



Australian Government

Department of the Environment and Heritage



National Pollutant Inventory

# **Emission Estimation Technique Manual**

**for**

## **Ammonium Sulfate Manufacturing**

### **Version 2.0 12 March 2004**

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## **Erratum – version 2.0 – 12 March 2004**

### **Ammonia Sulfate Manufacturing**

## **Update (from first version published July 1999) – 12 March 2004 Erratum**

| Page | Outline of alteration  |
|------|--|
| 22   | Table 7 typographical error corrected. The pressure relief valve value should be 0.104 |

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**EMISSION ESTIMATION TECHNIQUES  
FOR  
AMMONIUM SULFATE MANUFACTURING**

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## AMMONIUM SULFATE MANUFACTURING

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## **1 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 ammonium sulfate manufacturing.

EET MANUAL:            Ammonium Sulfate Manufacturing

HANDBOOK:            Fertiliser Manufacturing

ANZSIC CODES:        2531

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 industry stakeholders.

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## 2 Processes and Emissions

The following section presents a brief description of the ammonium sulfate manufacturing industry and identifies likely sources of emissions of NPI-listed substances.

### 2.1 Process Description

Ammonium sulfate ( $[\text{NH}_4]_2\text{SO}_4$ ) is commonly used as a fertiliser, derived from natural gas. Figure 1 shows the process of deriving ammonia from natural gas. Ammonia is then combined with compounds to form the three types of ammonium sulfate fertilisers discussed in this Manual.

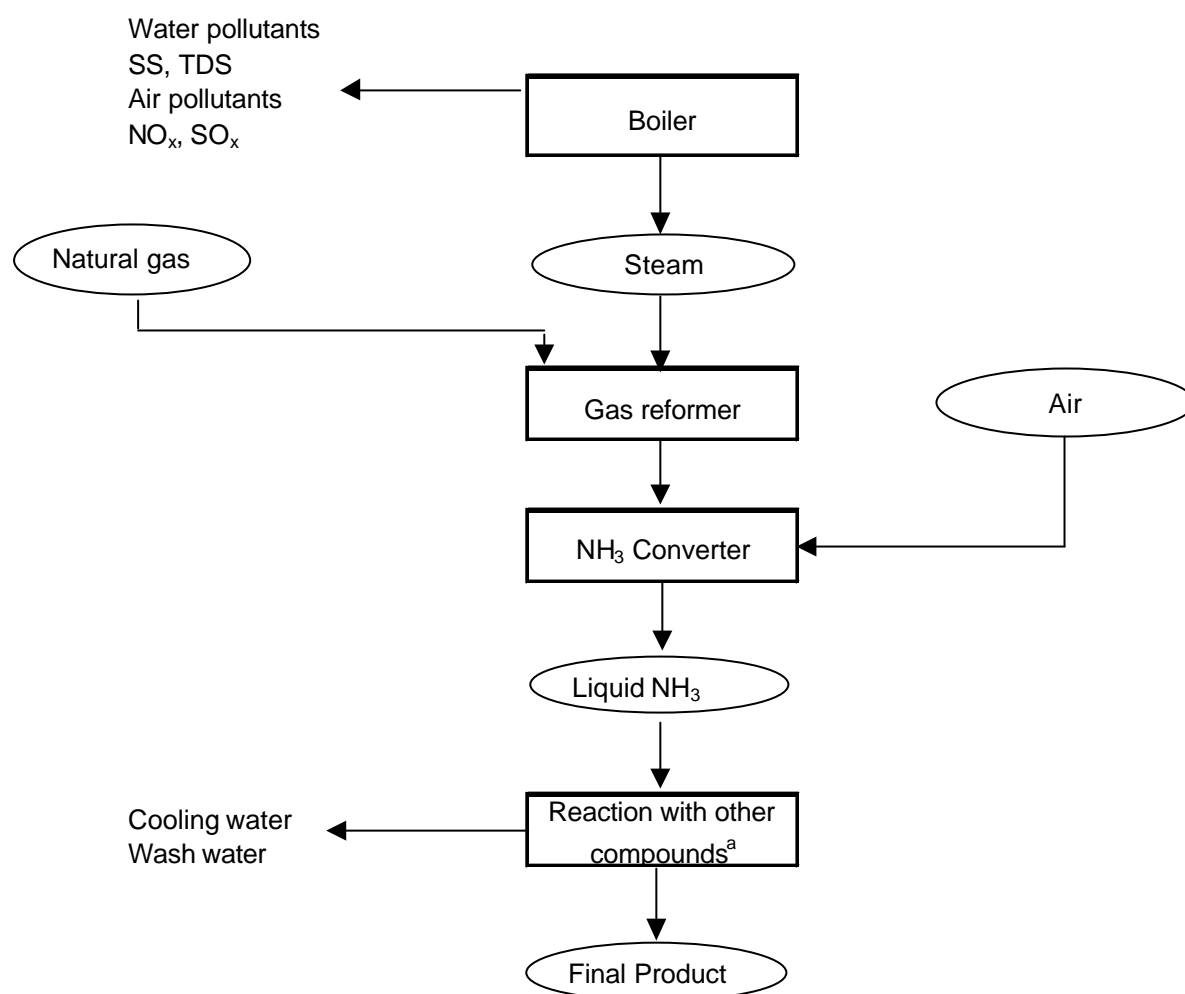
Ammonium sulfate is produced as a by-product from the caprolactam oxidation process stream and the rearrangement reaction stream. Synthetic ammonium sulfate is produced by combining anhydrous ammonia and sulfuric acid in a reactor. Coke oven by-product ammonium sulfate is produced by reacting the ammonia recovered from coke oven off-gas with sulfuric acid. Figure 2 is a diagram of typical ammonium sulfate manufacturing for three primary commercial processes.

After the formation of the ammonium sulfate solution, manufacturing operations of each process are similar. Ammonium sulfate crystals are formed by circulating the ammonium sulfate liquor through a water evaporator, which thickens the solution. Ammonium sulfate crystals are separated from the liquor in the centrifuge. In the caprolactam by-product process, the product is first transferred to a settling tank to reduce the liquid load on a centrifuge. The saturated liquor is returned to the diluted ammonium sulfate brine of the evaporator. The crystals are fed to either a fluidised-bed or a rotary drum dryer. Fluidised-bed dryers are continuously steam heated, while rotary dryers are fired directly with either oil or natural gas or may use steam-heated air.

At coke oven by-products plants, rotary vacuum filters may be used in place of a centrifuge and dryer. The crystal layer is deposited on the filter and is removed as a product. These crystals are generally not screened, although they contain a wide range of particle sizes. They are then carried by conveyors to bulk storage.

At synthetic plants, a small quantity of a heavy organic is added to the product after drying to reduce caking.

Dryer exhaust gasses pass through a particulate collection device, such as a wet scrubber. This collection controls emissions and reclaims residual product. After being dried, the ammonium sulfate crystals are screened into coarse and fine crystals. This screening is done in an enclosed area to restrict fugitive dust in the building.



Notes:

(a) This section refers to the three primary processes shown in Figure 2.

(b) SS = suspended solids; TDS = total dissolved solids

(c) NO<sub>x</sub> = Oxides of nitrogen; SO<sub>x</sub> = Sulfur dioxide

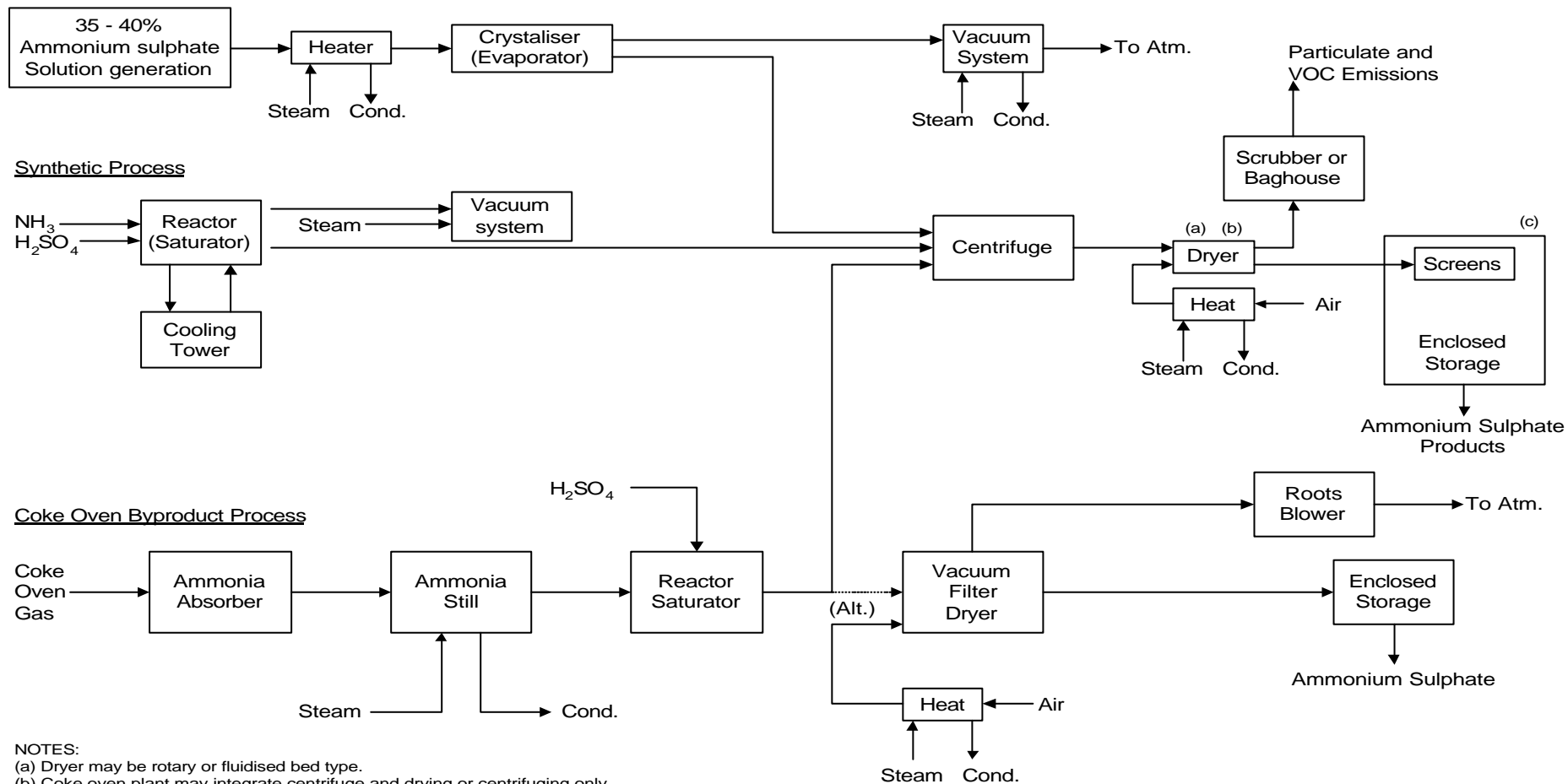
### Figure 1 - Nitrogen Fertiliser Processing and Associated Water Pollutants

Source: Griffith University, *Industrial Water and Waste Water Treatment* - Study Guide, 1996.

Figure 3 illustrates the manufacture of high nutrient value ammonium sulfate. Ammonia and sulfuric acid are combined in a special mixer reactor and the resultant reaction forms a slurry, which is sprayed into the granulator to produce ammonium sulfate in a granular form. The granulated product is passed through the dryer for drying before passing over the screens. On-size material is conveyed to storage for bagging or bulk dispatch and any off-size material is recycled to the granulator (Incitec, 1998).



### Caprolactam Byproduct Process

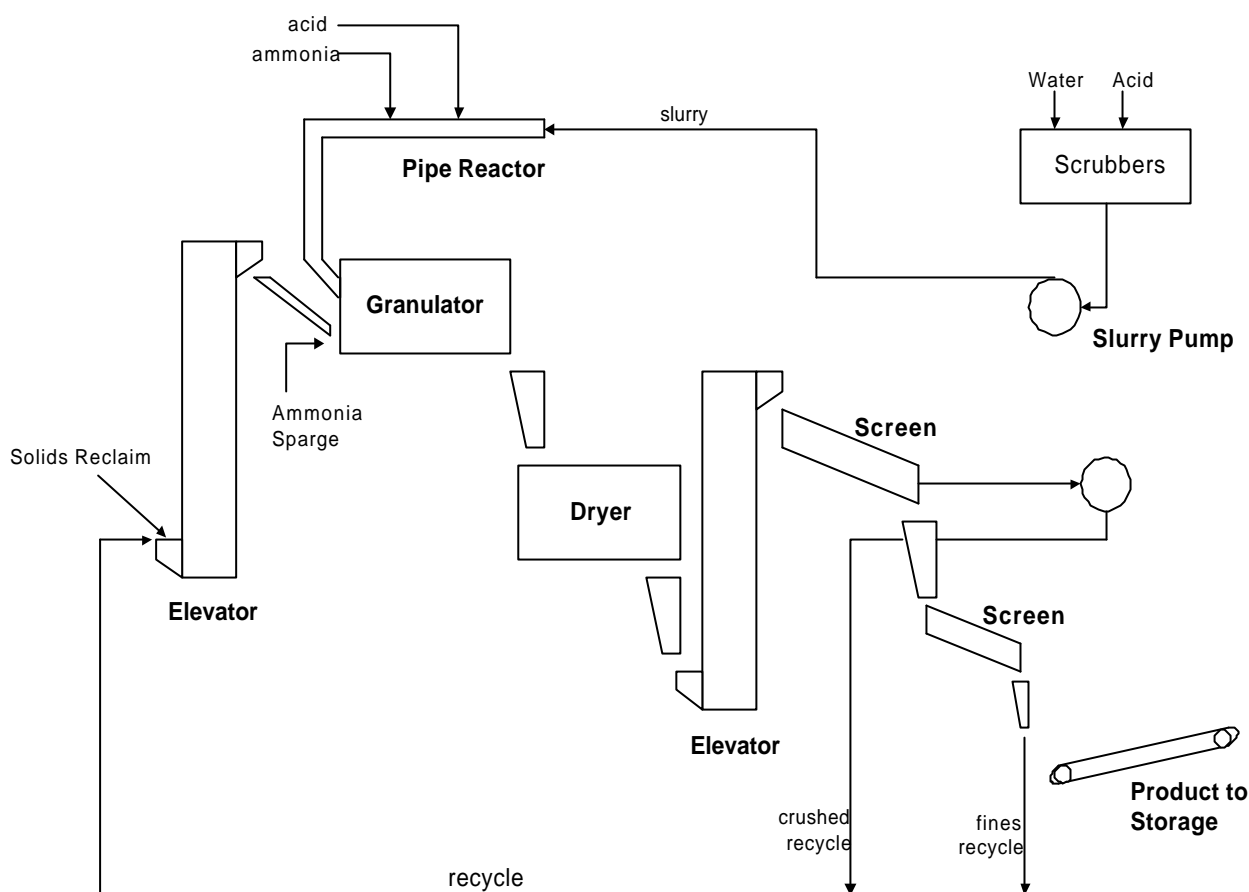


#### NOTES:

- (a) Dryer may be rotary or fluidised bed type.
  - (b) Coke oven plant may integrate centrifuge and drying or centrifuging only.
  - (c) Coke oven plant not screened.
- Atm. = atmosphere Alt. = alternative Cond. = condensate

**Figure 2 - Typical Diagram of Ammonium Sulfate Process**

Source: USEPA, AP 42, Section 8.4.1, 1993



**Figure 3 - Typical Granulation Plant**

Source: Incitec, 1998.

## 2.2 Emissions to Air

Air emissions may be categorised as either fugitive or point source emissions.

### 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. Some plants may have on-site boilers, so for emissions from the products of combustion in boilers, refer to the *Combustion in Boilers Emission Estimation Technique Manual*.

### Point Source Emissions

These emissions are exhausted into a vent or stack and emitted through a single point source into the atmosphere. Table 1 highlights common air emissions of NPI-listed substances from ammonium sulfate manufacturing processes.

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## 2.3 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.

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. This existing sampling data can be used to calculate annual emissions.

If no wastewater monitoring data exists, emissions to process water can be calculated based on a mass balance or using emission factors.

The discharge of listed substances to a sewer or tailings dam does not require reporting 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*.) Table 1 indicates listed substances likely to be emitted to water.

## 2.4 Emissions to Land

Emissions of substances to land on-site include solid wastes, slurries, and sediments. Emissions arising from spills, leaks, and storage and distribution of materials containing listed substances may also occur to land. These emission sources can be broadly categorised as:

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

**Table 1 - Common Emissions of NPI-Listed Substances from Ammonium Sulfate Manufacturing Processes**

| Substance                              | Emission Media |          |                 |
|--|----------------|----------|-----------------|
|  | To Atmosphere  | To Water | Via Solid Waste |
| Ammonia                                | X              | X        | X               |
| Total Nitrogen                         |                | X        |                 |
| Particulate Matter (PM <sub>10</sub> ) | X              |          |                 |
| Volatile Organic Compounds (VOCs)      | X              |          |                 |

Source: Queensland Department of Environment and Heritage, 1998

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### 3 Emission Estimation Techniques

This section presents equations and examples of calculations for estimating emissions of particulate matter (PM<sub>10</sub>), total VOCs, speciated organics, and inorganic substances (ammonia, total nitrogen) from ammonium sulfate manufacturing processes.

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** 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, **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.

**Table 2 - List of Variables and Symbols**

| Variable  | Symbol      | Units                                     |
|---|-------------|---|
| Annual emissions of pollutant i   | $E_{kpy,i}$ | kg/yr                                     |
| Hourly emissions of pollutant i   | $E_i$       | kg/hr or kg/hr/source                     |
| Substance entering the process  | $Q_{in}$    | kg/yr                                     |
| Substance leaving the process (as an emission, transfer, or in product) | $Q_{out}$   | kg/yr                                     |
| Filter catch  | $C_f$       | grams                                     |
| Moisture content  | $moist_R$   | %   |
| Overall control efficiency  | CE          | %   |
| Average weight fraction of pollutant i                                  | $WF_i$      | %   |
| Number of pieces of applicable equipment type                           | N           | unitless                                  |
| Volume of sample at standard temperature and pressure                   | $V_{m,STP}$ | m <sup>3</sup>                            |
| Volume of mixture containing substance i                                | $M_i$       | kg/yr                                     |
| Hourly volume of wastewater   | $V_w$       | L/hr                                      |
| Stack gas flow rate (actual)  | $Q_a$       | m <sup>3</sup> /s                         |
| Concentration of pollutant i  | $C_i$       | ppmv or g/m <sup>3</sup> or mg/L or mg/kg |
| Molecular weight of pollutant i   | $MW_i$      | kg/kg-mole                                |
| Stack gas volumetric flow rate (dry)                                    | $Q_d$       | m <sup>3</sup> /sec                       |
| Operating hours   | OpHrs       | hr/yr                                     |
| Emission factor for pollutant i   | $EF_i$      | kg/tonne or kg/units                      |
| Activity factor   | A           | tonnes/hr or units/h                      |
| Temperature   | T           | °C  |

Source: Queensland Department of Environment and Heritage, 1998.

### 3.1 Using Sampling or Direct Measurement

#### 3.1.1 For Emissions to Atmosphere

##### **Particulate Matter (PM<sub>10</sub>) Emissions**

Stack sampling test reports often provide emissions data in terms of kg/hr or g/m<sup>3</sup> (dry standard). Annual emissions for NPI reporting can be calculated from this data. Stack tests

for NPI reporting should be performed under representative or normal operating conditions. Some tests undertaken for a State or Territory license condition may require that the test be taken under maximum emissions rating, where emissions are likely to be higher than when operating under normal operating conditions. Data from these tests may need to be *scaled back* for NPI reporting purposes.

An example summary of a test method is shown in Table 3. 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<sup>3</sup>. 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<sup>3</sup>.

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

#### Equation 1

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

where:

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

#### Equation 2

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

where:

$$\begin{aligned} E_{PM} &= \text{hourly emissions of PM (kg/hr)} \\ Q_d &= \text{stack gas volumetric flow rate (m}^3\text{/s)} \\ 3.6 &= \text{3 600 seconds per hour multiplied by 0.001 kilogram per hour} \end{aligned}$$

**Table 3 - 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 <sup>3</sup> /s)        |              | $1.67 * 10^{-4}$ | $1.67 * 10^{-4}$ | $1.67 * 10^{-4}$ |
| Standard metered volume (m <sup>3</sup> )        | $V_{m, STP}$ | 1.185            | 1.160            | 1.163            |
| Volumetric flow rate (m <sup>3</sup> /s), dry    | $Q_d$        | 8.48             | 8.43             | 8.45             |
| Concentration of particulate (g/m <sup>3</sup> ) | $C_{PM}$     | 0.0718           | 0.0387           | 0.0537           |

Source: Queensland Department of Environment and Heritage, 1998

### Example 1 - Estimating Particulate Matter (PM<sub>10</sub>) Emissions

PM emissions calculated using Equation 1 and Equation 2 and the stack sampling data for Test 1 (presented in Table 3) and an exhaust gas temperature of 150°C (423K)). This is shown below:

$$\begin{aligned}C_{PM} &= C_f / V_{STP} \\&= 0.085 / 1.185 \\&= 0.072 \text{ g/m}^3 \\E_{PM} &= C_{PM} * Q_d * 3.6 * [273 / (273 + T)] \\&= 0.072 * 8.48 * 3.6 * (273 / 423K) \\&= 1.42 \text{ kg/hr}\end{aligned}$$

The information from some stack tests may be reported in grams of particulate per cubic metre of exhaust gas (wet). Use **Error! Reference source not found.** to calculate the dry particulate emissions in kg/hr.

### Equation 3

$$E_{PM} = Q_a * C_{PM} * 3.6 * \left(1 - \frac{\text{moist}_R}{100}\right) * \left[\frac{273}{(273 + T)}\right]$$

where:

$$\begin{aligned}E_{PM} &= \text{hourly emissions of PM in kilograms per hour, kg/hr} \\Q_a &= \text{actual (ie. wet) cubic metres of exhaust gas per second, m}^3/\text{s} \\C_{PM} &= \text{concentration of PM or gram loading, g/m}^3 \\3.6 &= 3600 \text{ seconds per hour multiplied by } 0.001 \text{ kilograms per gram} \\\text{moist}_R &= \text{moisture content, \%} \\273 &= 273 \text{ K (0}^\circ\text{C)} \\T &= \text{stack gas temperature, } ^\circ\text{C}\end{aligned}$$

Total suspended particulates (TSP) are also referred to as total particulate matter (total PM). To determine PM<sub>10</sub> from total PM emissions, a size analysis may need to be undertaken. The weight PM<sub>10</sub> fraction can then be multiplied by the total PM emission rate to produce PM<sub>10</sub> emissions. Alternatively, assume that 100% of PM emissions are PM<sub>10</sub>; 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.

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

where

moist<sub>R</sub> = moisture content, %  
g<sub>moist</sub> = moisture collected, g  
V<sub>m,STP</sub> = metered volume of sample at STP, m<sup>3</sup>  
ρ<sub>STP</sub> = dry density of stack gas sample, kg/m<sup>3</sup> at STP  
{if the density is not known a default value of 1.62 kg/m<sup>3</sup> may be used. This assumes a dry gas composition of 50% air, 50% CO<sub>2</sub>}

#### Example 2 - Calculating Moisture Percentage

A 1.2m<sup>3</sup> sample (at STP) of gas contains 410g of water. To calculate the moisture percentage use Equation 4.

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

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

#### Gaseous Emissions

Sampling test methods can be used to estimate inorganic pollutant emission rates from ammonium sulfate manufacturing processes. Airflow rates can be determined from flow rate metres or from pressure drops across a critical orifice.

Sampling test reports often provide chemical concentration data in parts per million by volume (ppmv).



---

If the concentration is known, an hourly emission rate can be determined using Equation 5:

**Equation 5**

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

where:

|        |   |  |
|--------|---|--|
| $E_i$  | = | total emissions of pollutant i, kg/hr  |
| $C_i$  | = | concentration of pollutant i, ppmv   |
| $MW_i$ | = | molecular weight of pollutant i, kg/kg-mole  |
| $Q_d$  | = | stack gas volumetric flow rate, m <sup>3</sup> /s  |
| 22.4   | = | volume occupied by 1 mole of ideal gas at standard temperature and pressure (0 °C and 101.3kPa), m <sup>3</sup> /kg-mole |
| 3 600  | = | conversion factor, s/hr  |
| T      | = | temperature of gas sample, °C  |

Emissions in kilograms per year can be calculated by multiplying the average hourly emission rate (kg/hr) from Equation 5 by the number of operating hours (shown in Equation 6 below) or by multiplying an average emission factor (kg/L) by the total annual amount of material used (L).

**Equation 6**

$$E_{kpy,i} = E_i * OpHrs$$

where:

|             |   |  |
|-------------|---|--|
| $E_{kpy,i}$ | = | annual emissions of pollutant i, kg/yr       |
| $E_i$       | = | total hourly emissions of pollutant i, kg/hr |
| OpHrs       | = | annual operating hours, hr/yr                |

Concentration data obtained from source testing may come in a variety of units, including parts per million volume (ppmv), or grams per cubic metre (g/m<sup>3</sup>), and in a variety of conditions, such as wet, dry, or excess O<sub>2</sub>. This may require conversion of concentration data to consistent units for compatibility with the equations given above. Example 3 illustrates the use of Equation 5 and Equation 6.

### Example 3 - Estimating Ammonia Emissions to Atmosphere

This example shows how annual ammonia (NH<sub>3</sub>) emissions can be calculated using the data obtained from a stack or other point-source emission point from a plant manufacturing ammonium sulfate. Using a known ammonia concentration and an exhaust gas temperature of 150 °C (423K), hourly emissions are calculated using Equation 5, and annual emissions are calculated using Equation 6.

Given:

|       |   |                              |        |   |                          |
|-------|---|------------------------------|--------|---|--------------------------|
| $C_i$ | = | 15.4 ppmv                    | $MW_i$ | = | 17 kg/kg-mole of ammonia |
| $Q_d$ | = | 8.48 m <sup>3</sup> /s       | OpHrs  | = | 1 760 hr/yr              |
| $M$   | = | 22.4 m <sup>3</sup> /kg-mole | $T$    | = | 150 °C                   |

Hourly emissions of NH<sub>3</sub> are calculated using Equation 5:

$$\begin{aligned} E_{NH_3} &= (C_i * MW_i * Q_d * 3600) / [22.4 * \{(T + 273)/273\} * 10^6] \\ &= (15.4 * 17 * 8.48 * 3600) / [22.4 * (423/273) * 10^6] \\ &= 7\,992\,330 / 34\,707\,692 \\ &= 2.303 * 10^{-1} \text{ kg/hr} \end{aligned}$$

Annual emissions of NH<sub>3</sub> are calculated using Equation 6:

$$\begin{aligned} E_{kpy,NH_3} &= E_{NH_3} * \text{OpHrs} \\ &= 2.303 * 10^{-1} * 1760 \\ &= 405.33 \text{ kg/yr} \end{aligned}$$

#### 3.1.2 For Emissions to Water

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. This existing monitoring data can be used to calculate annual emissions by the use of Equation 7:

#### Equation 7

$$E_{kpy,i} = C_i * V_w * \text{OpHrs} / 1\,000\,000$$

where:

|             |   |   |
|-------------|---|---|
| $E_{kpy,i}$ | = | emissions of pollutant i, kg/yr                     |
| $C_i$       | = | concentration of pollutant i in wastewater,<br>mg/L |
| $V_w$       | = | hourly volume of wastewater, L/hr                   |

---

|           |   |   |
|-----------|---|---|
| OpHrs     | = | operating hours per year for which data apply, hr |
| 1 000 000 | = | conversion factor, mg/kg                          |

### 3.2 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 divided by the unit weight, volume, distance, or duration of the activity emitting the substance, for example, kilograms of ammonia emitted per tonne of ammonium sulfate. Table 4 and Table 5 provide emission factors for emissions to atmosphere and water respectively.

Equation 8 is used to estimate a facility's emissions from the application of emission factors.

#### Equation 8

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

where :

|             |   |   |
|-------------|---|---|
| $E_{kpy,i}$ | = | emission rate of pollutant i, kg/yr               |
| A           | = | activity 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 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 used in emission estimation, the collection efficiency of the abatement equipment needs to be considered.

With regards to emission controls for PM<sub>10</sub>, 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.

Application of Equation 8 is illustrated by Example 4.

#### Example 4 - Using Emission Factors

Table 4 shows that 0.2 kg of particulate matter (PM<sub>10</sub>) is emitted from rotary dryers with wet scrubbers in place for each tonne of ammonium sulfate produced. If it is assumed that the facility operates for 5 400 hours per year and production rate is 2 t/yr.

$$EF_{PM10} = 0.2 \text{ kg/t}$$

$$\begin{aligned} E_{kpy,PM10} &= A * OpHrs * EF_{PM10} * [1-CE_i/100] \\ &= 2 \text{ t/yr} * 5\,400 \text{ hr/yr} * 0.2 \text{ kg/t} \\ &\quad (\text{as this is the controlled emission factor no further} \\ &\quad \text{correction for control efficiency is needed}) \\ &= 2160 \text{ kg/yr} \end{aligned}$$

**Table 4 - Emission Factors for Ammonium Sulfate Manufacture**

| Emission Source      | PM <sub>10</sub> <sup>b</sup> (kg/t) | VOC <sup>c</sup> (kg/t) | NH <sub>3</sub> (kg/t) |
|----------------------|--------------------------------------|-------------------------|------------------------|
| Rotary Dryers        |                                      |                         |                        |
| Uncontrolled         | 23                                   | 0.74                    | NA                     |
| Wet Scrubber         | 0.2                                  | 0.11                    | NA                     |
| Fluidised-bed Dryers |                                      |                         |                        |
| Uncontrolled         | 109                                  | 0.74                    | NA                     |
| Wet Scrubber         | 0.14                                 | 0.11                    | NA                     |

Adopted from USEPA, AP-42 section 8.4, 1993

<sup>a</sup> Emission factor rating C: (except as noted)

<sup>b</sup> PM<sub>10</sub> = particulate matter of aerodynamic diameter less than or equal to 10 micrometres

<sup>c</sup> VOC emission occur only at caprolactam plants. The emissions are caprolactam vapour

<sup>d</sup> Emission factor rating A

**Table 5 - Emission Factors for Total Nitrogen (N)<sup>a</sup>**

| Ammonium Sulfate | Emission Factor (kg/unit <sup>b</sup> ) | Emission Factor Rating |
|------------------|---|------------------------|
| Untreated        | 10                                      | U                      |
| Treated          | 0.1                                     | U                      |

Source: Economopoulos, A.P. 1993

<sup>a</sup> Emission factors apply to emission to water only

<sup>b</sup> Unit = tonne of ammonium sulfate produced.

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. You are required to have the emission factor reviewed and approved by State or Territory environment agencies prior to its use for NPI estimations.

---

### 3.3 Using 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 within the equipment should be accounted for in your calculation.

Mass balance calculations for estimating emissions to air of NPI-listed substances can be represented conceptually by Equation 9.

#### Equation 9

$$E_{kpy,i} = \text{Amount in}_i - \text{Amount out}_i$$

where:

|                       |   |  |
|-----------------------|---|--|
| $E_{kpy,i}$           | = | emissions of pollutant i, kg/yr  |
| $\text{Amount in}_i$  | = | amount of pollutant i entering the process, kg/yr                                      |
| $\text{Amount out}_i$ | = | amount of pollutant i leaving the process as a waste stream, article or product, kg/yr |

The term “Amount out<sub>i</sub>” may actually involve several different fates for an individual pollutant. This could include the amount recovered or recycled, the amount leaving the process in the manufactured product, the amount leaving the process in wastewater, or the amount of material transferred off-site as hazardous waste or to landfill. A thorough knowledge of the different fates for the pollutant of interest is necessary for an accurate emission estimate to be made using the mass balance approach.

The amount of a particular substance entering or leaving a facility is often mixed within a solution as a formulation component or as a trace element within the raw material. To determine the total weight of the substance entering or leaving the process, the concentration of the substance within the material is required. Using this concentration data, Equation 10 can be applied as a practical extension of Equation 9.

#### Equation 10

$$E_{kpy,i} = [Q_{in} * C_{in} - Q_{pr} * C_{pr} - Q_{rec} * C_{rec} - Q_{waste} * C_{waste}] / 10^6$$

where:

|                                      |   |  |
|--------------------------------------|---|--|
| $E_{kpy,i}$                          | = | emissions of pollutant i, kg/yr  |
| $Q_{in}, Q_{pr}, Q_{rec}, Q_{waste}$ | = | quantity of raw material, product, recycled material or waste respectively, that is processed annually (generally expressed in kg for solids, L for liquids)                               |
| $C_{in}, C_{pr}, C_{rec}, C_{waste}$ | = | concentration of substance i in the raw material, product, recycled material or waste respectively, that is processed annually (generally expressed in mg/kg for solids, mg/L for liquids) |
| $10^6$                               | = | conversion from milligrams to kilograms.   |

Example 5 illustrates the application of Equation 9.

### **Example 5 - Using a Mass Balance for NH<sub>3</sub> Emissions**

This example shows how NH<sub>3</sub> emissions to air may be calculated using Equation 9 within an ammonium sulfate manufacturing process.

A facility produces 233 166 tonnes of ammonium sulfate per year, which would theoretically require 59 992.5 tonnes NH<sub>3</sub> per year. The facility actually uses 60 000 tonnes NH<sub>3</sub> per year.

Assuming that there are no emissions to wastewater, Equation (8) can be used to determine NH<sub>3</sub> emissions to atmosphere in kilograms per year.

$$\begin{aligned} E_{\text{kpy,NH}_3} &= \text{Amount in}_i - \text{Amount out}_i \\ &= 60\,000\,000 - 59\,992\,500 \\ &= 7500 \text{ kg / year} \end{aligned}$$

Where a facility uses a listed mineral acid or base, with this acid or base being effectively neutralised in use or during wastewater treatment (to a pH of 6 to 8, as required by most State and Territory effluent standards), no emission quantities should be reported. If the acid or base is itself transformed into another listed substance, however, the quantity of this substance coincidentally produced must be determined to assess if a threshold value has been reached. For example, sulfuric acid often yields hydrogen sulfide in effluent streams, which is itself a listed substance and requires reporting where annual emissions total 10 or more tonnes.

Wastewater treatment may transport the reportable chemical in a sludge. Facilities are often required to obtain data on the concentration of metals or other substances in sludges as part of their licensing requirement and this data can be used to calculate the emissions as kilograms of sludge multiplied by the concentrations of the substance in the sludge. Alternatively, the loss in the sludge can be estimated by Equation (9). Although listed substances in sludges transferred off-site do not require reporting, determining this loss can assist with determining other process losses or may require reporting if the sludge is disposed of on-site.

For many chemicals used and emitted during chemical processes, some degradation in treatment may occur so that all of the chemical is not transferred to the sludge. Facilities can estimate the amount of reportable compounds in the sludge by using measured data, or by subtracting the amount biodegraded from the total amount removed in treatment. The amount of removal can be determined from operating data, and the extent of biodegradation might be obtained from published studies. If the biodegradability of the chemical cannot be measured or is not known, reporting facilities should assume that all removal is due to absorption to sludge.

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### 3.4 Using Engineering and Site-Specific Equations

Theoretical and complex equations or *models* can be used for estimating emissions from ammonium sulfate manufacturing. Inputs for theoretical equations generally fall into the following categories:

- (1) chemical/physical properties of the material involved, such as vapour pressure and vapour molecular weight;
- (2) operating data, such as the amount of material processed and operating hours; and
- (3) physical characteristics and properties of the source, such as tank colour and diameter.

Use of engineering equations to estimate emissions from ammonium sulfate manufacturing processes is a more complex and time-consuming process than the use of emission factors. Engineering 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.

Engineering equations are suitable for estimating emissions from several chemical manufacturing processes. For example, for any process involving a transfer of a chemical species from the liquid phase to the vapour phase, the saturation or equilibrium vapour pressure and exhaust flow rate from the process can be used to establish the upper limit of emissions from that particular process. This is a conservative approach because of the assumption that the total airflow is saturated. An alternative method based on mass transfer kinetics does not assume airflow saturation and results in a lower emission rate estimate than would be obtained assuming saturation. For emissions from fugitive sources such as spills, refer to the *Emission Estimation Technique Manual for Fugitive Emissions*.

#### 3.4.1 Fugitive Emissions

Many of the engineering equations presented in this section are to be applied to estimate emissions of organic compounds. Other than using emission factors or applying the mass balance technique for estimating emissions, there is little information currently available for estimating fugitive emissions of inorganic compounds. However, in ammonium sulfate manufacturing, it may be necessary to estimate emissions of inorganic compounds for NPI-reporting purposes. This is particularly the case for mineral acids and ammonia in the gas/vapour phase.

Emission estimates of inorganic compounds can be obtained for ammonium sulfate manufacturing processes by the following methods:

- develop correlations specific to particular chemical manufacturing processes;
- use a portable monitoring instrument to obtain actual concentrations of the inorganic compounds and then apply the screening values obtained (see paragraph below) into the applicable correlation equation shown in Table 6 and Equation 11; or
- use the emission factors from Table 7.

Screening data is collected by using a portable monitoring instrument to sample air from potential leak interfaces on individual pieces of equipment. A screening value (SV) is a measure of the concentration of leaking compounds in the ambient air that provides an indication of the leak rate from an equipment piece, and is measured in units of parts per million by volume (ppmv).

Also, surrogate measurements can be used to estimate emissions of inorganic compounds. For example, potassium iodide (KI), or a similar salt solution, is an indicator for equipment leaks from acid process lines at ammonium sulfate plants. Equation 11 illustrates an approach for estimating fugitive inorganic chemical emissions using data from Table 6. An example of this estimation technique is given at Example 6.

### Equation 11

$$E_{kpy,i} = ER_i * (C_i/100) * OpHrs$$

where:

$$\begin{aligned} E_{kpy,i} &= \text{mass emissions of pollutant i calculated from either the screening values, correlation equation, or emission factors, kg/yr/source} \\ ER_i &= \text{emission rate, kg/hr/source} \\ C_i &= \text{concentration of pollutant i in the equipment, \%} \\ OpHrs &= \text{operating hours, hr/yr} \end{aligned}$$

**Table 6 - Correlation Equations, Default Zero Emission Rates, and Pegged<sup>c</sup> Emission Rates for Estimating Fugitive Emissions**

| Equipment Type                  | Default Zero Emission Rate (kg/hr/source) | Pegged Emission Rates (kg/hr/source) |              | Correlation Equation (kg/hr/source) <sup>a</sup> |
|---------------------------------|---|--------------------------------------|--------------|--|
|                                 |   | 10 000 ppmv                          | 100 000 ppmv |  |
| Gas valves                      | $6.6 * 10^{-7}$                           | 0.024                                | 0.11         | $LR = 1.87 * 10^{-6} * (SV)^{0.873}$             |
| Light liquid valves             | $4.9 * 10^{-7}$                           | 0.036                                | 0.15         | $LR = 6.41 * 10^{-6} * (SV)^{0.797}$             |
| Light liquid pumps <sup>b</sup> | $7.5 * 10^{-6}$                           | 0.14                                 | 0.62         | $LR = 1.90 * 10^{-5} * (SV)^{0.824}$             |
| Connectors                      | $6.1 * 10^{-7}$                           | 0.044                                | 0.22         | $LR = 3.05 * 10^{-6} * (SV)^{0.885}$             |

Source: Eastern Research Group, 1996.

LR = leak rate.

<sup>a</sup> SV is the screening value (ppmv) measured by the monitoring device. To estimate emissions, use the default zero emission rates only when the screening value (adjusted for background) equals 0.0 ppmv; otherwise use the correlation equations. If the monitoring device registers a pegged value, use the appropriate pegged emission rate.

<sup>b</sup> The emission estimates for light liquid pump seals can be applied to compressor seals, pressure relief valves, agitator seals, and heavy liquid pumps.

<sup>c</sup> When the monitoring device reads a pegged value; for example 10 ppmv for a gas valve, the pegged emission rate of 0.024 kg/hr per source would be used rather than determining the emission rate using a correlation equation, or a default zero emission rate.



### Example 6 - Calculating Fugitive Chemical Leaks

An ammonium sulfate plant operates a light-liquid pump on an 80 percent ammonia solution storage tank. The pump is run for 8 760 hours during the year.

#### **For a Screening Value of zero ppmv**

$$\begin{aligned}\text{OpHrs} &= 8\,760 \text{ hr/yr} \\ \text{SV (screening value)} &= 0 \text{ ppmv} \\ \text{Default-zero emission rate} &= 7.5 * 10^{-6} \text{ kg/hr/source} \\ \\ \text{NH}_3 \text{ emissions} &= \text{ER}_i * \text{C}_i * \text{OpHrs} \\ &= 7.5 * 10^{-6} \text{ kg/hr/source} * \\ &\quad (80/100) * 8\,760 \text{ hr/yr} \\ &= 5.26 * 10^{-2} \text{ kg/yr}\end{aligned}$$

#### **For a Screening Value of 20 ppmv**

$$\begin{aligned}\text{OpHrs} &= 8\,760 \text{ hr/yr} \\ \text{SV (screening value)} &= 20 \text{ ppmv} \\ \\ \text{NH}_3 \text{ emissions (kg/hr)} &= 1.90 * 10^{-5} (\text{SV})^{0.824} \\ &= 1.90 * 10^{-5} (20)^{0.824} \\ &= 2.24 * 10^{-4} \text{ kg/hr} \\ \text{NH}_3 \text{ emissions (kg/yr)} &= 2.24 * 10^{-4} \text{ kg/hr} * 8\,760 \text{ hr} * \\ &\quad (80/100) \\ &= 1.68 \text{ kg NH}_3/\text{yr}\end{aligned}$$

The average emission factor approach is commonly used to calculate emissions when site-specific screening data is unavailable. To estimate emissions using the emission factors in Table 7, the concentration in weight percent of the pollutant of interest within the equipment is needed. This is important because equipment with higher pollutant concentrations tend to have higher emission leak rates. The equipment should be grouped into *streams*, such that all equipment within a *stream* has approximately the same pollutant weight percent.

This approach for estimating emissions allows use of average emission factors in combination with unit-specific data that is relatively simple to obtain. This data includes:

- (1) the number of each type of component in a unit (valve, connector, etc.);
- (2) the service each component is in (gas, light liquid, or heavy liquid);
- (3) the pollutant concentration of the stream; and
- (4) the time period each component was in that service during the NPI reporting year.

Equation 12 can be used to estimate emissions from all of the equipment of a given equipment type in a *stream* using the emission factors from Table 7.

---

**Equation 12**

$$E_{kpy,i} = EF * WF_i * OpHrs * N$$

where:

|             |   |   |
|-------------|---|---|
| $E_{kpy,i}$ | = | emission rate of pollutant i from all equipment in the <i>stream</i> of a given equipment type, kg/yr |
| EF          | = | applicable average emission factor for the equipment type, kg/hr/source                               |
| $WF_i$      | = | average weight fraction of pollutant i in the <i>stream</i> ,   |
| OpHrs       | = | annual operation hours of equipment in the <i>stream</i> , hr/yr                                      |
| N           | = | number of pieces of the applicable equipment type in the <i>stream</i>                                |

Example 7 illustrates the emission factor approach for Streams A and B. Note that Stream A contains water, which is not an NPI-listed substance, and that this is accounted for when total emissions are estimated from Stream A.

**Example 7 - Average Emission Factor Technique**

This example shows how annual ammonia (NH<sub>3</sub>) emissions can be calculated from pump seals using the emission factors from Table 7 and Equation 12. The following data is given:

| Stream ID | Equipment Count (N) | Emission Factor (kg/hr/source) | Weight Fraction | OpHrs (hr/yr) |
|-----------|---------------------|--------------------------------|-----------------|---------------|
| A         | 15                  | 0.0199                         | 0.80            | 8.760         |
| B         | 12                  | 0.0199                         | 1.00            | 4.380         |

$$E_{kpy,NH_3} = EF * WF_{NH_3} * OpHrs * N$$

**Stream A**

$$\begin{aligned} E_{kpy,NH_3} &= 0.0199 * 0.80 * 8\,760 * 15 \\ &= 2\,092 \text{ kg NH}_3/\text{yr} \end{aligned}$$

**Stream B**

$$\begin{aligned} E_{kpy,NH_3} &= 0.0199 * 1.00 * 4\,380 * 12 \\ &= 1\,046 \text{ kg NH}_3/\text{yr} \end{aligned}$$

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**Table 7 - Emission Factors for Equipment Leaks**

| <b>Equipment Type</b>   | <b>Service</b> | <b>Emission Factor<br/>(kg/hr/source)</b> |
|-------------------------|----------------|---|
| Valves                  | Gas            | 0.00597                                   |
|                         | Light liquid   | 0.00403                                   |
|                         | Heavy liquid   | 0.00023                                   |
| Pump seals <sup>a</sup> | Light liquid   | 0.0199                                    |
|                         | Heavy liquid   | 0.00862                                   |
| Compressor seals        | Gas            | 0.228                                     |
| Pressure relief valves  | Gas            | 0.104                                     |
| Connectors              | All            | 0.00183                                   |
| Open-ended lines        | All            | 0.0017                                    |
| Sampling connections    | All            | 0.0150                                    |

Source: Eastern Research Group, 1996.

<sup>a</sup> The light liquid pump seal factor can be used to estimate the leak rate from agitator seals.

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## **4 Emission Estimation Techniques: 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 ammonium sulfate manufacturing facilities. The technique chosen is dependent on available data, 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 Section 3.0 of this Manual.

### **4.1 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 ammonium sulfate 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 a period of time, and to cover all aspects of production of ammonium sulfate.

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.

### **4.2 Mass Balance**

Calculating emissions from an ammonium sulfate manufacturing facility using mass balance appears to be a straightforward approach to emissions estimations. However, it is likely that few Australian industries 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 of 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.

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### 4.3 Engineering Calculations

Theoretical and complex equations or *models* can be used for estimating emissions from ammonium sulfate manufacturing processes.

Use of emission equations to estimate emissions from ammonium sulfate 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.

### 4.4 Emission Factors

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 Section 5.0 of this Manual. 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       |

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## 5 References

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USEPA, October 1992, *VOC / PM Speciation Data System - Version 1.5*, United States Environmental Protection Agency, Office of Air Quality, Planning and Standards, Research Triangle Park, NC, USA.

The following Emission Estimation Technique Manuals are available at the NPI Homepage and from your local environmental protection agency (see the front of the NPI Guide for details):

- Emission Estimation Technique Manual for Phosphate Manufacturing;
- Emission Estimation Technique Manual for Urea Manufacturing;
- Emission Estimation Technique Manual for Synthetic Ammonia Manufacturing; and
- Emission Estimation Technique Manual for Sewage and Wastewater Treatment.