHrs \\
&= (8.53 * 1\ 500) + (8.11 * 2\ 000) + (7.23 * 1\ 800)\ kg \\
&= 42\ 021\ kg/yr
\end{aligned}
$$

Emissions, in terms of kg/tonne of product produced when operating in the same mode as Time Period 1, can be calculated using Equation 7.

$$
\begin{aligned}
E_{kpt,SO2} &= E_{SO2} / A \\
&= 8.53 / 290 \\
&= 2.94 * 10^{-2}\ kg\ SO_2\ emitted\ per\ tonne\ of\ product\ produced
\end{aligned}
$$

When the kiln is operating as in Time Periods 2 or 3, similar calculations can be undertaken for emissions per tonne.

A.2   Mass Balance

A mass balance identifies the quantity of substance going in and out of an entire facility, process, or piece of equipment. Emissions can be calculated as the difference between input and output of each listed substance. Accumulation or depletion of the substance in the facility should also be accounted for.

A mass balance is based on the following principles:

Equation 8

Overall:

Total Mass In	=	Total Mass Out	+	(Accumulation	-	Depletion)

Where:

Total Mass Out	=	Mass Out in Product Streams	+	Mass Out in Waste Streams	+	Mass Out in Emissions

Equation 9

Component:

Total Component Mass In	+	Component Mass Generated	=	Component Mass Consumed	+	Total Component Mass Out

where:

Total Component Mass Out	=	Component Mass Out in Product Stream	+	Component Mass Out in Waste Streams	+	Component Mass Out in Emissions

Example 4 illustrates the application of mass balance.

Example 4   Using a Mass Balance

A facility uses 15 tonnes of an NPI -listed substance in one reporting year. It is recorded that 12 tonnes of the substance is utilised in the production process. From test data, it is found that 2.5 tonnes is sent to sewer via a wastewater stream. None of the substance is accumulated of depleted. To calculate untested stack emissions and fugitive emissions of that product, use Equation 9.

Total Component Mass In + Component Mass Generated = Component Mass Consumed + Total Component Mass Out

Total Component Mass Out = Component Mass Out in Product Streams + Component Mass Out in Waste Streams + Component Mass Out in Emissions

where:

Total Component Mass In	= 15 tonnes
Component Mass Out in Product Streams	= 0.0 tonnes
Component Mass Out in Waste Streams	= 2.5 tonnes
Component Mass Generated	= 0.0 tonnes
Component Mass Consumed	= 12 tonnes

Therefore:

Component Mass Out in Emission	= 15 - 12 - 2.5 tonnes
	= 0.5 tonnes

A.3   Engineering Calculations

An engineering calculation is an estimation method based on physical/chemical properties (e.g. vapour pressure) of the substance and mathematical relationships (e.g. ideal gas law).

A.3.1 Fuel Analysis

Fuel analysis is an example of an engineering calculation and can be used to predict SO_2, metals, and other emissions based on application of conservation laws, if fuel rate is measured. The presence of certain elements in fuels may be used to predict their presence in emission streams. This includes elements such as sulfur that may be converted into other compounds during the combustion process.

The basic equation used in fuel analysis emission calculations is the following:

Equation 10

$$E_{kpy,i} = Q_f * C_{i,w}/100 * (MW_i/EW_i) * OpHrs$$

where:

$E_{kpy,i}$	=	annual emissions of pollutant i, kg/yr
Q_f	=	fuel use, kg/hr
OpHrs	=	operating hours, hr/yr
MW_i	=	molecular weight of pollutant emitted, kg/kg-mole
EW_i	=	elemental weight of pollutant in fuel, kg/kg-mole

$C_{i,w}$ = concentration of pollutant i in fuel, weight percent, wt%

For instance, SO_2 emissions from fuel oil combustion can be calculated based on the concentration of sulfur in the fuel oil. This approach assumes complete conversion of sulfur to SO_2. Therefore, for every kilogram of sulfur (EW = 32) burned, two kilograms of SO_2 (MW = 64) are emitted. The application of this EET is shown in Example 5.

Example 5   Using Fuel Analysis Data

This example shows how SO_2 emissions can be calculated from fuel combustion based on fuel analysis results, and the known fuel flow of the engine. $E_{kpy,SO2}$ may be calculated using Equation 10 and given the following:

Fuel flow (Q_f) = 20 900 kg/hr
Weight percent sulfur in fuel = 1.17 wt%
Operating hours = 1500 hr/yr

$$E_{kpy,SO2} = Q_f * C_i/100 * (MW_p / EW_f) * OpHrs$$
$$= (20\ 900) * (1.17/100) * (64 / 32) * 1500$$
$$= 733\ 590 \text{ kg/yr}$$

A.4   Emission Factors

An emission factor is a tool used to estimate emissions to the environment. In this Manual, it relates the quantity of substances emitted from a source, to some common activity associated with those emissions. Emission factors are obtained from US, European, and Australian sources and are usually expressed as the weight of a substance emitted, divided by the unit weight, volume, distance, or duration of the activity emitting the substance (e.g. kilograms of sulfur dioxide emitted per tonne of air-dried unbleached pulp produced).

Emission factors are used to estimate a facility's emissions by the general equation:

Equation 11
$$E_{kpy,i} = A * OpHrs * EF_i * [1 - (CE_i/100)]$$

where :

$E_{kpy,i}$	=	emission rate of pollutant i, kg/yr
A	=	production rate, t/hr
OpHrs	=	operating hours, hr/yr
EF_i	=	uncontrolled emission factor of pollutant i, kg/t
CE_i	=	overall control efficiency of pollutant i, %.

Emission factors developed from measurements for a specific process may sometimes be used to estimate emissions at other sites. Should a company have several processes of similar operation and size, and emissions are measured from one process source, an emission factor can be developed and applied to similar sources. It is necessary to have the emission factor reviewed and approved by State or Territory environment agencies prior to its use for NPI estimations.

A.4.1 Industry-Wide Emission Factors

Table 4 includes emission factors for the malt manufacturing industry.

Table 4   Emission Factors for Malt Manufacturing

Substance	Emission Factor	Emission Factor Code Rating
Particulate (PM_{10}) Emissions from Gas-fired Malt Kiln	0.085 kg particulate matter emitted/ tonne barley[b]	E
Particulate (PM_{10}) Emissions from Fabric Filter	0.008 kg particulate matter emitted/ tonne barley[b]	E
Total Volatile Organic Compounds (VOCs)	0.6 kg VOCs emitted/ tonne barley[a]	E
Source: [a] Passant, Richardson, Swannell, Gibson & Woodfield, 1993 [b] US EPA, 1998		

Estimating VOC Emissions

The methodology for calculating volatile organic compound (VOC) emissions from malt manufacturing processes is quite straightforward. By multiplying the annual barley (or other input grain) tonnage by the emission factor one will arrive at the estimated VOC emissions for malt manufacturing. Remember, as stated in Passant et.al. (1993 p.2559) this is most likely an overestimation of VOC emissions, and hence will illustrate the worse case situation.

Equation 12

$$E_{VOC} = A_{in} * EF$$

where:

E_{VOC} = total emissions of VOCs from malting operations, kg/yr
A_{in} = total tonnage of grain used (tonnes/yr)
EF = Emission Factor (0.6 kg VOCs/tonne grain)

Example 6 illustrates the use of Equation 12:

Example 6   Calculating VOC Emissions using an Emission Factor

30 000 tonnes of barley are used in a malt manufacturing facility over a reporting year.

Using Equation 12, emissions of Total Volatile Organic compounds can be calculated as follows:

$$E_{VOC} = A_{in} * EF$$

$$E_{VOC} = 30\ 000\ tonnes/yr * 0.6\ kg\ VOC\ emitted\ /tonne$$
$$= 18\ 000\ kg\ VOCs/yr$$

Since 18 000 kg VOCs is below the threshold value of 25 tonnes (25 000 kg), this facility does not need to report VOCs under Category 1a.

A.4.2 Predictive Emission Monitoring (PEM)

Predictive emission monitoring is based on developing a correlation between pollutant emission rates and process parameters. A PEM allows facilities to develop site-specific emission factors, or emission factors more relevant to their particular process.

Based on test data, a mathematical correlation can be developed that predicts emissions using various parameters.

Appendix B - EETs: Acceptable Reliability and Uncertainty

This section is intended to give a general overview of some of the inaccuracies associated with each of the techniques. Although the National Pollutant Inventory does not favour one emission estimation technique over another, this section does attempt to evaluate the available emission estimation techniques with regards to accuracy.

Several techniques are available for calculating emissions from Malt Manufacturing facilities. The technique chosen is dependent on available data, and available resources, and the degree of accuracy sought by the facility in undertaking the estimate. In general, site-specific data that is representative of normal operations is more accurate than industry-averaged data, such as the emission factors presented in Appendix A of this Manual.

B.1   Direct Measurement

Use of stack and/or workplace health and safety sampling data is likely to be a relatively accurate method of estimating air emissions from Malt Manufacturing facilities. However, collection and analysis of samples from facilities can be very expensive and especially complicated where a variety of NPI-listed substances are emitted, and where most of these emissions are fugitive in nature. Sampling data from a specific process may not be representative of the entire manufacturing operation, and may provide only one example of the facility's emissions.

To be representative, sampling data used for NPI reporting purposes needs to be collected over an extended period, and to cover all aspects of production.

In the case of CEMS, instrument calibration drift can be problematic and uncaptured data can create long-term incomplete data sets. However, it may be misleading to assert that a snapshot (stack sampling) can better predict long-term emission characteristics. It is the responsibility of the facility operator to properly calibrate and maintain monitoring equipment and the corresponding emissions data.

B.2   Mass Balance

Calculating emissions from using a mass balance appears to be a straightforward approach to emission estimation. However, the Malt Manufacturing industry has few substances that lend themselves to this estimation technique. Also, it is likely that few Australian Malt Manufacturing facilities consistently track material usage and waste generation with the overall accuracy needed for application of this method. Inaccuracies associated with individual material tracking, or other activities inherent in each material handling stage, can result in large deviations for total facility emissions. Because emissions from specific materials are typically below 2 percent of gross consumption, an error of only $\pm$ 5 percent in any one step of the operation can significantly skew emission estimations.

B.3   Engineering Calculations

Theoretical and complex equations, or *models*, can be used for estimating emissions from malting processes.

Use of emission equations to estimate emissions from Malt Manufacturing facilities is a more complex and time-consuming process than the use of emission factors. Emission equations require more detailed inputs than the use of emission factors but they do provide an emission estimate that is based on facility-specific conditions

B.4   Emission Factors

Emission factors often have an associated emission factor rating (EFR) code. The EFR is a guide to the degree of certainty for pollutant emission estimates from an emission factor. This rating system is common to EETs for many industries and sectors and therefore, to many Industry Handbooks. They are based on rating systems developed by the United States Environmental Protection Agency (US EPA) and the European Environment Agency (EEA). Consequently, the ratings may not be directly relevant to Australian industry. Sources for all emission factors cited can be found in the reference section of this document. The emission factor ratings will not form part of the public NPI database.

When using emission factors, you should be aware of the associated EFR code and what that rating implies. An A or B rating indicates a greater degree of certainty than a D or E rating. The less certainty, the more likely that a given emission factor for a specific source or category is not representative of the source type. These ratings notwithstanding, the main criterion affecting the uncertainty of an emission factor remains the degree of similarity between the equipment/process selected in applying the factor, and the target equipment/process from which the factor was derived.

The EFR system is as follows:

A	-	Excellent
B	-	Above Average
C	-	Average
D	-	Below Average
E	-	Poor
U	-	Unrated

Appendix C - Variables and Symbols

Table 5 lists the variables and symbols used throughout this Manual.

Table 5   List of Variables and Symbols

Variable	Symbol	Units
Annual emissions of pollutant i	$E_{kpy,i}$	kg/yr
Concentration of PM	C_{PM}	grams/m^3
Concentration of pollutant i by volume	C_i	ppm$_{vd}$
Concentration of pollutant i by wt %	$C_{i,w}$	%
Dry density of stack gas sample	ρ_{STP}	kg/m^3
Elemental weight of pollutant i	EW_i	kg/kg-mole
Emission Factor	EF	kg/tonne
Emissions of pollutant i per tonne of fuel consumed	$E_{kpt,i}$	kg/t
Filter Catch	C_f	g
Fuel used	Q_f	t/hr
Gas flow rate	Q	m^3/s
Hourly emissions of PM	E_{PM}	kg/hr
Metered volume of sample at STP	$V_{m,STPt}$	m^3
Moisture collected	g_{MOIST}	g
Moisture content	$MOIST_R$	%
Molecular weight of pollutant i	MW_i	kg/kg-mole
Multiplication sign	*	
Operating hours	OpHrs	hr/yr
Overall control efficiency, (i.e. Emission reduction control factor)	CE_i	% reduction in emissions of pollutant i
Production rate	A	tonnes/hr
Standard Temperature & Pressure	STP	0°C (273 K) and 1 atmosphere 101.3 kPa
Temperature	T	^{o}Celsius
Total emissions of pollutant i per hour	E_i	kg/hr
Total grain input	A_{in}	tonnes/yr
Uncontrolled emission factor for pollutant i	EF_i	kg of pollutant/unit of weight, volume, distance or duration of activity emitting the pollutant
Volumetric flow rate of stack gas, dry	Q_d	dry cubic metres per second (m^3/s)
Volumetric flow rate of stack gas, wet	Q_w	wet cubic metres per second (m^3/s)

Appendix D - Glossary of Technical Terms and Abbreviations

ANZSIC	Australian and New Zealand Standard Industrial Classification
CEMS	Continuous Emission Monitoring System
CO	Carbon Monoxide
EEA	European Environment Agency
EET	Emission Estimation Technique
EFR Code	Emission Factor Rating Code
MW	Molecular Weight
NEPM	National Environment Protection Measure
NO_x	Oxides of Nitrogen
NPI	National Pollutant Inventory
O_2	Oxygen
PEM	Predictive Emission Monitoring
PM	Particulate Matter
PM_{10}	Particulates which have an aerodynamic diameter equal to or less than 10 micrometers ($\leq 10\mu m$)
SO_2	sulfur dioxide
STP	Standard Temperature and Pressure (0^oC (273 K) and 1 atmosphere 101.3 kPa)
Transfer	Transfers consist of a deposit of a substance into landfill, or discharge of a substance to a sewer or tailings dam, or removal of a substance from a facility for destruction, treatment, recycling, reprocessing, recovery or purification (NEPM. Clause 3(3)). Emissions classed as transfers are NOT required to be reported under NPI legislation.
TSP	Total Suspended Particulate
VOC	Volatile Organic Compounds