



National Pollutant Inventory

Emission Estimation Technique Manual

for

Cement Manufacturing

First published in August 1999

CEMENT MANUFACTURING

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1.0 Introduction

The purpose of all 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 cement manufacturing activities.

The Manual covers cement (excepting adhesive or refractory cement) manufacturing activities.

EET MANUAL : Cement Manufacturing

HANDBOOK : Cement & Lime Manufacturing

ANZSIC CODE : 2631 (all codes within the 263 ANZSIC code group are required to report to the NPI).

This Manual was drafted by the NPI Unit of the Queensland Department of Environment and Heritage on behalf of the Commonwealth Government. It has been developed through a process of national consultation involving State and Territory environmental authorities and key stakeholders.

2.0 Process Description

Cement is a fine powder consisting predominantly of calcium silicates, aluminates, aluminoferrites and, to a lesser degree, gypsum and limestone. Around five different raw material groups are used in the manufacture of cement in Australia. These materials are chemically combined through pyroprocessing and subjected to subsequent mechanical processing operations.

2.1 Types of Cement Produced

Cement manufacturers in Australia produce several types of cement, but Portland cement and blended cement are by far the most common. Portland cement consists primarily of a kiln-fired, fused material known as clinker, that is ground and combined with small amounts of gypsum or a similar material. Portland cement is produced in several grades designed to lend certain properties to concrete. The major ingredients of blended cement are Portland cement, flyash, and slag. Smaller amounts of specialty cements are also produced and include masonry, oilwell, and off-white cements. Off-white cement, which is made from iron-free materials of exceptional purity (usually limestone, china clay or kaolin, and silica), is primarily used to manufacture decorative concrete. Masonry cement, produced by adding limestone and/or other materials to Portland cement, is a hydraulic cement used as a component of mortar for masonry construction.

2.2 Portland Cement

Portland cement, one of the principal components of blended cement and concrete, is generally made from calcareous materials (eg. limestone) and argillaceous materials (eg. clays or shales) together with smaller quantities of iron-bearing materials and sand. To make Portland cement, the raw materials are ground, mixed, heated, and fused in a rotary kiln, cooled, and finally reduced to a fine powder. Figure 1 illustrates the typical cement production process and shows possible emission points throughout the plant.

2.3 Production Processes

Cement is manufactured in Australia in four kiln types: wet kilns, grate preheater kilns, preheater kilns, and precalciner kilns. Similar raw materials are used in all kiln types. However, the moisture content and processing techniques differ, as do the kiln designs. Fuels used for firing the kilns include oil, pulverised coal, natural gas, and supplementary waste fuels such as used tyres, spent solvents, and waste fuel oils. In the wet kiln process the raw materials are ground with water which is subsequently evaporated. As a result, this process is more energy-intensive than dry processes. Preheater and precalciner kiln processes use dry grinding technology utilising kiln exhaust gases for drying. All kilns are equipped with grate or planetary type coolers which cool the fused clinker and recuperate energy for firing the kilns or drying raw materials. Over 70% of Australian Portland cement clinker is produced in modern precalciner or preheater kilns. The most common method of cooling the clinker is a reciprocating grate, which is cooled by ambient air. The cooled clinker is transferred to storage. Clinker, together with four-to-six percent gypsum, is then ground to produce a homogeneous cement powder, which is generally sent to a bulk storage and then transported by truck, ship, or rail.

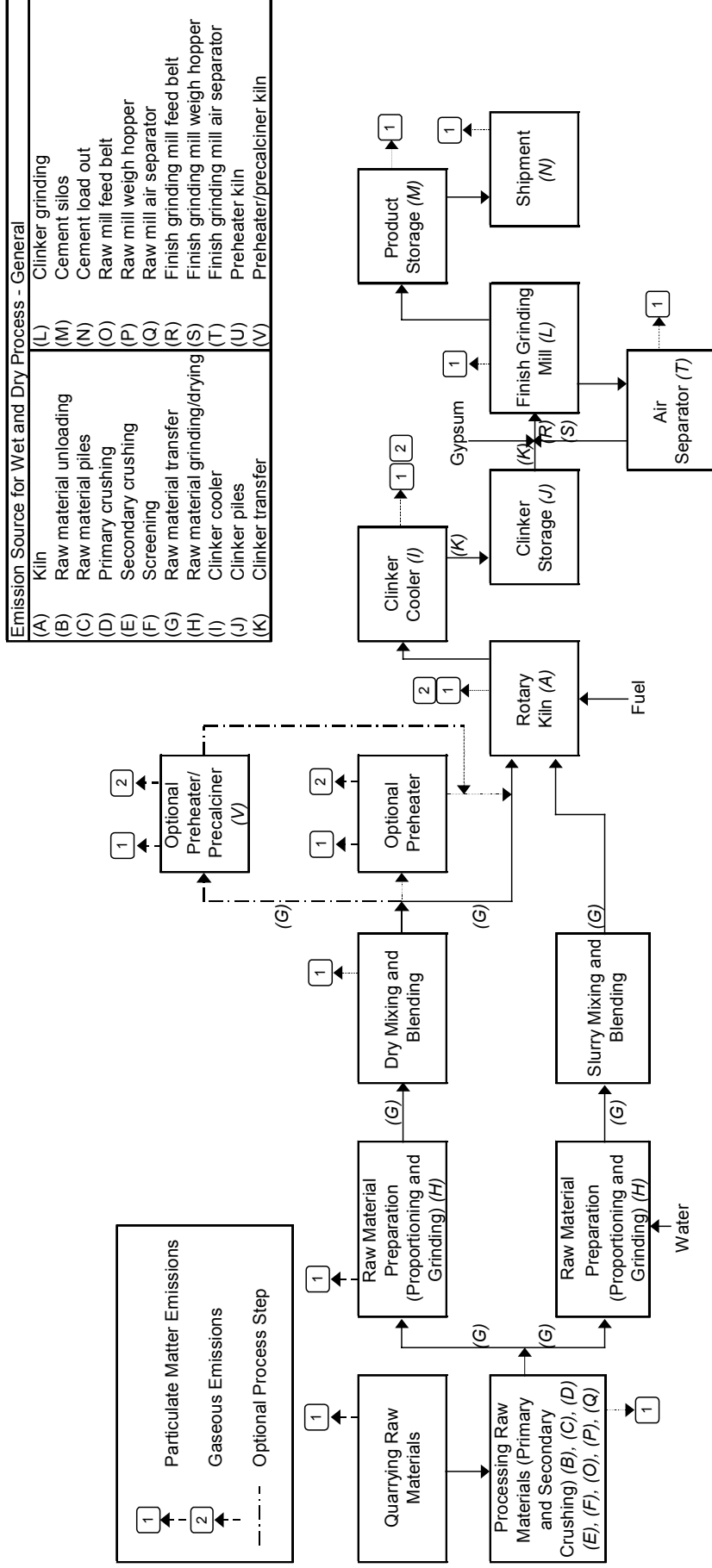


Figure 1 - Process Flow Diagram
 (Adapted from USEPA AP-42 Section 11.6)

3.0 Emission Sources

Emissions from cement manufacturing plants include combustion gases; wastewater; plant maintenance waste; and research and laboratory wastes. Particulate from kiln stacks is the largest emission stream from cement plants. It is commonly collected in baghouses or precipitators and is returned to the process.

Particulate matter (particles with an equivalent aerodynamic diameter of 10 micrometres or less ie. $\leq 10\mu\text{m}$), oxides of nitrogen, sulfur dioxide, and carbon monoxide are the most likely listed substances emitted during the production of cement. Trace quantities of volatile organic compounds (including benzene and phenol), ammonia, chlorine, some listed metals, and hydrochloric acid may also be emitted.

3.1 Particulate Matter (PM₁₀)

Sources of PM₁₀ emissions at cement plants include:

- quarrying and crushing;
- raw material storage;
- grinding and blending (in the dry process only);
- clinker production;
- finish grinding; and
- packaging and loading.

The largest single source of PM₁₀ within cement plants is the pyroprocessing system that includes the kiln and raw material grinding exhaust stacks. Additional sources of PM₁₀ are raw material storage piles, conveyors, storage silos, and unloading facilities.

The major constituents of PM₁₀ as cement kiln dust are alumina, silica, calcium carbonate, and clay (the primary constituents of cement itself).

3.2 Oxides of Nitrogen (NO_x)

NO_x are generated during fuel combustion by oxidation of chemically bound nitrogen in the fuel and by thermal fixation of nitrogen in the combustion air. As flame temperature increases the amount of thermally generated NO_x increases. The amount of NO_x generated from fuel increases with the quantity of nitrogen in the fuel. In the cement manufacturing process, NO_x is generated in both the burning zone of the kiln and the burning zone of the precalcining vessel. Fuel use affects the quantity and type of NO_x generated. For example, in the kiln, natural gas combustion with a high flame temperature and low fuel nitrogen may generate a larger quantity of NO_x than does oil or coal, which have higher fuel nitrogen but which burn with lower flame temperatures.

3.3 Sulfur Dioxide (SO₂)

SO₂ emissions may be generated both from the sulfur compounds in the raw materials and from the sulfur content of the fuel. The sulfur content of both raw materials and fuels varies, and depends on the facility and the location in Australia. However, the alkaline nature of the cement provides for direct absorption of SO₂ into the product, thereby mitigating the quantity of SO₂ emissions in the exhaust stream. Depending on the process and the source of the sulfur, SO₂ absorption ranges from about 70 to more than 95 percent.

3.4 Organics

Cement plants may emit a wide range of organic compounds in trace quantities. The range of

organic compounds emitted depends on the nature of raw materials and fuels used and the combustion efficiency of the process, and may include polycyclic aromatic hydrocarbons (PAHs) and polychlorinated dioxins and furans.

3.5 Metal Compounds

Emissions of metal compounds from cement kilns can be grouped into three general classes: volatile metals, eg mercury; semi-volatile metals, including antimony, cadmium, lead, selenium, and zinc; and refractory or non-volatile metals, including chromium, arsenic, nickel, manganese, and copper. Although partitioning of these metal groups is affected by kiln operating procedures, the refractory metals tend to concentrate in the clinker, while volatile metals tend to be emitted through the primary exhaust stack, and semi-volatiles are partitioned between clinker and the primary exhaust.

3.6 Emissions to Water

The cement manufacturing process also generates wastewater from the cooling of process equipment. The pollutants contained in cooling waters are principally dissolved solids (potassium and sodium hydroxide, chlorides, and sulfates) and suspended solids. The main control and treatment methods for wastewater involve recycling and reusing wastewater through cooling towers or ponds, settling ponds, containment ponds, and clarifiers. Wastewaters may not always contain NPI-listed substances.

If no wastewater monitoring data exists, emissions to process water can be calculated using a mass balance calculation, or emission factors. The discharge of listed substances to a sewer or tailings dam does not require you to report to the NPI. However, leakage and other emissions (including dust) from a tailings storage facility are reportable. (See also Section Three of *The NPI Guide*.)

3.7 Emissions to Land

Emissions of substances to land on-site include solid wastes, slurries, sediments, spills and leaks, storage and distribution of liquids and may contain listed substances. These emission sources can be broadly categorised as:

- surface impoundment of liquids and slurries; and
- unintentional leaks and spills.

4.0 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 emission estimation techniques 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 Manual does not necessarily 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 document. You must, however, seek the consent of your relevant environmental authority. For example, if your company has developed site-specific emission factors, you may use these if approved by your relevant environmental authority.

In general, direct measurement is the most accurate method for characterising emissions and, where available, such data should be used in preference to other EETs presented in this Manual. However, additional direct measurement is not required under the NPI Measure. Direct monitoring may be undertaken as an element of other EETs.

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 (eg. spills) will 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, ie. 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 Volatile Organic Compounds, VOCs) reporting threshold is exceeded. If the threshold is exceeded, **emissions** 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.

Table 1 lists the variables and symbols used throughout this Manual.

Table 1 - List of Variables and Symbols

Variable	Symbol	Units
Clinker production (Activity rate)	A	tonnes/hour
Concentration	C	parts per million volume dry, ppmvd
Emission reduction control factor (ie. Overall control efficiency ^a .)	ER _i	% reduction in emissions of pollutant i
Filter catch	C _f	grams (g)
PM ₁₀ concentration	C _{PM}	grams/m ³
Emission factor for pollutant i	EF _i	kg/t, kg/area, and/or kg/vehicle km travelled.
Total emissions of pollutant i per hour	E _i	kg/hr
Annual emissions of pollutant i	E _{kpy,i}	kg/year
Moisture collected	g _{moist}	grams
Moisture in exhaust gas (wet)	moist _R	%
Molecular weight	MW	kg/kg-mole
No of wheels for vehicle	NW	
Annual operating hours	OpHrs	hours/year
Volumetric flow rate	Q _w	wet cubic metres per second (m ³ /s)
Volumetric flow rate	Q _d	dry cubic metres per second (m ³ /s)
Fuel use	Q _f	Typically, kg/hr
Temperature	T	°Celsius, <i>specify</i> °C (or if necessary Kelvin, ie. absolute temperature, K) in each equation
Wind speed	U	m/sec
Molar volume @ STP (standard temperature and pressure)	V	22.4 m ³ /kg-mole @ 0°C and 101.3 kPa
Metered volume at standard temperature and pressure	V _{m, STP}	m ³
Vehicle kilometre travelled	VKT	vehicle

Source: Queensland Department of Environment and Heritage, 1998.

^a Some users may be accustomed to using Control Efficiency (CE).

4.1 Sampling Data or 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.

Stack sampling test reports often provide emissions data in terms of kg/hr or g/m³ (dry). Annual emissions for NPI reporting can be calculated from this data using Equation 1 or Equation 2 overleaf. Stack tests for NPI reporting should be performed under representative (ie. 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.

This section shows how to calculate emissions in kg/hr based on stack sampling data and how to convert this to an annual emissions figure. Calculations involved in determining PM₁₀ emissions are used as an example, although the same calculations are applicable for most of the substances listed on the Inventory.

With regards to emission controls for PM₁₀, 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.

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 m³/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 m³. 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

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

where:

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

Equation 2

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

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	=	temperature of the gas sample, °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

PM emissions calculated using Equation 1 and Equation 2, and the stack sampling data for Test 1 (presented in Table 2, and an exhaust gas temperature of 150°C (423 K)). This is shown below:

$$\begin{aligned} C_{PM} &= C_f / V_{m,STP} \\ &= 0.0851 / 1.185 \\ &= 0.072 \text{ g/m}^3 \\ \\ E_{PM} &= C_{PM} * Q_d * 3.6 * [273/(273+T)] \\ &= 0.072 * 8.48 * 3.6 * (273/423K) \\ &= 1.42 \text{ kg/hr} \end{aligned}$$

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 the dry particulate emissions in kg/hr.

Equation 3

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

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, %
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 PM₁₀ from total PM emissions, it may be necessary for facility operators to first undertake a size analysis of the stack filter catch. The weight PM₁₀ fraction can then be multiplied by the total PM emission rate to produce PM₁₀ emissions. Alternatively, assume that 100% of PM emissions are PM₁₀; ie. assume that all particulate matter emitted to air has an equivalent aerodynamic diameter of 10 micrometres or less ie. ≤10µm.

To calculate moisture content use Equation 4

Equation 4

Moisture percentage = 100 % * weight of water vapour per specific volume of stack gas/ total weight of the stack gas in that volume.

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

where

$moist_R$	=	moisture content, %
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% air, 50% CO ₂ }

Example 2 - Calculating Moisture Percentage

A 1.2m³ sample (at STP) of gas contains 410g of water. To calculate the moisture percentage use Equation 4.

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

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

4.2 Emission Factors

An emission factor is a tool that is 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 multiplied by the unit weight, volume, distance, or duration of the activity emitting the substance (eg. kilograms of sulfur dioxide emitted per tonne of clinker produced.)

When using emission factors, you should be aware of the associated emission factor rating (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

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

Equation 5

$$E_{kpy,i} = [A * OpHrs] * EF_i$$

where :

$$\begin{aligned} E_{kpy,i} &= \text{emission rate of pollutant } i, \text{ kg/yr} \\ A &= \text{activity rate, t/hr} \\ OpHrs &= \text{operating hours, hr/yr} \\ EF_i &= \text{uncontrolled emission factor of pollutant } i, \text{ kg/t} \end{aligned}$$

Emission factors developed from measurements for a specific kiln or process may sometimes be used to estimate emissions at other sites. For example, a company may have several units of similar model and size; if emissions were measured from one kiln or belt, an emission factor could be developed and applied to similar units. You are required to have the emission factor reviewed and approved by State or Territory environment agencies prior to its use for NPI estimations. Table 3 to Table 9 present emission factors for cement manufacturing processes.

Example 3 - Using Emission Factors

Table 3 shows that 2.7kg of NO_x are emitted for each tonne of clinker produced from a gas-fired precalciner kiln. It is assumed that the cement plant operates for 1 500 hours per year and that clinker production (activity) averages 250 tonnes per hour during the reporting year. Emissions of NO_x can be estimated from Equation 5.

$$\begin{aligned} EF_{NO_x} &= 2.7 \text{ kg/tonne} \\ \text{Activity rate (A)} &= 250 \text{ t/hr} \\ OpHrs &= 1\,500 \text{ hr/yr} \\ E_{kpy,NO_x} &= [A * OpHrs] * EF_i \\ &= [250 \text{ t/hr} * 1\,500 \text{ hr/yr}] * 2.7 \text{ kg/t} \\ &= 1\,012\,500 \text{ kg NO}_x/\text{yr} \end{aligned}$$

Table 3 - Emission Factors for SO₂, NO_x, and CO for Cement Manufacturing

Process Type	Fuel Type	NO _x (kg/tonne)	SO ₂ (kg/tonne)	CO (kg/tonne)
Wet and semi-wet process kilns	Lignite	5.0	2.6	0.8
	Gas	8.2	0.02	0.3
	Coal	6.9	0.07	0.4
Preheater kilns	Coal	3.7	0.02	0.8
Precalciner kilns	Coal	2.1	0.5	1.7
	Gas	2.7	0.005	0.08

Source: The Cement Industry Federation Limited, 1998.

Factor units are kg of substance emitted per tonne of clinker produced.

Emission factors are based on a survey of Australian cement manufacturing facilities and have an emission factor rating code of 'C'.

4.2.1 Emission Factors for PM₁₀ for Cement Manufacturing

Emissions of PM₁₀ from the various activities in cement production may be calculated using the following information and the data presented in Table 4 to Table 6.

Table 4 - Emission Factors for Cement Kilns – Inorganics

Substance Emitted	Type of Control	Emission Factor 10 ⁻⁶ kg/tonne ^a	Emission Factor Code Rating
Arsenic	ESP	6.5	E
Arsenic	FF	6.0	D
Beryllium	FF	0.33	D
Cadmium	ESP	4.2	D
Cadmium	FF	1.1	D
Chromium	ESP	3.9	E
Chromium	FF	70	D
Copper	FF	2600	E
Fluoride	ESP	450	E
Hydrochloric acid	ESP	25000	E
Hydrochloric acid	FF	73000	D
Mercury	ESP	110	D
Mercury	FF	12	D
Manganese	ESP	430	E
Ammonia	FF	5100	E
Ammonium	ESP	54000	D
Lead	ESP	360	D
Lead	FF	38	D
Sulfuric acid	ESP	100000	D
Sulfuric acid	FF	3600	D
Selenium	ESP	75	E
Selenium	FF	100	E
Zinc	ESP	270	D
Zinc	FF	170	D

Source: USEPA AP42 Section 11.6, 1995.

ESP Electrostatic Precipitator.

FF Fabric Filter.

^a Units are kg of substance emitted/tonne of clinker produced.

Note: These default emission factors are based on USA emission factors that relate to USA conditions. As soon as Australian data is available, these emission factors will be updated to better reflect Australian conditions. If you have more site-specific data available, you are required to have any alternate EET approved by your local environmental authority.

For more information on Emission Factor reliability refer to Section 4.2, Paragraph 2.

Table 5 - Emission Factors for Cement Kilns - Organics

CASR Number	Substance Emitted	Type of Control	Emission Factor 10 ⁻⁶ (kg/tonne)	Emission Factor Code Rating
67-64-1	acetone	ESP	190	D
71-43-2	benzene	ESP	1600	D
71-43-2	benzene	FF	8000	E
	Total polycyclic aromatic hydrocarbons (PAHs)	FF	70.839	E
95-52-4	1,1-biphenyl	ESP	3.1	E
117-81-7	bis(2-ethylhexyl) phthalate	ESP	48	D
75-15-0	carbon disulfide	ESP	55	D
101-41-4	ethylbenzene	ESP	9.5	D
50-00-0	formaldehyde	FF	230	E
78-93-3	methyl ethyl ketone	ESP	15	E
75-09-2	dichloromethane	ESP	2.50	E
108-95-2	phenol	ESP	5.5 * 10 ⁻⁵	D
100-42-5	styrene	ESP	7.5 * 10 ⁻⁷	E
108-88-3	toluene	ESP	0.00010	D
	total dioxins	FF	2.6 * 10 ⁻⁹	E
	total furans	FF	2.8 * 10 ⁻¹⁰	E
1330-20-7	xylene	ESP	6.5 * 10 ⁻⁵	D

Source: USEPA AP42 Section 11.6 (1995).

Units are kg of substance emitted/tonne of clinker produced.

ESP Electrostatic precipitator.

FF Fabric filter.

CASR Chemical Abstract Service Registry.

Note: These default emission factors are based on USA emission factors, which relate to USA conditions. As soon as Australian data is available, these emission factors will be updated to better reflect Australian conditions. If you have more site-specific data available, you are required to have any alternate EET approved by your local environmental authority.

For more information on Emission Factor reliability refer to Section 4.2, Paragraph 2.

Table 6 - Emission Factors for Total Volatile Organic Compounds (Total VOCs)

Process	Emission Factor (kg/tonne)	Emission Factor Rating
Wet process kiln	1.05 * 10 ⁻²	D
Preheater process kiln	6.75 * 10 ⁻²	D
Preheater/precalciner kiln	4.43 * 10 ⁻²	D

Source: adapted from USEPA AP42 Section 11.6 (1995).

Units are kg of substance emitted/tonne of clinker produced.

4.2.1.1. Materials Handling

a) **unenclosed:** Equation 6 can be used to calculate the emission factor of PM₁₀ when materials handling operations are carried out in an unenclosed area. Wind speed and moisture content of material must be taken into consideration.

Equation 6

Default formula
$$EF_{PM_{10}} = 0.75 * 0.001184 * \left[\frac{(U/2.2)^{1.3}}{(M/2)^{1.4}} \right] * ER_{PM_{10}}$$

where:

$EF_{PM_{10}}$ = emission factor, kg of PM_{10} /tonne of material handled
 U = mean wind speed, m/sec
 M = mean moisture content of material, %
 $ER_{PM_{10}}$ = emission reduction rate. %, Table 7

NB For materials where $M=0$ use default of 0.0036 kg/t of material handled.

The emission factor derived above can now be substituted into the general emission factor equation (Equation 5) to determine annual emissions of PM_{10} specific to your operation.

Table 7 - Emission Reduction Factors for Materials Handling and Storage

Reduction Method	Reduction Factors ($ER_{PM_{10}}$)	Control Efficiency ($CE_{PM_{10}}$)
- wind breaks	0.7	30%
- water sprays	0.5	50%
- chemical suppression	0.2	80%
- enclosure (2 or 3 walls)	0.1	90%
- covered stockpiles	0.0	100%

Source: The Cement Industry Federation Limited, 1998

^a Some users may be accustomed to using Control Efficiencies (CE) in similar calculations.
 An ER of 0.2 equates to a CE of 80%.
 $ER = (1-CE/100)$

b) **bag filters venting outside:** Equation 7 can be used to calculate annual emissions of PM_{10} when using outside-venting bag filters.

Equation 7

$$E_{kpy,PM_{10}} = EF_{PM_{10}} * A * OpHrs * 10^{-6}$$

where:

$E_{kpy,PM_{10}}$ = annual emissions of PM_{10} , kg/yr
 $EF_{PM_{10}}$ = emission factor for PM_{10} , mg/m^3 , in this case $12mg/m^3$
 A = activity rate (hourly flow of air exhausted through the bag filter), m^3/hr
 $OpHrs$ = operating hours, hr/yr
 10^{-6} = conversion factor mg to kg.

(Where $12mg/m^3$ is 80% of the total particulate matter ($15mg/m^3$) vented from the bag filter.)

c) **Enclosed:** There are no emissions of PM_{10} from material handling operations when these activities are performed inside the building.

4.2.1.2. Materials Storage

Particulate matter emissions from active stockpiles due to wind can be calculated using the

following equation.

Equation 8

$$E_{PM10} = EF_{PM10} * \text{area} * ER_{PM10}$$

where:

$$\begin{aligned} E_{PM10} &= \text{hourly emissions of PM}_{10}, \text{ kg/hr} \\ EF_{PM10} &= \text{emission factor of PM}_{10}, \text{ kg/ha/hr} \\ \text{area} &= \text{area of base of stockpile, ha} \\ ER_{PM10} &= \text{emission reduction of PM}_{10}, \%, \text{ (Table 7)} \end{aligned}$$

NB: In the absence of available PM₁₀ data use the default EF_{PM10} = 0.3 kg/ha/hr.

Example 4 - Stockpile Emissions

A stockpile with a half-hectare base is active for the full year. Emissions of PM₁₀ are calculated using Equation 8. No information is available on site-specific factors hence the default emission factor is used. Water sprays are used to suppress dust, see Table 7.

Hourly emissions

$$\begin{aligned} E_{PM10} &= EF_{PM10} * \text{Area} * ER_{PM10} \\ &= 0.3 * 0.5 * 0.5 \\ &= 0.075 \text{ kg/hr} \end{aligned}$$

Annual emissions

$$\begin{aligned} E_{kpy,PM10} &= E_{PM10} * \text{OpHrs} \\ &= 0.075 * 8760 \\ &= 657 \text{ kg/year} \end{aligned}$$

4.2.1.3. Equipment Traffic

For vehicles with a gross mass greater than 5 tonnes operating on unsealed roads use the following equation for PM₁₀ emissions (kg/VKT on unsealed roads).

NB: VKT = Vehicle Kilometre Travelled.

Equation 9

$$EF_{PM10} = 0.0019 * (NW)^{3.4} * (\text{Silt})^{0.2} * ER_{PM10}$$

where:

$$\begin{aligned} EF_{PM10} &= \text{emission factor (kg / vehicle kilometre travelled)} \\ NW &= \text{number of wheels} \\ \text{Silt} &= \text{road surface material silt content (g/m}^2 \text{ as per AS3638)} \\ ER_{PM10} &= \text{emission reduction (Table 8)} \end{aligned}$$

In the absence of available data use the default $EF_{PM_{10}} = 1.5 \text{ kg/VKT}$, which is 75% of total suspended particulate (TSP) matter emitted. Equation 10 can be used to calculate VKT.

Equation 10

$$\text{VKT} = D * \text{NU}$$

where:

$$\begin{aligned} \text{VKT} &= \text{vehicle kilometre travelled per year, km/yr} \\ D &= \text{average distance travelled, km/vehicle/yr} \\ \text{NU} &= \text{number of vehicles on-site, vehicles} \end{aligned}$$

Example 5 illustrates the use of Equation 10 when calculating vehicle kilometre travelled.

Example 5 - Calculating VKT

A reporting facility has two trucks that each travel approximately 13 000 kilometres on-site per year.

Using Equation 10:

$$\begin{aligned} \text{VKT} &= D * \text{NU} \\ &= 13\,000 \text{ km/vehicle/yr} * 2 \text{ vehicles} \\ &= 26\,000 \text{ km/yr} \end{aligned}$$

Table 8 - Emission Reduction Factors for Dust Suppression on Roads

Reduction Method	Reduction Factors (ER)	Control Efficiency (CE)
watering (to eliminate visible dust)	0.25	75%
chemical spraying (rate)	0.2	80%

Source: The Cement Industry Federation Limited, 1998

^a Some users may be accustomed to using Control Efficiencies (CE) in similar calculations. An ER of 0.2 equates to a CE of 80%.
 $ER = (1 - CE/100)$

4.2.1.4. Fuel Preparation & Drying

To calculate emissions of PM_{10} from coal drying with dust collectors use Equation 7 above (bag filters)

4.2.1.5. Cement Manufacturing including: Limestone/Raw Material Crushing, Kiln, Clinker Processing and Finished Cement Grinding

To calculate the emissions from the various activities use the emission factors from Table 9. Example 6 demonstrates how to use these emission factors.

Example 6 - Cement Manufacturing PM₁₀ Generation

A cement plant uses an uncontrolled limestone crusher, a preheater kiln with an electrostatic precipitator and has an electrostatic precipitator fitted to the clinker processing and finished cement grinding operations. The throughput is 50 000 tonne per annum. 1.4 tonne of limestone and 0.9 tonne of clinker are processed per tonne of cement.

The total emission factor from the Limestone Crushing, Kiln, Clinker Processing and Cement Grinding operations (from Table 9) is:

$$\begin{aligned} EF_{PM10} &= (0.017) * 1.4 + (0.1 + 0.01) * 0.9 + 0.004 \\ &= 0.127 \text{ kg/tonne of cement} \end{aligned}$$

Annual Emissions

$$\begin{aligned} E_{kpy,PM10} &= EF_{PM10} * \text{Activity Rate} \\ &= 0.127 * 50\ 000 \\ &= 6350 \text{ kg/yr.} \end{aligned}$$

Note: This figure represents the PM₁₀ emissions from the processing sources only. The emissions from all other sources, eg. stockpiles, roads etc, will need to be added to these.

Source: The Cement Industry Federation Limited, 1998.

Table 9 - Emission Factors for PM₁₀ for Cement Manufacturing

Component/Activities	PM₁₀ Emission Factors (kg/tonne)
Limestone/Raw Material Crushing	
– material through crusher (kg/tonne)	
- uncontrolled	0.017
- fabric filter	0.0002
- wet or chemical suppression	0.0005
- wet scrubber	0.004
Kiln	
<i>wet process</i>	
- electrostatic precipitator	0.3
<i>preheater kiln</i>	
- fabric filter	0.1
- electrostatic precipitator	0.1
<i>precalciner process kiln</i>	
- fabric filter	0.1
- electrostatic precipitator	0.1
Clinker Processing	
- fabric filter	0.001
- electrostatic precipitator	0.01
- gravel bed filter	0.03
Finished Cement Grinding	
- uncontrolled	0.3
- fabric filter	0.003
- electrostatic precipitator	0.004
(Assumes a default factor of 60mg/m ³ split into 40mg/m ³ PM ₁₀ and 20mg/m ³ > PM ₁₀)	

Source: The Cement Industry Federation Limited, 1998

4.3 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.

To monitor SO₂, NO_x, VOC, and CO emissions using a CEMS, you use a pollutant concentration monitor that measures the concentration in parts per million by volume dry air ($\text{ppm}_{\text{vd}} = \text{volume of pollutant gas}/10^6 \text{ volumes of dry air}$). 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 10 presents example CEM data output for three periods for a hypothetical kiln. The output includes pollutant concentrations in parts per million dry basis (ppm_{vd}), diluent (O₂ or CO₂) 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.

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 emissions estimations.

Table 10 - Example CEMS Output for an Hypothetical Kiln Firing Waste Fuel Oil

Time	O ₂ (% by volume)	Concentration (C) (ppm _{vd})				Gas Flow Rate (Q _d)	Clinker Rate (A) (tonnes / hour)
		SO ₂	NO _x	CO	VOC		
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 11.

Equation 11

$$E_i = (C * MW * Q_d * 3\ 600) / [22.4 * (T+273/273) * 10^6]$$

where:

- E_i = emissions of pollutant i, kg/hr
- C = pollutant concentration, ppm_{vd}
- MW = molecular weight of the pollutant, kg/kg-mole
- Q_d = stack gas volumetric flow rate, m³/s, dry
- 3 600 = conversion factor, s/hr
- 22.4 = volume occupied by one mole of gas at standard temperature and pressure (0°C and 101.3 kPa), m³/kg-mole
- T = temperature of gas sample, °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 12, for each typical time period and summing the results.

Equation 12

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

where:

- E_{kpy,i} = annual emissions of pollutant i, kg/yr
- E_i = emissions of pollutant i, kg/hr (from Equation 11)
- 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 activity rate (clinker production rate (tonnes/hr) during the same period Equation 13) as shown below. It should be noted that the emission factor calculated below assumes that the selected time period (ie. 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 7.

Equation 13

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

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 = clinker production, t/hr

Example 7 illustrates the application of Equation 11, Equation 12 and Equation 13.

Example 7 - Using CEMS Data

This example shows how SO₂ emissions can be calculated using Equation 11 based on the CEMS data for Time Period 1 shown in Table 10, and an exhaust gas temperature of 150°C (423 K).

$$\begin{aligned} E_{SO_2,1} &= (C * MW * Q * 3\,600) / [(22.4 * (T+273/273) * 10^6)] \\ &= (150.9 * 64 * 8.52 * 3\,600) / [22.4 * (423/273) * 10^6] \\ &= 296\,217\,907 / 34\,707\,692 \\ &= 8.53\text{kg/hr} \end{aligned}$$

For Time Period 2, also at 150°C

$$E_{SO_2,2} = 8.11\text{kg/hr}$$

For Time Period 3, also at 150°C

$$E_{SO_2,3} = 7.23\text{kg/hr}$$

Say representative operating conditions for the year are:

$$\text{Period 1} = 1500 \text{ hr}$$

$$\text{Period 2} = 2000 \text{ hr}$$

$$\text{Period 3} = 1800 \text{ hr}$$

Total emissions for the year are calculated by adding the results of the three Time Periods using Equation 12:

$$\begin{aligned} E_{kpy,SO_2} &= E_{SO_2,1} * \text{OpHrs} + E_{SO_2,2} * \text{OpHrs} + E_{SO_2,3} * \text{OpHrs} \\ &= (8.53 * 1500) + (8.11 * 2000) + (7.23 * 1800) \text{ kg} \\ &= 42021 \text{ kg/yr} \end{aligned}$$

Emissions, in terms of kg/tonne of clinker produced when operating in the same mode as time period 1, can be calculated using Equation 13:

$$\begin{aligned} E_{kpt,SO_2} &= E_{SO_2} / A \\ &= 8.53 / 290 \\ &= 2.94 * 10^{-2} \text{ kg SO}_2 \text{ emitted per tonne of clinker produced} \end{aligned}$$

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

5.0 References

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Written Communication from The Cement Industry Federation Limited, St Leonards, NSW, to the Queensland Environmental Protection Agency, Brisbane, QLD, August 1998.

The following Emission Estimation Technique Manuals are available at the NPI Homepage (<http://www.npi.gov.au>) and from your local environmental protection agency (see the front of the NPI Guide for details):

- Emission Estimation Technique Manual for Combustion Engines; and
- Emission Estimation Technique Manual for Lime & Dolomite Manufacturing.