National Pollutant Inventory

Emissions Estimation Technique Manual

for

Bricks, Ceramics, & Clay Product Manufacturing

EMISSIONS ESTIMATIONS TECHNIQUES
FOR
BRICKS, CERAMICS, & CLAY PRODUCT MANUFACTURING

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BRICKS, CERAMICS, & CLAY PRODUCT MANUFACTURING

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1.0   Introduction

The purpose of all Emission Estimation Techniques (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 ceramics, brick and clay product manufacturing.

The bricks, ceramics, and clay product manufacturing activities covered in this Manual apply to facilities engaged in the production of bricks, and clay related brick products (eg. clay pipe, pottery, and some refractory bricks), ceramic products (eg. tiles and stoneware), earthenware, ceramic, terracotta and clay tiles, vitreous china, and ceramic and porcelain products.

  EET MANUAL: Brick, Ceramics and Clay Manufacturing

  HANDBOOK: Ceramic Product Manufacturing
          - Clay Brick Manufacturing
          - Ceramic Product Manufacturing
          - Ceramic Tile and Pipe Manufacturing
          - Ceramic Product Manufacturing n.e.c.

  ANZSIC CODE :   262 (including 2621, 2622, 2623 and 2629)

This Manual was drafted by the NPI Unit of the Queensland Department of Environment 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, and has been considered by independent reviewers.

2.0   General Description

Clay can be categorised into six primary groups:

- **Ball clay** is a plastic, white-firing clay that has a high degree of strength as well as plasticity. It is used in pottery, floor and wall tiles, and toilet and bathroom ware.
- **Bentonite** is a clay composed mainly of smectite minerals. It is mainly used in drilling mud, foundry sand, and iron ore pelletising.
- **Common clay** and **Shale** contain mixtures of differing proportions of clay, including illite, chlorite, kaolinite, and montmorillonite, plus other nonclay materials. The largest user of these clays is the structural clay products industry, which manufactures bricks, sewer pipes, drain tiles, conduit tiles, glazed tiles, and terracotta.
- **Fire clay** consists mainly of kaolinite and can withstand very high temperatures. These clays are used in commercial refractory products such as firebrick and block.
- **Fuller's earth** either the attapulgite-type or montmorillonite-type, is used as 'kitty-litter' absorbents, oil and grease absorbents, and pesticide carriers.
- **Kaolin** has many industrial applications because it has good covering or hiding power when used as a pigment, is soft and non-abrasive, has low conductivity of heat and electricity, and is inexpensive. Major uses for kaolin are paper coating, paper sizing, fibreglass, paint, rubber, brick, and portland cement.

3.0   Industrial Process Description

This Section contains a description of commonly used production processes, associated raw materials, the by-products produced and NPI listed substances emitted, and the materials either recycled or transferred off-site. This information, coupled with schematic drawings of the identified processes, identifies the points from which emissions and wastes may be produced through these processes. This Section also describes the potential fate - to air, water, or land - of these emissions and waste products.

The manufacture of bricks and clay products involves the conditioning of basic clay ores using a series of processes. These processes include the separation and concentration of clay minerals by screening, floating, wet and dry grinding, and blending of desired ore varieties. Further processes include forming, cutting or shaping, drying or curing, and firing of the final product. The processing of clay may alter its chemical or mineralogical characteristics.

Figure 1 is a flow diagram for a process common in the production of bricks and clay products, and highlights the likely emission points for particulate matter (PM_{10}) and volatile organic compounds (VOCs), including benzene and acetone. Because every facility in Australia is likely to be unique, you are encouraged to develop a flow diagram for your own operations detailing the input of materials and listed substances, and the waste sources and emissions resulting from the operation of each process.

Particulate matter (PM$_{10}$)   Particulate matter (PM$_{10}$)   Particulate matter (PM$_{10}$)

```
┌──────────┐      ┌──────────────┐      ┌──────────────┐      ┌──────────────┐      ┌──────────────┐
│ Mining of│ ───▶ │ Crushing and │ ───▶ │  Pulverising │ ───▶ │  Screening   │ ───▶ │ Forming and  │
│ materials│      │   storage    │      │              │      │              │      │   cutting    │
└──────────┘      └──────────────┘      └──────────────┘      └──────────────┘      └──────────────┘
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Hot gases

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┌──────────┐      ┌──────────────┐      ┌──────────────┐      ┌──────────────┐
│  Glazing │ ───▶ │    Drying    │ ───▶ │     Kiln     │ ───▶ │ Storage and  │
│          │      │              │      │              │      │  shipping    │
└──────────┘      └──────────────┘      └──────────────┘      └──────────────┘
```

Particulate matter (PM$_{10}$)   Particulate matter (PM$_{10}$),   Particulate matter (PM$_{10}$)
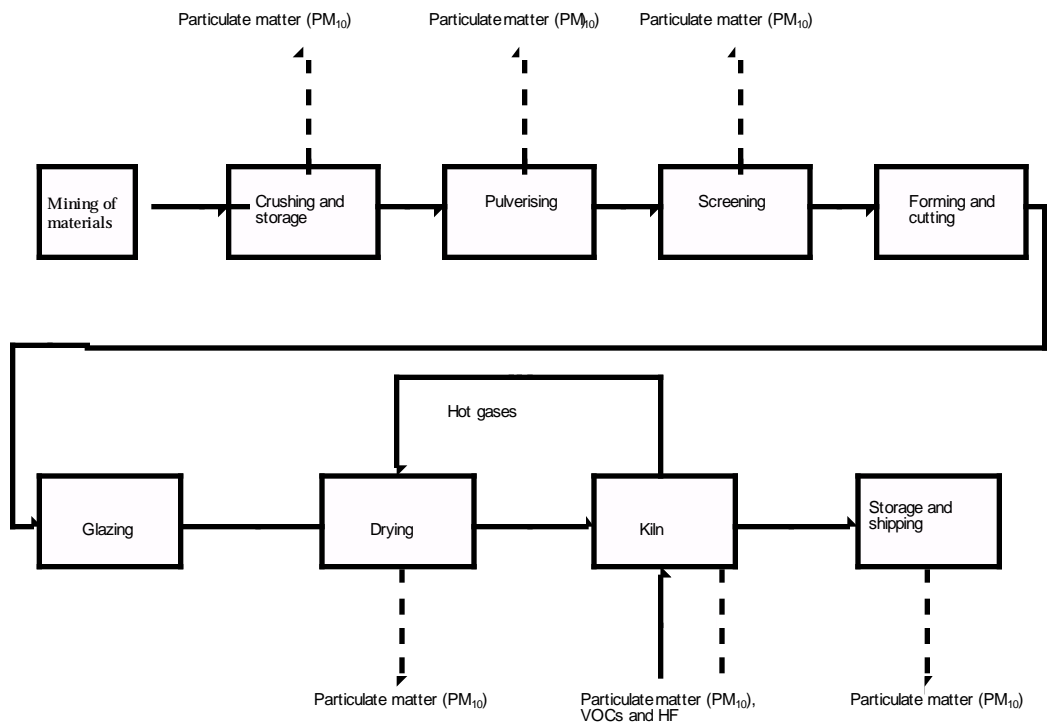   VOCs and HF

Figure 1.   Process Flow Diagram of a Brick Manufacturing Facility.

Adapted from USEPA 1996, AP-42

3.1 Brick Products

Clay product manufacturers are required to use different production techniques for brick, other structural clay products, pottery products, and ceramic tiles. Bricks and related clay products, including building tiles, paving brick, and chimney blocks, are produced from a clay/water mixture. The four principal processes for manufacturing brick are the extrusion, stiff mud, soft mud, and dry press methods. In the stiff mud process, water is added to give the clay plasticity, and bricks are formed by forcing the clay through a steel or ceramic dye. This process forms all structural tile and most types of brick. The soft mud process uses clay with a high moisture content. This clay is mixed with water and the bricks are then formed in moulds. With the dry press process, clay is mixed with a small amount of water and formed in steel mould under pressure.

The dominant process in manufacturing structural clay products is extrusion. The dry material is fed into a trough, sprayed with water, and cut and kneaded (pugged) by rotating knives into a homogeneous mixture. The resulting plastic mass is forced into a de-airing chamber where a vacuum is maintained. Following de-airing, the material is forced through a dye having the appropriate cross section (extrusion) and cut into correct lengths. The structural clay products are then dried and fired in a kiln.

3.2 Pottery Products

Pottery products such as stoneware, earthenware, and garden pottery, are made of crude clay. To manufacture pottery products, soft plastic forming is used to process plastic clays with 20-30 percent water and certain additives, that may include barium compounds and aluminium oxide. Jiggering is a soft plastic process used to form ware with symmetrical circular cross sections. The raw materials are prepared by blunging and filter pressing. They are mixed with a blunger (a vertical cylindrical tank with horizontal blades or paddles) attached to a vertical shaft. The homogeneous mixture or slip, is then de-aired, forced through a dye with the desired cross section, and cut into slugs. The slug is placed in a mould using the inside or outside of the ware, and pressed onto the mould. High-pressure air is used to separate the ware from the mould. The product is then thermally treated using a tunnel kiln, and slowly cooled with fans.

3.3 Ceramic Products

Ceramic tile manufacturing involves the conditioning of two basic raw materials: kaolinite and montmorillonite. These clays are refined by separation and bleaching, and are then blended, formed, and kiln-dried.

4.0   Likely Emissions

4.1   Brick Products

The emissions generated from manufacturing bricks and other structural clay products result mainly from the handling of raw materials, processing, plant maintenance and pollution control equipment.

Various phases of the clay production process generate particulate emissions. The main source of dust is the materials handling process, including the pulverising, screening, and storage of raw materials. Figure 1 illustrates the phases of the clay manufacturing process, during which major particulate emissions are likely to occur.

Pollution control emissions from the clay industry include dust accumulated in baghouses, and the solid residues from wet scrubbers (where applicable) used to treat nitrogen oxide emissions, and to control acid gases and trace combustion products when burning low quality fuels. Plant maintenance emissions consist primarily of waste oils and solvents generated from a range of mechanical equipment.

4.2   Pottery Products

Emissions generated during the manufacturing of pottery products occur largely through the use of paints, glazes, and finishing coatings. These materials may be solvent or water-based, with varying heavy metal content. Where solvent-based finishes are used, solvents are used to clean the paint line and application equipment. The sludge waste emissions generated from this cleaning are typically transferred off-site to a solvent recycler or are recovered for fuel blending. When water-based finishes are used, the paint line and equipment are cleaned with water. Depending on the location of your facility, and on the content of this waste, wastewater emissions may be subject to licensing limits because of the presence of heavy metals. In addition, the sludge accumulated prior to emission may also be a hazardous waste because of a heavy metal content.   Sludges generated by the pottery industry commonly contain traces of glaze which may contain NPI listed metals including lead, mercury, and boron.

Some pottery manufacturers will also generate dry powder waste from pollution control equipment. The sludge generated from equipment washing is commonly from glaze lines, glaze mills, glaze tanks and containers, and wet filters. About 10 percent (by weight) of the glaze used ends up in sludges. It is estimated that for each square metre of tile surface glazed, 100 grams of glaze waste is generated.

Manufacturers of clay products often use sintering to diminish entrained volatile organic matter from the clay. Because it is desirable for the clay to contain a sufficient amount of volatile matter so that the resultant aggregate will not be too heavy, it is sometimes necessary to mix the clay with finely pulverised coke prior to sintering. The addition of pulverised coke is likely to generate further emissions because the sintering of coke-impregnated clay produces more particulate emissions than the sintering of natural clay.

Table 1. Brick and Clay Products Manufacturing Material Inputs and Pollutant Outputs

Process	Material Inputs	Air Emissions	Water and Land Emissions	Other Emissions, Wastes, and Transfers
Clay Product Manufacturing	Kaolinite clay, montmorillonite clay, glazes (and other minerals such as illites, feldspars and quartz) containing heavy metals.	Particulates, fluorides, acids, sulphur dioxide, oxides of nitrogen, CO, solvents.	Heavy metals, spent solvent wastes.	Materials handling wastes furnace slag, paint wastes.

Adapted from USEPA 1995 *Notebook Project*

Table 1 shows that Particulate matter (PM_{10}) is the main substance emitted from clay and brick product manufacturing. Substances such as oxides of nitrogen, sulphur dioxide, carbon monoxide, hydrogen fluoride, and calcium fluoride, are likely to be emitted from the combustion processes. Smaller quantities of volatile organic compounds (VOCs), ammonia, chlorine, and hydrochloric acid may also be emitted. Other emissions might include NPI listed metals and organic compounds generated from the fuel and raw materials used, or as products of incomplete combustion. If your facility in Australia burns waste fuels (in kilns), particularly spent solvents, there may also be lesser emissions of organic pollutants (eg. polycyclic aromatic hydrocarbons (PAHs)). Table 2 identifies the primary substances emitted by US industry.

Additional Manuals in this series are available to assist in estimating emissions from production related activities. *Combustion in Boilers* and *Fuel and Organic Liquid Storage* detail techniques for estimating emissions from fuel combustion, and the storage of organic liquids, and should be available from your local environmental authority.

Table 2. The Top-10 Substances Emitted by the Brick and Clay Products Industry in the US (USEPA 1994)

Listed Substance	Listed Substance
Ammonia	Phenol
Formaldehyde	Styrene
Hydrochloric acid	Sulphuric acid
Hydrogen fluoride	Toluene
Methanol	Xylenes (mixed isomers)

Adapted from USEPA 1995 *Notebook Project*

5.0 Emission Estimation

Estimates of emissions of 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. These are described in *The NPI Guide*. Select the EET, or mix of EETs, which is most appropriate for your purposes. If you estimate your emission by using any of these EET"s, 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'.

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.

> **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 you already undertake direct measurement, you may use this information for NPI reporting purposes (if you do not undertake direct measurement, the NPI does not require you to do so).**

5.1   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 or open vessels, and material 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.

Point source emissions

These emissions are exhausted into a vent or stack and emitted through a single point source into the atmosphere. An air emissions control device such as a carbon adsorption unit, scrubber, baghouse, or afterburner may be added to the stack prior to the atmospheric release.

5.2   Emissions To Water

Emissions of substances to water can be categorised as discharges to:

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

The discharge of listed substances to a sewer or tailings dam does not require you to report to the NPI (See also Section 3.0 of *The NPI Guide*). The main source of wastewater from this industry is usually from air pollution control equipment such as wet scrubbers.

The most appropriate method for determining emissions to the environment via wastewater is to use direct measurement, however, you may use other EETs for the purposes of reporting to the NPI.

5.3   Emissions To Land

Emissions of substances to land on-site include solid wastes, slurries, sediments, spills and leaks, storage and distribution of liquids, and the use of chemicals to control various elements of the environment where these emissions contain listed substances. These emission sources can be broadly categorised as:
- surface impoundments of liquids and slurries
- unintentional leaks and spills.

6.0   Emission Factor Rating

Every emission factor has an associated emission factor rating (EFR) code. This rating system is common to EETs for all industries and sectors and therefore, to all Industry Handbooks. They are based on rating systems developed by the United States Environmental Protection Agency (USEPA), and by 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 references 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

Estimating your facility's emissions based on emission factors only, and without taking into account any control measures, may have an uncertainty as high as 100%.

Other EETs, such as release calculations based on mass balance of solvent consumption and without taking into account control measures, may have an uncertainty of 50%.

An EET based on an audit or direct measurement, and taking into account control measures, may have an uncertainty of 20% .

7.0   Application of Emission Estimation Techniques (EETs)

Stack sampling test reports often provide emissions data in terms of kg/hr or grams/dscm (dry standard cubic metre).   Annual emissions for NPI reporting can be calculated from this data using Equations (1) or (2) overleaf.   Stack tests for NPI reporting should be performed under representative (ie. normal) operating conditions. As stated previously, 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.

You should be aware that some tests required for State and Territory license conditions may need to be undertaken when operating under maximum emissions rating. Consequently, emissions are likely to be higher than when operating under normal conditions.

This Section shows how to calculate emissions in kg/hr based on stack sampling data, and then how to convert this to an annual emissions figure. Calculations involved in determining PM_{10} emissions are used as an example, although the same calculations are applicable for most of the substances listed on the NPI. Table 3 is a list of variables and symbols that will assist you with the examples used later in this Manual.

Table 3.   List of Variables and Symbols

Variable	Symbol	Units
Concentration	C	parts per million volume dry
Molecular weight	MW	kg/kg-mole
Molar volume @ STP (standard temperature and pressure)	V	22.4 m^3/kg-mole @ 0°C and 1 atmosphere
Flow rate	Q_a	actual cubic metres per second (acms)
Flow rate	Q_d	dry standard cubic metres per second (dscms)
Emissions	E_x	typically kg/hr or pollutant x
Annual emissions	$E_{tpy,x}$	tonnes/year of pollutant x
Filter catch	C_f	grams (g)
Fuel use	Q_f	typically, kg/hr
PM_{10} concentration	C_{PM}	grams/dscm
Metered volume at standard temperature and pressure	$V_{m, STP}$	dscm
Moisture	R	percent
Temperature	T	degrees celsius
Brick or clay production	A	tonnes/year
Annual operating hours	OpHrs	hours/year

QLD Department of the Environment, 1998

An example summary of a test method is shown in Table 4. 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 dscms. 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 dscm. 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.

$$C_{PM} = C_f \div V_{m, STP} \tag{1}$$

where:

C_{PM} = concentration of PM or gram loading (grams/dscm)
C_f = filter catch (grams)
$V_{m,STP}$ = metered volume of sample at STP (dscm)

$$E_{PM} = C_{PM} \text{ x } Q_d \text{ x } 3\,600 \div 1\,000 \tag{2}$$

where:

E_{PM} = hourly emissions of PM in kg/hr
Q_d = stack gas volumetric flow rate (dscms)
3 600 = seconds/hr
1 000 = grams per kg

Table 4.   Stack Sample Test Results

Parameter	Symbol	Test 1	Test 2	Test 3
Total sampling time (secs)	sec	7 200	7 200	7 200
Moisture collected (grams)	grams	395.6	372.6	341.4
Filter catch (grams)	C_f	0.0851	0.0449	0.0625
Average sampling rate (dscms)	dscms	1.67×10^{-4}	1.67×10^{-4}	1.67×10^{-4}
Standard metered volume (dscm)	$V_{m, STP}$	1.185	1.160	1.163
Volumetric flow rate (acms or dscms)	Q_a or Q_d	8.48	8.43	8.45
Concentration of particulate (grams/dscm)	C_{PM}	0.00467	0.00252	0.00350
Particulate emission rate (kg/hr)	E_{PM}	2.20	1.19	1.65

QLD Department of Environment, 1998

Example 1.
PM emissions calculated using Equations 1. and 2. and the stack sampling data for Test 1 (presented in Table 4.) are shown below:

$$C_{PM} = C_f \div V_{m, STP}$$
$$= 0.085 \div 1.185$$
$$= 0.072 \text{ grams/dscm}$$

$$E_{PM} = C_{PM} \times Q_d \times 3600 \div 1\,000$$
$$= 0.072 \times 8.48 \times (3\,600 \text{ seconds/hr}) \div (1kg/1\,000grams)$$
$$= 2.20 \text{ kg/hour}$$

The information from some stack tests may be reported in kilograms of particulate per kilograms of exhaust gas (wet). Use Equation (3) to calculate the dry particulate emissions in kg/hr.

$$E_{PM} = Q_a \div 1\,000 \times 3\,600 \times 1.2 \ (1 - R) \times [293 \div (273 + T)] \qquad (3)$$

where:

E_{PM}	=	hourly emissions in kg/hr of PM
Q_a	=	actual cubic metres of exhaust gas per second (acms)
1 000	=	1 000 kg exhaust gas per kg of PM
3 600	=	3 600 seconds per hour
1.2	=	1.2 kg/m^3
R	=	moisture content (%)
293	=	293K
273	=	273K
T	=	stack gas temperature in °C

7.1   Using 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 carbon monoxide emitted per tonne of bricks produced). Table 5 provides emission factors for ceramic products - PM$_{10}$ and lead, and Tables 6-10 provides some additional emission factors.

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

$$E = A \times T \times EF \times [1 - (ER/100)] \qquad (4)$$

where :

E = emissions;
A = activity rate (usually production rate);
T = time (or another variable);
EF = uncontrolled emission factor; and
ER = overall emission reduction efficiency, %.

To determine PM_{10} emissions from PM, it may be necessary for facility operators to first undertake a sizing analysis of the stack filter catch. The weight PM_{10} fraction can then be multiplied by the total PM emission rate to produce a PM_{10} number.

Emission factors developed from measurements for a specific brick kiln or process may sometimes be used to estimate emissions at other sites. Should a company operate several units of similar size and configuration and if emissions were measured from one brick kiln or kiln process, an emission factor could be developed and applied to similar kilns and processes. As previously mentioned, it is advisable to have the emission factor reviewed and approved by your local environmental authority prior to its use for NPI estimations.

Example 2.
Table 6. shows that 1.65kg of carbon monoxide (CO) are emitted for each tonne of bricks produced from an uncontrolled gas-fired tunnel kiln. It is assumed that the brick plant operates for 1 500 hours per year.

$EF_{carbon\ monoxide}$	=	1.65kg/tonne
Brick production rate	=	250 tonnes/hour
CO emissions	=	$EF_{carbon\ monoxide}$ x brick production rate x operating time
	=	1.65 x 250 x 1 500
	=	412.5 kg/hr x (1 tonne ÷ 1 000kg) x 1 500 hr/yr
	=	618.75 tonnes per year

Table 5.   Emission Factors for Ceramic Products –PM$_{10}$ and Lead [1,a]

Process	PM$_{10}$ (kg/tonne)	Factor Rating	Lead (kg/tonne)	Factor Rating
Raw material crushing and screening line with fabric filter[b]	0.06	D	ND	N/A
Dryer[c]	1.15	E	ND	N/A
Cooler[c]	0.055	E	ND	N/A
Granualtion - natural gas fired spray dryer - with fabric filter[d] - with venturi scrubber[e]	0.03 0.095	E D	ND ND	N/A N/A
Firing - natural gas fired kiln	0.245	D	ND	N/A
Refiring - natural gas fired kiln[e]	0.0335	E	ND	N/A
Ceramic glaze spray booth - uncontrolled[f] - with wet scrubber[g]	9.5 0.9	E D	1.5 ND	E N/A

[1] USEPA AP-42 Section 11.7 (1996).

[a] Emission factors are expressed as kg of substance emitted per tonne of ceramic clay product produced (unless otherwise stated). ND = no data , N/A = not applicable

[b] Emission factor for raw material processing of quarry tile. Emissions expressed as kg pollutant per tonne material processed

[c] Emissions expressed as kg pollutant per tonne of dry material produced

[d] Emissions expressed as kg pollutant per tonne of dry material produced

[e] Kiln is used for refiring tile after application of decals, paint or ink screening

[f] Emissions expressed as kg pollutant per tonne of glaze used. (~24% lead oxide in glaze)

[g] Emissions expressed as kg pollutant per tonne of glaze used

Table 6. Emission Factors for Ceramic Products Manufacturing - Uncontrolled [1,a]

Emission Factor Rating E (Other Pollutants)

Source	SO_2	NO_X	CO	VOC[b]	HF[c]	Fluorides[c]
Firing Natural Gas fire kiln - Sulphur content (of raw material) > 0.07% - Sulphur content (of raw material) < 0.07%	22*S[d] 4.75*S[d]	0.27 0.27	1.65 1.65	0.215 0.215	0.23 0.23	0.28 0.28
Refiring Natural Gas fired kiln	ND	ND	ND	ND	ND	0.0095
Forming tape casters[e]	ND	ND	ND	29	ND	ND

[1] USEPA AP-42 Section 11.7 (1996)

[a] Emissions are expressed as kg pollutant per tonne of ceramic product produced unless otherwise specified. ND = no data. Factors are uncontrolled unless otherwise stated

[b] Total VOC reported on a propane basis.

[c] Total Fluoride comprises HF emissions, but only total fluoride compounds require NPI reporting. A mass balance on fluorine will yield a better estimate on fluoride emissions for individual facilities.

[d] S = sulphur content of natural gas and raw material.

[e] Emissions expressed as kg of pollutant per tonne of product formed. Controlled by an afterburner

Table 7.   Emission Factors for Brick Manufacturing [1,a]

Emission Factor Rating E (Criteria Pollutants)

Process	PM_{10}	SO_2[b]	CO	Oxides of Nitrogen
Primary Crusher with Fabric Filter	0.000295	N/A	N/A	N/A
Grinding and Screening Operations				
- processing dry material	0.265	N/A	N/A	N/A
- processing wet material	0.00115	N/A	N/A	N/A
- with fabric filter	0.0016	N/A	N/A	N/A
Extrusion Line with fabric filter	0.0018	N/A	N/A	N/A
Brick Dryer with supplemental gas burner	N/A	N/A	0.155	0.049
Natural gas fired kiln	0.435	0.39	0.6	0.175
Natural gas fired kiln firing high sulphur material				
- uncontrolled	0.435	2.55	0.6	0.175
- with medium efficiency wet scrubber	0.435	0.5	0.6	0.175
- with high efficiency packed bed scrubber	0.435	0.00245	0.6	0.175
Coal fired kiln				
- uncontrolled	0.7	0.6	0.4	0.255
- with fabric filter	ND	ND	ND	ND
Sawdust fired kiln	0.425	0.435	0.8	0.185
Sawdust fired kiln and sawdust dryer	0.6505	ND	ND	ND

[1] USEPA AP-42 Section 11.3 (1997).

[a] Units are expressed as kilograms of substance emitted per tonne of bricks produced.
  ND = no data available. N/A = not applicable
  Average mass of one brick = 3kg .

[b] S = % sulphur in coal, typical sulphur content of Australian black coal = 0.5 percent. SO_2 emissions can be estimated using a mass balance on sulphur. To develop emission factors based on a mass balance, the sulphur percentage must be presented as a percentage of dry raw material, since the emission factor is based on brick production (dry) rather than raw material (wet) basis. Since SO_3 emissions are generally small, it can be assumed that total SO_X is SO_2. When using coal or other hydrocarbon based fuels, the sulphur content of these fuels must be accounted for in the mass balance.

Table 8.   Emission Factors for Brick Manufacturing - **Uncontrolled** [1,a]

Emission Factor Rating E (Other)

Process	Total Fluorides	HCl	Total VOCs
Coal fired tunnel kiln	ND	ND	ND
Sawdust or natural gas fired kiln			
- uncontrolled	0.295	0.085	ND
- with dry scrubber[b]	0.014	ND	ND
- with medium efficiency wet scrubber[c]	0.09	ND	ND
- with high efficiency packed bed scrubber	0.00065	ND	ND
Brick Dryer	ND	ND	0.015
Brick Dryer with supplemental gas burner	ND	ND	0.015
Brick Kiln	ND	ND	0.012
Sawdust fired kiln and sawdust dryer	ND	ND	0.09

[1] USEPA AP-42 Section 11.3 (1997).

[a] Units are expressed as kilograms of substance emitted per tonne of bricks produced.
  ND = no data available. N/A = not applicable
  Average mass of one brick = 3kg.

[b] Dry scrubber using limestone as a sorption medium

[c] Kiln firing material with a high fluorine content. Uses soda-ash/water solution.

Table 9. **Emission Factors for Brick Manufacturing - VOCs Speciated Uncontrolled [1,a]**

Emission Factor Rating E

Source	Substance	Emission Factor kg/tonne
Coal Fired Kiln	Acetone	3.40×10^{-4}
	Benzene	1.45×10^{-4}
	Carbon Disulphide	1.15×10^{-6}
	Chloroethane	0.55×10^{-5}
	Chloroform	0.5×10^{-7}
	Dibenzofuran	1.8×10^{-7}
	Ethylbenzene	1.05×10^{-5}
	Xylene	8.85×10^{-5}
	Phenol	1.75×10^{-5}
	Styrene	0.5×10^{-7}
	Tetrachloroethane	0.5×10^{-7}
	Trichloroethane	0.5×10^{-7}
	Toluene	1.25×10^{-4}
Natural Gas Fired Kiln	Acetone	0.00085
	Benzene	0.00145
	Carbon Disulphide	2.15×10^{-5}
	Chlorine	0.00065
	Chloroethane	0.000235
	Ethylbenzene	2.2×10^{-5}
	Xylene	6.25×10^{-5}
	Phenol	4.3×10^{-5}
	Styrene	1.0×10^{-5}
	Tetrachloroethane	1.4×10^{-6}
	Toluene	0.0008
Sawdust Fired Kiln	Acetone	1.95×10^{-4}
	Acrylonitrile	7.5×10^{-6}
	Benzene	2.6×10^{-4}
	Carbon Disulphide	7.8×10^{-6}
	Chloroform	1.5×10^{-7}
	Dibenzofuran	7.5×10^{-6}
	Ethylbenzene	4.25×10^{-6}
	Methylene Chloride	3.75×10^{-6}
	Xylene	1.64×10^{-5}
	Phenol	3.6×10^{-5}
	Styrene	2.2×10^{-7}
	Tetrachloroethane	1.5×10^{-7}
	Toluene	5.5×10^{-5}
	Trichloroethane	1.5×10^{-7}

Table 9. Emission Factors for Brick Manufacturing - VOCs Speciated (contd)

Source	Substance	Emission Factor kg/tonne
Sawdust fired kiln and sawdust dryer	Acetone	0.0005
	Acrylonitrile	9.5×10^{-6}
	Benzene	2.8×10^{-4}
	Carbon Disulphide	9.0×10^{-6}
	Chloroform	1.9×10^{-7}
	Dibenzofuran	1.2×10^{-9}
	Ethylbenzene	5.0×10^{-6}
	Methylene Chloride	3.1×10^{-5}
	Xylene	1.815×10^{-5}
	Phenol	5.0×10^{-5}
	Styrene	2.1×10^{-6}
	Tetrachloroethane	1.9×10^{-7}
	Toluene	2.15×10^{-4}
	Trichloroethane	1.9×10^{-7}

[1] USEPA AP-42 Section 11.3 (1997).

[a] Units are expressed as kilograms of substance emitted per tonne of bricks produced.
   ND = no data available. N/A = not applicable
   Average mass of one brick = 3kg.

[b] Dry scrubber using limestone as a sorption medium

[c] Kiln firing material with a high fluorine content. Uses soda-ash/water solution.

Table 10.   Emission Factors for Brick Manufacturing - Uncontrolled [1]

Source	Substance	Emission Factor kg/tonne
Kiln	Antimony	1.35×10^{-5}
	Cadmium	7.5×10^{-6}
	Chromium	2.55×10^{-5}
	Cobalt	1.05×10^{-6}
	Lead	7.5×10^{-5}
	Nickel	3.6×10^{-5}
	Selenium	1.15×10^{-4}
Coal Fired Kiln	Arsenic	6.5×10^{-5}
	Beryllium	8.0×10^{-6}
	Manganese	1.45×10^{-5}
	Mercury	4.8×10^{-5}
Natural Gas Fired Kiln	Arsenic	1.55×10^{-5}
	Beryllium	2.1×10^{-7}
	Manganese	1.45×10^{-4}
	Mercury	3.75×10^{-6}
Sawdust Fired Kiln	Arsenic	1.55×10^{-5}
	Beryllium	2.1×10^{-7}
	Manganese	0.0065
	Mercury	3.75×10^{-6}
Sawdust Fired Kiln and Sawdust Dryer	Antimony	1.4×10^{-6}
	Arsenic	1.05×10^{-5}
	Beryllium	1.55×10^{-7}
	Cadmium	1.1×10^{-5}
	Chromium	2.4×10^{-5}
	Lead	6.0×10^{-5}
	Manganese	2.4×10^{-4}
	Mercury	5.5×10^{-6}
	Nickel	1.7×10^{-5}
	Selenium	2.35×10^{-5}

[1] USEPA AP-42 Section 11.3 (1997).

[a] Units are expressed as kilograms of substance emitted per tonne of bricks produced.
  ND = no data available. N/A = not applicable
  Average mass of one brick = 3kg.

7.2   Using Fuel Analysis Data

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

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

$$E_x \quad = Q_f \text{ x pollutant concentration in fuel x T x } (MW_p \div EW_f) \quad (5)$$

where:

E_x	=	emissions of pollutant x
Q_f	=	fuel use (kg/hr)
T	=	time (or another variable)
MW_p	=	molecular weight of pollutant emitted (kg/kg-mole)
EW_f	=	elemental weight of pollutant in fuel (kg/kg-mole)

For instance, SO_2 emissions from oil combustion can be calculated based on the concentration of sulphur in the oil. This approach assumes complete conversion of sulphur to SO_2. Therefore, for every kilogram of sulphur (EW = 32) burned, two kilograms of SO_2 (MW = 64) are emitted. The application of this emission estimation technique is shown in Example 3.

Example 3.
This example shows how SO_2 emissions can be calculated from oil combustion based on fuel analysis results and the fuel flow information. The brick plant is assumed to operate 2 500 hours per year.

E_{SO2} = may be calculated using Equation (5)

Assume a given Q_f =   2 000 kg/hr
Weight percent sulphur in fuel   =   1.17

E_{SO2} = Q_f x pollutant concentration in fuel x T x (MW_p ÷ EW_f)
               = (2 000) x (1.17 ÷ 100) x (2 500) x (64 ÷ 32)
               = 46.8kg/hr x tonne/1 000 g x 2 500 hr/yr
               = 117 tonnes/year

7.3   Using CEMS Data

To monitor SO_2, NO_x, VOC, and CO emissions using a CEMS, a facility uses a pollutant concentration monitor, which measures concentration in parts per million by volume dry air (ppmvd). 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 stack. Emission rates (kg/hr) are then calculated by multiplying the stack gas concentrations by the stack gas flow rates.

Table 11 (overleaf) presents example CEM data output averaged for three periods for a brick kiln. The output includes pollutant concentrations in parts per million dry basis (ppmvd), diluent (O_2 or CO_2) concentrations in percent by volume dry basis (%v,d), and emission rates in kilograms per hour (kg/hr). This data represents a snapshot of a brick 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 derived by adding the hourly emission estimates if the CEMS data is representative of representative operating conditions.

Although CEMS can report real-time hourly emissions automatically, it may be necessary to manually estimate annual emissions from hourly concentration data. This sub-Section details 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, facilities should develop a protocol for collecting and averaging the data in order that the estimate satisfies the State/Territory environmental authorities requirements for NPI emissions estimations.

Table 11. Example CEM Output Averaged for a Brick Kiln Firing Waste Fuel Oil

Time	O₂ (%V)	Concentration (C) (ppmvd)				Gas Flow Rate (Q)	Emission Rate (E) (kg/hr)				Oil Use Rate (A) (tonnes / hour)
		SO₂	NOₓ	CO	VOC		SO₂	NOₓ	CO	VOC	
1	10.3	150.9	142.9	42.9	554.2	8.52	12.34	11.69	1.54	11.33	29
2	10.1	144.0	145.7	41.8	582.9	8.48	11.72	11.86	1.49	11.86	29
3	11.8	123.0	112.7	128.4	515.1	8.85	10.45	9.57	4.77	10.94	27

QLD Department of Environment, 1998

Hourly emissions can be based on concentration measurements as shown in Equation (6) and Example 4.

$$E_x = (C \times MW \times Q \times 3\,600) \div (V \times 10^6) \qquad (6)$$

where:

E_x =   hourly emissions in kg/hr of pollutant x
C   =   pollutant concentration in ppmvd
MW   =   molecular weight of the pollutant (kg/kg-mole)
Q   =   stack gas volumetric flow rate in dscms
3 600   =   seconds per hour
V   =   volume occupied by one mole of gas at standard temperature and pressure (22.4 m³/kg-mole at 20°C and 1 atmosphere)

Actual emissions in tonnes per year can be calculated by multiplying the emission rate in kg/hr by the number of actual operating hours (OpHrs) as shown in Equation (7) and Example 4.

$$E_{tpy,x} = E_x \times OpHrs \div 1\,000 \qquad (7)$$

where:

$E_{tpy,x}$ =   annual emissions in tonnes/year of pollutant x
E_x =   hourly emissions in kg/hr of pollutant x
OpHrs   =   annual operating hours in hr/yr

Emissions in kilograms of pollutant per tonne of fuel oil consumed can be calculated by dividing the emission rate in kg/hr by the oil consumption rate (tonnes/hr) during the same period (Equation (8)) 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 that longer time periods should be used for NPI reporting where they are available. Use of the calculation is shown in Example 4.

$$E_{tpy,x} = E_x \div A \qquad\qquad (8)$$

where:

$E_{tpy,x}$ = emissions of pollutant x (kg/tonnes) per tonne of fuel oil consumed

E_x = hourly emissions in kg/hr of pollutant x

A = fuel oil consumption (tonnes/hr)

Example 4.
This example shows how SO_2 emissions can be calculated using Equation (6) based on the average CEMS data for Time Period 1 shown in Table 11.

$$
\begin{aligned}
E_{SO2} &= (C \times MW \times Q \times 3\,600) \div (V \times 10^6) \\
&= (150.9 \times 64 \times 8.52 \times 3\,600) \div (22.4 \times 10^6) \\
&= 296\,217\,907 \div 22\,400\,000 \\
&= 13.22 \text{kg/hr}
\end{aligned}
$$

Emissions in tonnes/yr (based on a 2 500 hr/yr operating schedule) can then be calculated using Equation (7); however, based on the above period this estimate should be calculated from the average CEMS data for a year using Equation (6):

$$
\begin{aligned}
E_{tpy,SO2} &= E_{SO2} \times OpHrs \div 1\,000 \\
&= 13.22 \times (2\,500 \div 1\,000) \\
&= 33.05 \text{ tonnes per year}
\end{aligned}
$$

Emissions, in terms of kg/tonne of oil consumed, are calculated using Equation (8):

$$
\begin{aligned}
E_{tpy,SO2} &= E_{SO2} \div A \\
&= 13.22 \div 29 \\
&= 0.456 \times 10^{-2} \text{ kg } SO_2 \text{ emitted per tonne of fuel oil consumed}
\end{aligned}
$$

7.4   Using Predictive Emissions Monitoring

Emissions from Ceramics, brick and clay manufacturing processes depend on several variables, discussed in Section 3.0 of this Manual. For example, VOC process emissions for a given facility may vary with regards to several parameters, including:

(a) the type of fuel burned;
(b) the relative quantities of various fuel constituents;
(c) the firing configuration employed; and
(d) the fuel combustion rate.

An example of predictive emissions monitoring that could be used to develop a PEM protocol for acceptable NPI reporting would need to account for the variability in these parameters and, consequently, may require a complex testing algorithm.

To develop this algorithm, correlation testing of the process variables could be conducted over a range of potential operating conditions for a suite of listed Inventory substances including VOCs and SO_2. Based on the test data, a mathematical correlation can be developed which predicts emissions using the various parameters.   This method may be cost prohibitive for a single source and may need to be undertaken across the Australian brick and clay products industry generally.

8.0   Control Technologies

8.1   Brick Products

The re-use of particulate and other emissions generated by air pollution control equipment is one preventative option available to facilities that produce structural clay and brick products. Clay product manufacturers may use wet scrubbing to treat particulate emissions.   The waste and emissions generated by wet scrubbers can often be returned to the production process as a raw material substitute replacing clay, or other alkaline additives.

8.2   Pottery Products

Product substitution is one means of reducing paint emissions and wastes generated by facilities engaged in the finishing of pottery products. Water-based finishes, including paints and enamels, can be substituted for solvent-based finishes thereby reducing the amount of volatile emissions

from finishing processes. The use of water-based finishes may, however, result in hazardous waste generation and wastewater emissions.

Pottery manufacturers can recycle emissions recovered from pollution control devices. The dry particulate emissions recovered from air pollution control equipment is virtually identical in composition to the tile and ceramic product itself, and therefore can be recycled as raw materials into the body preparation process. The overspray dust gathered in dust collectors can also be recovered. Enamel overspray from finishing operations can be reused if it isn't contaminated. Enamel overspray is often washed down and collected in settling pits where it can be reclaimed and re-introduced into the process as a raw material.

8.3 Abatement Equipment

Abatement equipment and control technologies, (eg. electrostatic precipitators and fabric filters, etc) are often used to reduce emissions in the ceramics industry. If these, or other abatement equipment are installed at your facility, or if you have implemented work practices at your facility that reduce emissions, you should multiply the control efficiency of the technology or the practice adopted, by the appropriate emission factors.

Air emission control technologies, such as electrostatic precipitators, fabric filters or baghouses, and wet scrubbers, are commonly installed to reduce the concentration of particulates in process off-gases before stack emission. Where such emission abatement equipment has been installed, and where emission factors from uncontrolled sources have been applied in an emission estimation, the collection efficiency of the abatement equipment needs to be considered. Guidance on applying collection efficiencies to emission factor equations is provided in earlier sections.

In the absence of measured data, or knowledge of the collection efficiency for a particular piece of equipment, an efficiency of 0.9 should be used in the emission factor equation to calculate actual mass emissions.

9.0   References

Eastern Research Group. July 1997. *Introduction To Stationary Point Source Emission Inventory Development Volume II: Chapter 1.* Morrisville, NC, USA.

Economopoulos A. P. 1993. *Assessment of Sources of Air, Water, and Land Pollution. A Guide to Rapid Source Inventory Techniques and their use in Formulating Environmental Control Strategies. Part One: Rapid Inventory Techniques in Environmental Pollution.* World Health Organisation, Geneva, Switzerland.

EMEP/CORINAIR. (1996). *AIR: Atmospheric Emission Inventory Guidebook.* European Environment Agency, Copenhagen, Denmark.

USEPA. October 1992. *VOC / PM Speciation Data System - Version 1.50.* United States Environmental Protection Agency, Office of Air Quality Planning and Standards. Research Triangle Park, NC, USA.

USEPA. September 1995. *EPA Office of Compliance Sector Notebook Project. Profile of the Stone, Clay, Glass, and Concrete Products Industry.* United States Environmental Protection Agency, Office of Enforcement and Compliance Assurance. Washington, DC, USA.

USEPA. July 1996. *Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources, fourth edition, AP-42. Section 11.7 Ceramic Clay Manufacturing.* United States Environmental Protection Agency, Office of Air Quality Planning and Standards. Research Triangle Park, NC, USA.

USEPA. August 1997. *Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources, fourth edition, AP-42. Section 11.3 Bricks and Related Clay products.* United States Environmental Protection Agency, Office of Air Quality Planning and Standards. Research Triangle Park, NC, USA.