



**National Pollutant Inventory**

# **Emission Estimation Techniques Manual**

**for**

## **Beer Manufacturing**

*First published in February 1999*

**EMISSION ESTIMATION TECHNIQUES  
FOR  
BEER MANUFACTURING**

**TABLE OF CONTENTS**

<b>1.0 INTRODUCTION.....</b>	<b>1</b>
<b>2.0 PROCESSES AND EMISSIONS.....</b>	<b>2</b>
<b>2.1 Process Description.....</b>	<b>2</b>
<b>2.2 Emission Sources and Control Technologies.....</b>	<b>3</b>
2.2.1 Emissions to Air.....	3
2.2.2 Emissions to Water.....	4
2.2.3 Emissions to Land.....	5
<b>3.0 EMISSION ESTIMATION TECHNIQUES.....</b>	<b>8</b>
<b>3.1 Direct Measurement.....</b>	<b>9</b>
3.1.1 Sampling Data.....	7
3.1.2 Continuous Emission Monitoring System (CEMS) Data.....	7
<b>3.2 Mass Balance.....</b>	<b>7</b>
<b>3.3 Engineering Calculations.....</b>	<b>7</b>
<b>3.4 Emission Factors.....</b>	<b>8</b>
3.4.1 Industry-wide Emission Factors.....	10
3.4.2 Predictive Emission Monitoring (PEM).....	11
<b>3.5 Alternative Emission Estimation Technique for Ethanol         Emissions.....</b>	<b>11</b>
<b>4.0 EMISSION ESTIMATION TECHNIQUES: ACCEPTABLE     RELIABILITY AND UNCERTAINTY.....</b>	<b>14</b>
<b>4.1 Direct Measurement.....</b>	<b>13</b>
<b>4.2 Mass Balance.....</b>	<b>13</b>
<b>4.3 Engineering Calculations.....</b>	<b>14</b>
<b>4.4 Emission Factors.....</b>	<b>14</b>
<b>5.0 REFERENCES.....</b>	<b>16</b>

**EMISSION ESTIMATION TECHNIQUES  
FOR**

**BEER MANUFACTURING**

**LIST OF FIGURES AND TABLES**

**Figure 1. Typical Brewhouse Operations.....2**  
    **2. Fermentation and Filling Operations.....3**

**Table 1. Likely Air Emissions During the Production of Beer.....4**  
    **2. Emission Factors for Ethanol Emissions from Beer Brewing.....10**

## **1.0 Introduction**

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

The beer brewing activities covered by this Manual will pertain to facilities engaged in the manufacturing, bottling, or canning of beer, ale, stout or porter.

EET MANUAL:            Beer Manufacturing

HANDBOOK:            Beer and Malt Manufacturing

ANZSIC CODES :        2182

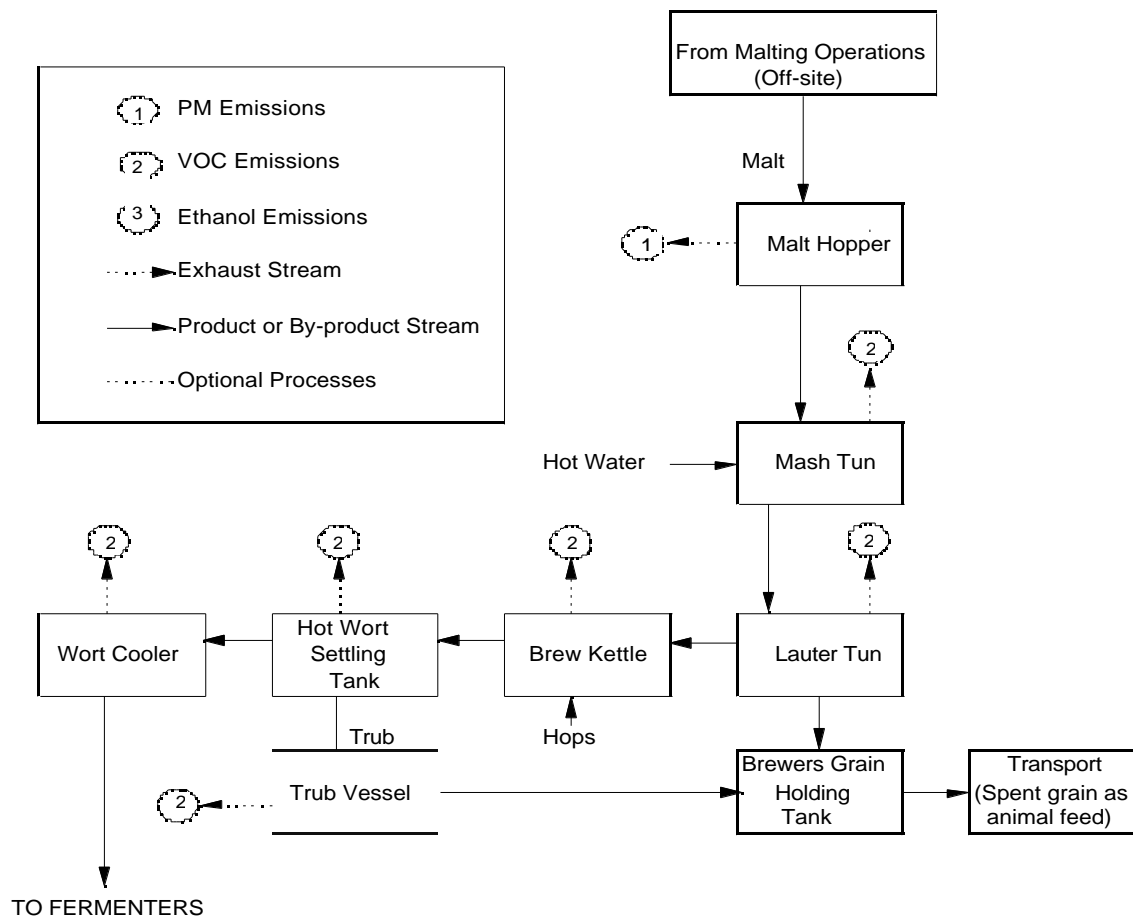
This Manual was drafted by the NPI Unit of the Queensland Department of Environment & Heritage on behalf of the Commonwealth Government. It has been developed through a process of national consultation involving State and Territory environmental authorities and key industry stakeholders.

## 2.0 Processes and Emissions

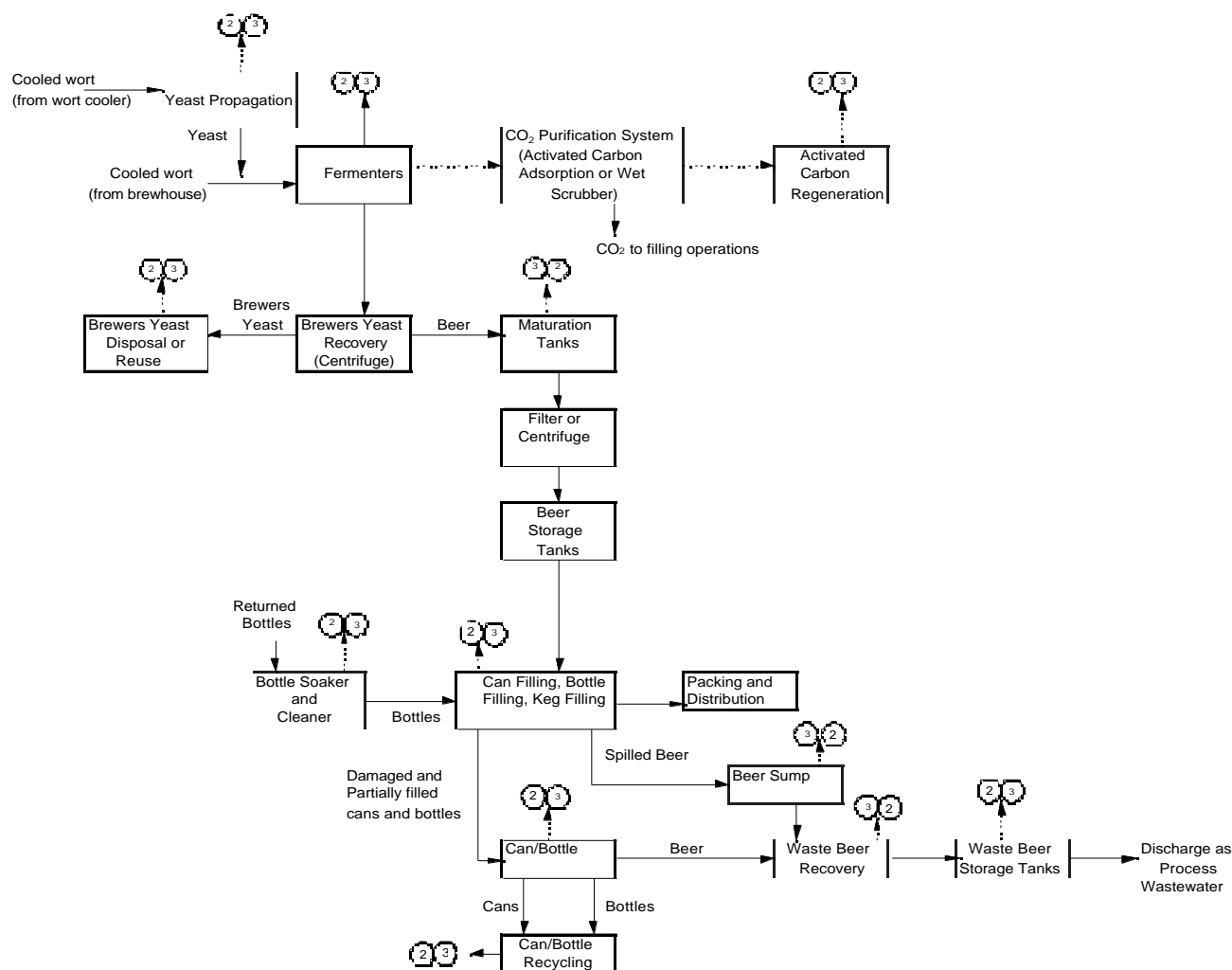
The following section presents a brief description of the beer manufacturing industry, and identifies likely sources of emissions.

### 2.1 Process Description

Beer is a beverage of low alcoholic content made by the fermentation of malted, starchy cereal grains. Barley is the principal grain used. The production of malt beverages, or beer, comprises four main stages: brewhouse operations, fermentation, aging or maturation, and packaging. Figures 1 and 2 illustrate the brewing processes and highlight likely emission points.



**Figure 1. Typical Brewhouse Operations**  
(adapted from USEPA AP-42 Section 9.12, 1995)



**Figure 2. Fermentation and Filling Operations**  
*(adapted from USEPA AP-42 Section 9.12, 1995)*

## 2.2 Emission Sources and Control Technologies

### 2.2.1 Emissions to Air

Air emissions may be categorised as :

#### Fugitive Emissions

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

## 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 from beer manufacturing processes.

**Table 1. Likely Air Emissions During the Production of Beer <sup>a</sup>**

Emissions from Beer Brewing	Emissions from Fuel Burning Activities
Ethanol Ethyl Acetate VOCs (including non- NPI listed VOCs)	Carbon Monoxide Sulfur Dioxide Oxides of Nitrogen Arsenic & compounds Beryllium & compounds Cadmium & Compounds Chromium (III) compounds Chromium (IV) compounds Copper & compounds Fluoride compounds Hydrochloric acid Lead & compounds Magnesium oxide fume Mercury & compounds Nickel & compounds Nickel carbonyl Nickel subsulfide Polychlorinated dioxins & furans Polycyclic aromatic hydrocarbons (PAHs) Total VOCs

<sup>a</sup> Queensland Department of Environment and Heritage, 1998

For assistance with determining emissions from fuel burning, please refer to the Combustion in Boilers Manual.

Generally, post-fermentation operations emit ethanol. However, small quantities of other volatile organic compounds (VOCs), including ethyl acetate, may also be emitted from fermenters and post fermentation.

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. The collection efficiency of the abatement equipment needs to be considered where such equipment has been installed, and where emission factors from uncontrolled sources have been used in an emission estimation. Guidance on applying collection efficiencies to emission factor equations is provided in later sections.

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.

### **2.2.2 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.

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 you to report to the NPI (See also Section Three of *The NPI Guide*).

### **2.2.3 Emissions to Land**

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

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

Some breweries may use treated waste water for irrigation. This wastewater need only be considered for NPI reporting if it contains an NPI listed substance.



### 3.0 Emission Estimation Techniques

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.

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

- sampling or direct measurement
- mass balance
- fuel analysis or other engineering calculations
- 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 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 EETs that are not outlined in this handbook, your data will also be displayed as being of 'acceptable reliability'.

This Manual seeks to provide the most effective emission estimation techniques for the NPI substances relevant to this industry. However, the absence of an EET for a substance in this handbook does not 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.**

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.

### **3.1 Direct Measurement**

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

#### **3.1.1 Sampling Data**

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 (ie.normal) operating conditions. You should be aware that some tests undertaken for a State or Territory license condition may require the test be taken under maximum emissions rating, where emissions are likely to be higher than when operating under normal operating conditions.

#### **3.1.2 Continuous Emission Monitoring System (CEMS) Data**

A continuous emission monitoring system provides a continuous record of emissions over time, usually by reporting pollutant concentration.

Once the pollutant concentration is known, emission rates are obtained by multiplying the pollutant concentration by the volumetric gas or liquid flow rate of that pollutant.

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

### **3.2 Mass Balance**

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

### **3.3 Engineering Calculations**

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

### 3.3.1 Fuel Analysis

Fuel analysis is an example of an engineering calculation and can be used to predict SO<sub>2</sub>, metals, and other emissions based on application of conservation laws, if fuel rate is measured. The presence of certain elements in fuels may be used to predict their presence in emission streams. This includes elements such as sulfur which may be converted into other compounds during the combustion process.

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

$$E_i = Q_f * \text{pollutant concentration in fuel } i \text{ (MW}_p \div \text{EW}_f) \quad (1)$$

where:

$E_i$	=	emissions of pollutant i
$Q_f$	=	fuel use (kg/hr)
$MW_p$	=	molecular weight of pollutant emitted (kg/kg-mole)
$EW_f$	=	elemental weight of pollutant in fuel (kg/kg-mole)
		Pollutant concentration by weight

For instance, SO<sub>2</sub> emissions from coal combustion can be calculated based on the concentration of sulfur in the coal. This approach assumes complete conversion of sulfur to SO<sub>2</sub>. Therefore, for every kilogram of sulfur (EW = 32) burned, two kilograms of SO<sub>2</sub> (MW = 64) are emitted. The application of this EET is shown in Example 1.

#### Example 1. Using Fuel Analysis

This example shows how SO<sub>2</sub> emissions can be calculated from coal combustion based on fuel analysis results and the fuel flow information. The facility is assumed to operate 1500 hours per year.

$E_{SO_2}$  = may be calculated using Equation (1)

Fuel flow	=	2 000 kg/h
Weight percent sulfur in fuel	=	0.5

$$\begin{aligned} E_{SO_2} &= Q_f * \text{pollutant concentration in fuel } i \text{ (MW}_p \div \text{EW}_f) \\ &= (2\ 000) * (0.5 \div 100) * (64 \div 32) \\ &= 20\text{kg/hr} * \text{t}/1\ 000\text{kg} * 1\ 500\ \text{hr/yr} \\ &= 30\ 000\ \text{kg/yr} \end{aligned}$$

### 3.4 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 (eg. grams of ethanol emitted per kilolitre of beer produced).

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

$$E_i = [A * OpHrs] EF_i * [1 - (CE_i/100)] \quad (2)$$

where :

- $E_i$  = 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 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 were measured from one process source, an emission factor could be developed and applied to similar sources. As previously mentioned, it is advisable to have the emission factor reviewed and approved by State or Territory environment agencies prior to its use for NPI estimations.

### 3.4.1 Industry-wide Emission Factors

Presently, the only emission factors available are for ethanol.

**Table 2. Emission Factors for Ethanol Emissions from Beer Brewing**

Process Emission Source	Emission Factor <sup>a</sup>	Emission Factor Rating Code *
Bottle Filling Line	<b>65.7 g/kL</b> of beer packaged	E
Bottle Soaker and Cleaner	<b>90.7 g/1000 cases</b> of bottles washed	D
Can Crusher with Pneumatic Conveyor	<b>10.5 g/L</b> beer recovered	D
Can Filling Line	<b>54.2 g/kL</b> of beer packaged	E
Fermenter Venting (Closed Fermenter)	<b>7.73 g/kL</b> of beer packaged	E
Keg Filling Line	<b>2.67 g/kL</b> of beer packaged	D
Sterilised Bottle Filling Line	<b>155 g/kL</b> of beer packaged	D
Sterilised Can Filling Line	<b>135 g/kL</b> of beer packaged	D

<sup>a</sup> USEPA AP-42 Section 9.12.1, 1996

\* See Section 4.4

### Example 2. Using Emission Factors

Table 2 shows that for the bottle filling line, 65.8 g/kL of ethanol is emitted for every 1000 litres of beer bottled. It is assumed that the brewery bottles 200 ML of beer per year.

Emission reduction efficiency for ethanol is effectively zero, with all ethanol produced emitted to air. (Therefore, CE = 0)

Emission Factor (EF <sub>ethanol</sub> )	=	65.8 g/kL
Beer Bottled (A)	=	200 ML
E <sub>ethanol</sub>	=	A * EF <sub>ethanol</sub> * [1 - (CE/100)]
Ethanol emission	=	Beer bottled/year * EF <sub>ethanol</sub>
	=	200 ML/year * 65.8g/kL
	=	200 000 kL * 65.8 g/kL * kg/1000g
	=	13160.0
	=	13160.0 kg/year of ethanol emitted.

### 3.4.2 Predictive Emission Monitoring (PEM)

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

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

### 3.5 Alternative Emission Estimation Technique for Ethanol Emissions

The main source of ethanol emissions from the brewing process, aside from the evolution of CO<sub>2</sub> from fermentation, is the loss of ethanol through processing and packaging operations.

Ethanol (contained in the beer) lost during production of beer flows to trade waste, or to on-site treatment. However, emissions of ethanol from beer loss also occur through evaporation prior to reaching the trade waste or treatment system. If the brewery has an on-site treatment facility, further emissions of ethanol and other VOCs will need to be considered for calculation.

Emission of ethanol to air, prior to trade waste transfer or treatment, may be estimated using the following parameters:

- volume of beer lost;
- average alcohol content of the beer;
- average temperature of the beer; and
- average time before the lost beer is transferred to trade waste or other treatment.

On-site experimentation utilising the above parameters, under controlled conditions, is an alternative method of estimating emissions of ethanol to the air from spilt beer.

For example,

**Step 1**

Measure the initial alcohol content of a known quantity of beer.

**Step 2**

Spill the beer onto a surface and leave it for a known period of time.

**Step 3**

Collect the beer and measure the alcohol content.

It may be assumed that for the given volume of beer, the amount of alcohol lost during the experiment is the loss of ethanol to the air.

The results may be used to estimate ethanol emissions from spills, or in the event of overfilling.

## **4.0 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 beer manufacturing facilities. The technique chosen is dependent on available data, and available resources, and the degree of accuracy sought by the facility in undertaking the estimate. In general, site-specific data that is representative of normal operations is more accurate than industry-averaged data, such as the emission factors presented in Section 3.4.1. 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 beer 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 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 cover all aspects of the production of beer. 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 a beer manufacturing facility using mass balance appears to be a straightforward approach to emission estimation. However, it is likely that few Australian breweries consistently track material usage and waste generation with the overall accuracy needed for application of this method. Inaccuracies associated with individual material tracking, or other activities inherent in each material handling stage, can result in large deviations for total facility emissions. Because emissions from specific materials are typically below 2 percent of gross consumption, an error of only  $\pm 5$  percent in any one step of the operation can significantly skew emissions estimations.



### 4.3 Engineering Calculations

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

Use of emission equations to estimate emissions from beer 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 the reference section of this document. The emission factor ratings will not form part of the public NPI database.

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

The EFR system is as follows :

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

In addition to the EFR code, the accuracy of emission factors is thoroughly dependent upon the degree of similarity between the reference source and the emission source being estimated.

## **5.0 References**

**USEPA. October 1995. *Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources, fourth edition, AP-42. Section 9.12.1 Malt Beverages.* United States Environmental Protection Agency, Office of Air Quality Planning and Standards. Research Triangle Park, NC, USA.**

**Verbal communication from Russell Peel, Carlton United Breweries, Melbourne, Australia, to Alison Wiltshire, National Pollutant Inventory Unit, Queensland Department of Environment, 8 April 1998.**

**Verbal communication from Jerry Piglas, Castlemaine Perkins, Milton, Australia, to Alison Wiltshire, National Pollutant Inventory Unit, Queensland Department of Environment, 15 May 1998.**