DEPARTMENT OF ENVIRONMENT AND NATURAL RESOURCES

# *Guidelines on Air Pollution Control Techniques and Devices*

***Air Quality Management***

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# Abbreviations

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# Abbreviations

| Abbreviation | Abbreviation Definition |
|---|---|
| BACT | Best Available Control Technology |
| CAA | Clean Air Act |
| CEMS | Continuous Emission Monitoring System |
| DENR | Department of Environment and Natural Resources |
| EIS | Environmental Impact Statement |
| EMB | Environmental Management Bureau |
| EOP | Emergency Operating Procedures |
| ESP | Electrostatic Precipitator |
| IRR | Implementing Rules and Regulations |
| LAER | Lowest Achievable Emission Rate |
| MAS | Mechanically-aided scrubber |
| NAAQS | National Ambient Air Quality Standards |
| NESSAP | National Emission Standard for Source Specific Air Pollutants |
| NOx | Nitrogen Oxide |
| OMP | Operation and Management Plan |
| VOC | Volatile Organic Compound |
| WG | Water Gauge |

# 1 INTRODUCTION

The management and control of air emissions from industrial sources is subject to the Implementing Rules (IRR) and Regulations made under RA 8749: the Philippines Clean Air Act of 1999 (CAA). Industrial activities that discharge pollutants to air must comply with the “National Emission Standards for Source Specific Air Pollutants” (NESSAP) and “National Ambient Air Quality Standards for Source Specific Air Pollutants from Industrial Sources/Operations” (NAAQS), as prescribed in Rules XXV and XXVI of the IRR.

New or modified industrial sources that emit contaminants to air require a Permit to Operate from the regulatory authority (EMB). The proponent of the new industrial activity (permit applicant) may sometimes be required by EMB to undertake a study to determine the potential impact of the emissions from their industrial sources on the surrounding air quality and/or to demonstrate the compliance of new/modified sources with the NAAQS, especially where larger or more environmentally significant emissions sources are involved.

Although individual sources are currently issued with permits, it is the off-site impact of all of the emission sources in aggregate from the site on the environment that must be assessed. Therefore, atmospheric dispersion modelling of all emission sources at the site is undertaken to demonstrate compliance with the NAAQS. The atmospheric dispersion modelling should be carried out in accordance with EMB’s “Guidelines on Dispersion Modelling”. The emissions from all point, area and volume sources at the site in aggregate can be assessed by the dispersion modelling process. Although each source is subject to specific emission limits, it is the impact of all of the sources from the site that is considered by EMB in determining the permit application.

Once a permit has been obtained, the permit holder needs to manage its site, activities and emission sources to ensure that the NESSAP and NAAQS continue to be complied with over the operating life of the plant. The company needs to manage and control its emissions via the selection of appropriate combustion, process equipment, fuels and materials, the installation, operation and maintenance of appropriate air pollution control devices, and the implementation of site operation and management plans. The company should also ensure that fuel burning equipment is well tuned and operating efficiently, contingency plans have been developed and implemented to manage the effects of unexpected or abnormal discharges that may result from the failure of control devices or other events, and have inspection and monitoring systems in place to check and verify that these actions are occurring.

EMB also has an important monitoring role in ensuring through regular inspections that operating facilities are complying with regulatory requirements and permit conditions. An example inspection protocol is provided in Appendix A. EMB has also developed a “Procedural Manual for Multi-Media Inspections” and associated inspection checklists for various industry sectors.

Section 11 of the Philippines Clean Air Act requires the Department of the Environment and Natural Resources (DENR) to revise and issue guidance on air pollution control techniques. The section states that:

*“The information shall include:*

**a)** *Best available technology and alternative methods of prevention, management and control of air pollution;*

**b)** *Best available technology economically achievable which shall refer to the technological basis/standards for emission limits applicable to existing, direct industrial emitters of non-conventional and toxic pollutants; and*

**c)** *Alternative fuels, processes and operating methods which will result in the elimination or significant reduction of emissions”*

The guidance on air pollution control techniques in these Guidelines has been developed by EMB in accordance with Section 11 of the CAA. The aim is to provide guidance on the selection and operation of air pollution devices, the performance criteria that should be applied in the assessment of proposals to install these devices, and the ongoing monitoring of emission control performance that should be undertaken.

EMB has also identified through its stack testing programs that guidance on the management of fuel burning equipment in terms of maintenance, tuning and efficiency monitoring, and the use of cleaner fuels, is required to reduce emissions and achieve reductions in fuel consumption which will have immediate benefits to the air quality in the Metro-Manila region.

The Guidelines also provide an environmental management framework within the CAA regulatory regime to ensure that air pollution control devices are appropriate to the type, size and scale of the industrial activity, they are operated in accordance with manufacturers' instructions and well maintained, their performance is adequately monitored, and contingency plans are in place to manage any failures of the control devices should they occur, in order to limit the adverse impact on the environment. It also provides guidance on the selection of fuels and the maintenance and tuning of fuel burning equipment.

Also, a risk assessment and management process is included in the guidelines to assist in the operators of industrial sites to prioritise actions and resources based on the level of risk posed by their site's activities and the individual emission sources. For larger sources, risk assessment and management programs may be required by EMB as part of its permitting and monitoring programs.

It is not the intent of these guidelines to provide definitive guidance on the selection and design of air pollution control devices. For further technical information on air pollution controls the reader should refer to reference books on the subject or recognised environmental engineering consultants and equipment suppliers.

# 2 AIR POLLUTION CONTROL TECHNIQUES

## 2.1 Background

There are a large range of air pollution control techniques and devices available to reduce emissions from industrial and commercial sources. The air pollution control devices selected and installed at a site have to be appropriate to the pollutants being discharged, the size and scale of the activity being undertaken and the emission source.

EMB has identified that guidance on fuel burning equipment in terms of maintenance, efficiency monitoring and tuning, and the use of cleaner fuels, are practices that if followed can reduce emissions and achieve reductions in fuel consumption which will have immediate benefit to the air quality in the Metro-Manila region. This guidance is provided in Section 4 of the guidelines.

## 2.2 Controls to Reduce Impacts

An application for a Permit to Operate must cover the plant processes and operations and the air pollution control devices that will generate, manage and control emissions to air from the plant. Options available for managing, controlling and reducing emissions include:

- Engineering Controls
- Operating Procedures and Practices
- Inspection, Maintenance and Performance Monitoring
- Emergency Contingency Plans (based on risk management).

## 2.3 Engineering Controls

Engineering controls offer the most effective emissions reduction option as, if designed and implemented well, they offer a reliable method of controlling emissions to air from the process. It is of note however, that they should normally be seen as additional to operating procedures and practices. There are many existing regulations and standard industry practices that require devices to be designed so as to be safe, mostly resulting from previous accidents. Examples include the fitting of relief valves to pressure vessels, and annual inspections and testing of potentially lethal equipment. However, despite these accepted regulatory methods more plant specific controls are invariably appropriate. Control devices are typically essential to ensure discharges of contaminants into air are kept within appropriate levels and that an activity complies with the conditions of a permit.

Best Available Control Technology (BACT) is defined under the Clean Air Act as: “refers to approaches, techniques or equipment which when used, result in lower air emissions but in a cost-effective manner”. The intention of the BACT principle is to attain emission rates that may be lower than those specified in the National Emission Standards. BACT must be considered when designing sources and selecting air pollution control equipment for new or modified sources of 100 tons per year or more of emissions of a regulated pollutant, whether these sources are to be established in attainment areas or areas for which the attainment status has not yet been determined. New or modified sources in non-attainment areas require the use of superior technology that complies with the “lowest achievable emission rate” (LAER) requirement in Rule XIII of the IRR.

The concept of ‘Best Practice’ should always be considered when reading these guidelines. ‘Best Practice’ is the undertaking of an activity in the best possible and practical way to ensure that emissions and their impacts are minimised. Best practice should always be employed by operators of existing sources. It is the minimum standard acceptable for the management and control of emissions from industrial facilities and other stationary sources.

Best practice requires an approach of 'continuous improvement' of on-site operations, emission control techniques and management practices. Meeting best practice should not incur excessive costs as it is usually the way an activity is heading and may actually be the norm rather than not. Best practice varies significantly for different types of activities. Not meeting best practice could include a spray painter that does not spray within an enclosed paint booth; a new thermal power station not using low NOx technology; or during construction, a developer not using enough water to control off-site dust emissions.

When selecting air pollution control devices the total cost of the device needs to be considered, including purchase cost, cost of operating, maintaining and monitoring the unit through its operational life, plus the cost associated with disposal of waste materials collected or created by the control device. For example, for a chemical scrubber the additional costs for disposal for the scrubber liquor needs to be factored in to the cost benefit analysis performed. Additional on-site waste liquor treatment will be required, before the liquor is of a quality that it is acceptable for disposal. The costs of installing the treatment plant and its operation need to be factored into the comparative calculations.

## 2.4 Operating and Management Procedures

Good practice with respect to the control and management of emissions to air from industrial activities requires the development of comprehensive operating and management procedures. These should be readily accessible to all employees who work or maintain the processes. They need to be reviewed and updated to take into account changes in the processes, or changes imposed by the result of safety or environmental audits. These procedures should identify critical pieces of process equipment and this in most circumstances should include air pollution control devices, i.e. how the process and control devices will be operated, and maintained.

## 2.5 Inspection and Performance Monitoring

It order to determine that air pollution control devices are operating correctly and operated in accordance with specified operating procedures, an internal monitoring and inspections regime should be developed and implemented. The monitoring and inspection regimes need to be carried out on a regular basis following a systematic method. Corrective actions identified by the monitoring and inspection of air pollution control devices need to be implemented within the time frames set in the site's Operation and Management Plan (OMP). EMB may require the development and implementation of an OMP as a Permit condition.

In addition to the internal monitoring and inspection regime, there is also routine stack testing conducted to meet CAA requirements in terms of emission standards and limits. All results should be analysed, failures investigated and corrective actions implemented to reduce emissions to permitted levels. This reporting and analysis should be included in the establishment's quarterly Self-Monitoring Report, while specific testing requirements may be specified as a condition in the Permit to Operate.

## 2.6 Contingency Plans

Contingency plans should be developed by the operators of all establishments with emissions to the air. These Plans should address the site's environmental risk, activities undertaken, processes employed and nature of control devices installed. EMB may require the development of a Contingency Plan as a condition of a Permit to operate, where it considers that significant environmental risks are associated with the operation of its pollution sources and emission control devices.

A suitable Contingency Plan may consist of the following elements:

- Procedures for informing the public and emergency services about releases.

- Documentation of actions and responsibilities of site personnel in dealing with the failure of an air pollution control device.
- Procedures and measures for emergency response, including shutting down the plant
- Procedures for dealing with air pollution control device failures.
- Procedures for using inspections, testing and maintaining emergency response equipment.
- Training for all employees in relevant procedures.
- Procedures to review and update the Plan as appropriate.

A Contingency Plan required by a Permit should be developed in consultation with EMB and other relevant government agencies.

## 2.7 Cleaner Production

'Cleaner Production' was formulated under the auspices of the United Nations Environmental Programme and is defined as

*"... the conceptual and procedural approach to production that demands that all phases of the life cycle of a product or process should be addressed with the objective of prevention or minimisation of short and long term risks to humans and to the environment."*

In other words cleaner production means:

- Avoiding or reducing the amount of waste produced;
- Using energy and resources efficiently;
- Producing environmentally sound products and services; and
- Achieving less waste, lower costs and higher profits per unit of goods.

The goal of cleaner production is to reduce the adverse impact of production and service activities on the environment. Implementing cleaner production practices has shown consistently significant reductions in waste, emissions and costs. Many of these improvements result from simple 'good housekeeping' changes, and implementing ideas from workers themselves.

The discharge of contaminants into the air from industrial processes is, after minimising quantities of waste and applying control technology to meet emission standards (or better), a common means of dealing with residuals from the production process. Cleaner production offers the potential to achieve this in a more cost effective manner, but by definition it must consider production and waste generation in a multi-media manner. Consequently, whilst a preventative approach can generate benefits to the air environment, it generally requires this to be considered in conjunction with water, solid waste and other environmental concerns. However, although cleaner production is not directly covered in these guidelines the fundamentals of Cleaner Production are used throughout.

EMB should consider the application of Cleaner Production principles in assessing major new industrial developments and their associated EISs and Permit applications.

# 3 ENGINEERING CONTROLS

## 3.1 Types of Air Pollution Control Devices

EMB considers that the reduction of air pollution at the source (e.g. through a Cleaner production approach) should be a priority for all industrial activities. Section 3 of the Clean Air Act says that it is the policy of the State to “focus primarily on pollution prevention rather than on control”.

Notwithstanding this, air pollution control devices are often required to ensure the emission of pollutants into air from an activity are minimised and significant adverse impacts are avoided. Therefore, EMB believes it is sensible to encourage operators to employ measures that reduce discharges into air using reliable and effective control technologies. Air pollution control devices are confined to a relatively limited range of technologies that have been used for many years. Most are well understood and have proven performance. There are two main categories of air pollution control devices to control and reduce:

1) Particulate emissions; and

2) Chemical contaminants from the gas stream including odorous substances.

For the control of particulate emissions the types of air pollution control devices commonly installed include:

- Fabric filtration including pulsejet and mechanical bag filter units;
- Electrostatic precipitators;
- Inertial separators which includes cyclones;
- Water scrubbing devices; and
- Ceramic filters.

For the control of gaseous chemical contaminants the types of air pollution devices commonly installed include

- Biofiltration;
- Incineration/thermal oxidation including afterburners;
- Chemical scrubbing devices;
- Adsorption (e.g. carbon adsorption).

This section focuses on promoting the use of efficient and effective air pollution control technology. Also EMB sets out what is considered to be the minimum design and operating criteria for a range of air pollution control devices. *Any Permit applications for these types of control devices will be assessed against these minimum criteria. EMB generally regards air pollution control devices that do not meet these minimum criteria as not meeting best practice and therefore emissions will not be minimised.* Best practice is defined in Section 2 of these guidelines.

Operators of industrial activities should ensure that air pollution devices installed at the site are operated within the criteria specified in these guidelines and that any control devices will be able to comply with the criteria over the life of the devices. In the event that control devices comply with the criteria given within this section but the emissions from the site are still causing a significant adverse impact, additional controls will need to be taken. In some instances a precautionary approach may be taken regarding the emission of pollutants into the air and the proposed control devices, particularly if an activity is within a very sensitive location or there is the potential for cumulative impacts. In these cases EMB may require more stringent criteria than given in these guidelines.

Air pollution control technology is complex and an experienced accredited engineer should design air pollution control devices. Installation of any air pollution control device should also be supervised and signed off by an accredited engineer. Once the appropriate pollution control device has been selected and installed to be effective it is vital that it is correctly operated and maintained.

Typical monitoring requirements for these devices are given in this Section 5 of the guideline. If an activity has a good history of reliable plant operation and the control devices in question are not being used for primary control then monitoring conditions may be relaxed. Conversely, more monitoring may be required for some activities where a precautionary approach is warranted, particularly if the control devices are for primary control, or if an activity is in a sensitive location or has a bad track record in non-conformance with emission limits.

Indicative costs as sourced from the US EPA Air Pollution Control Technology Fact Sheets for a number of the control devices discussed in this section are provided in Appendix D. The costs are for the purchase, installation, annual operation and maintenance, annualised, and effectiveness per cubic metre of air treated. These prices are for the purchase and operation of the control devices in the US and are based on 2002 figures.

A dispersion modelling assessment should also be carried out for significant new or modified sources, following a tiered approach to assess contaminant concentrations against CAA air quality standards. This tiered approach follows the approach recommended by the US Environmental Protection Agency and includes:

- Screening-level dispersion modelling techniques conducted using worst-case or default input data rather than site-specific data, and
- Refined level dispersion modelling techniques conducted using site specific meteorological data or derived regional meteorological data.

A fundamental assumption of the tiered approach to model selection is that the simpler modelling techniques always yield more conservative results. It was assumed that screening level models would always predict higher ground-level concentrations than refined modelling techniques, and that the refined models would predict higher impacts than the 'best-estimate' models.

## 3.2 Fabric Filtration

Fabric filters are a common means to remove particulate matter from a gas stream because of their high efficiency and applicability to many situations. During fabric filtration particulate laden gas is drawn or pushed through the fabric by fans. The fabric is responsible for some filtration, but more significantly it acts as a support for the dust layer that accumulates. The layer of dust, known as a cake, is a highly efficient filter, even for sub-micron particles. Fabric filters can be made of either woven or felted fabrics and may be in the form of sheets, cartridges, or most commonly cylindrical bags with a number of individual fabric filter units housed together in a group, hence the terms 'bag filters' or 'baghouses'.

Fabric filters possess key advantages over other types of particulate collection devices:

- Very high collection efficiencies;
- Flexibility to treat many types of dusts;
- Ability to handle a wide range of volumetric gas flows; and
- Low pressure drops.

The gas-to-cloth ratio is an important design consideration and has a major effect on particle collection mechanisms. The majority of the dust that penetrates a well designed and maintained filter is a result of dust that is dislodged during the cleaning cycle. Seepage occurs when particles migrate through the filter cake and the fabric by continuous capture and re-entrainment. Seepage is more common with smooth particles and with a lack of significant electrostatic forces.

To operate a fabric filter continuously, the collected dust must be dislodged from the filters and removed from the fabric filter on a regular basis. Fabric filters are frequently classified primarily by their cleaning method and with a secondary classification relating to the type of media. The three major types of fabric filter cleaning mechanisms are

- Mechanical shaker,
- Reverse-air, and
- Pulse-jet.

These types are discussed below along with a brief discussion of other less common types of cleaning methods and fabric filter configurations.

Site-specific criteria may be necessary for specialist applications where extremely high efficiencies are necessary. In some circumstances it may be necessary to impose performance criteria in the permit that can be monitored by filter pressure drop indicators or broken bag detectors. When operating normally, fabric filter systems generally achieve very high control efficiencies and the more important element may be to ensure consistent operation. It is therefore advisable to employ systems that are able to detect equipment faults.

- **Shaker Type Bag Filters.** As the name implies, a shaking process dislodges collected particulate in shaker-type fabric filters. For small units, shaking can be accomplished manually, while large fabric filters require mechanical shaking.

  The tops of the bags are usually attached to a shaker bar. When the bags are cleaned, the bar is moved briskly, which flexes the fabric, causing the dust cake to crack and fall into the hopper. The amount of dust that is removed during cleaning can be controlled by regulating the frequency, amplitude, and duration of the shaking cycles. The flow of gas through the bags must be stopped during the cleaning cycle to allow the filter cake to release from the fabric and to prevent dust from working through the bag during the shaking. In order to accomplish this, shaker-cleaned fabric filters are often designed with several separate compartments. Each compartment can then be isolated from the gas flow and cleaned while the other compartments continue to filter the stream (off-line cleaning).

  Typical new equipment design efficiencies are between 99 and 99.9%. Good quality existing devices have a range of actual operating efficiencies of 95 to 99.9%. Both shaker bag filter units and reverse air bag filters can be assisted by the use of “sonic horns” to enhance the collection efficiency. A number of older shaker bag filter units are being replaced by pulse-jet bag filter units, which are becoming the industry norm for bag filtration technology.

- **Reverse Air Bag Filters.** Most reverse-air fabric filters operate in a manner similar to shaker-cleaned fabric filters. The bags are open on the bottom, closed on top and the gas flows from the inside to the outside of the bags with dust being captured on the inside. However, some reverse-air designs collect dust on the outside of the bags. In either design, reverse-air cleaning is performed by forcing clean air through the filters in the opposite direction of the dusty gas flow.

  The change in direction of the gas flow causes the bag to flex and crack the filter cake. As with mechanical shaker-cleaned fabric filters, the most common approach is to have separate compartments within the fabric filter so that each compartment can be isolated and cleaned separately while the other compartments continue to treat the dusty gas.

  Reverse-air cleaning alone is used only in cases where the dust releases easily from the fabric. Reverse air units normally operate on a low gas-to-cloth ratio (velocity of gas through the bag), generally less than 1.2 $m^3$/min of gas per $m^2$ of cloth (m/min). In comparison pulse-jet units may operate on gas-to-cloth ratios as high as 3.0 m/min. The efficiency of the units is similar to mechanical and pulse jet systems. The units perform well where the particle density is low, such as collection of fine material in pneumatic conveying air from timber processing industries.

**Figure 1: Reverse Air Bag Filter**

- **Pulse-Jet Bag Filters.** Pulse-jet cleaning of fabric filters can treat high dust loadings, operate at constant pressure drop, and occupy less space than other types of fabric filters.

  During pulse-jet cleaning a short burst of high pressure air is injected into the bags (about 6 bar for 0.03 to 0.1 seconds). The pulse is blown through a venturi nozzle at the top of the bags and this generates a shock wave that continues on to the bottom of the bag. The wave flexes the fabric, pushing it away from the cage, and then snaps it back, thus dislodging the dust cake.

  The cleaning pulse is very brief, and as a result the flow of dusty gas does not have to be stopped during cleaning. The other bags continue to filter, taking on extra duty because of the bags being cleaned. This enables the pulse-jet fabric filters to operate on a continuous basis with solenoid valves as the only significant moving parts. Pulse-jet cleaning is also more intense and occurs with greater frequency than the other fabric filter cleaning methods. As a result, pulse-jet filters cannot rely on a dust cake to provide filtration. Felted fabrics are used because they do not require a dust cake to achieve high collection efficiencies. Woven fabrics are not as satisfactory with pulse-jet fabric filters because they leak a great deal of dust after they are cleaned.

**Figure 2: Pulse-Jet Bag Filter**

A disadvantage of pulse-jet units that use very high gas velocities is that the dust from the cleaned bags can be drawn immediately to the other bags. If this occurs, little of the dust falls into the hopper and the dust layers on the bags becomes too thick. To prevent this, pulse-jet fabric filters can be designed with separate compartments that can be isolated for cleaning.

Typically, pulse-jet filters operate at gas temperatures up to about 260°C, with surges to about 300°C. However higher temperatures are possible with specialist fabrics. The minimum temperature of the pollutant stream must remain above the dew point of any condensable in the stream. The bag filter unit and associated ductwork should be insulated and possibly heated if potential for condensation exists.

Typical inlet concentrations for bag filter units are 1 to 20 g/$m^3$ but in extreme cases, inlet conditions may vary between 0.1 to more than 200 g/$m^3$.

- **Cartridge Collectors.** Cartridge collectors have the filter media contained in completed closed containers, or cartridges. These collectors offer high efficiency filtration combined with a significant size reduction in the fabric filter unit. Cartridge collectors can operate at higher gas-to-cloth ratios than bag filter systems. Cartridges can be pulse cleaned, and some types can be washed and reused.

  There are a wide variety of cartridge designs and dimensions. Typical designs include flat panels, V-shaped packs or cylindrical packs. Cartridge filters are relatively insensitive to fluctuations in particulate loading. Filter outlet air may be sufficiently clean to be re-circulated within the plant in many cases (for energy conservation) but this should not be used when collecting toxic contaminants.

  Achievable emission reductions for older existing cartridge collector types are in the range of 99 to 99.9%. Typical new devices design efficiencies are between 99.99 and 99.999+%. In addition, commercially available designs are able to control submicron particulate with a removal efficiency of 99.999+%. Standard cartridge collectors are factory-built, off the shelf units. They may handle air flow rates upward of 0.10 $m^3$/s.

The type of filter media and sealants used in the cartridge limits the temperature range cartridge filters can operate in. Standard cartridges utilising paper filter media can accommodate gas temperatures up to about 95°C. Cartridge filters utilising synthetic non-woven media, such as needle-punched felts fabricated of polyester or Nomex, can withstand temperatures of up to 200°C.

Typical inlet concentrations to paper cartridge collectors are 1 to 20 g/m³. Filters that utilise synthetic, non-woven media are able to handle inlet concentrations up to 50g/m³.

**Figure 3: Cartridge Filter**

- **Static Bag Filters.** In a static bag filter the bags are suspended in an enclosure on wires or springs and fixed to the bag filter unit structure. The filter cake collects on the inside of the bag. Movement of the bag within the air stream and stretching due to the increase in weight periodically contributes to the dust cake detaching from the bag and falling into the hopper. Removal can be assisted by manually shaking or rapping the outside surface. The bags being accessed from doors on the outside of the structure

  Static bag filter unit efficiency should be better than 90% if carefully maintained. The system is only suitable for small applications with relatively low inlet dust burdens and is generally limited to air flows of less than 5 m³/s. They are frequently used to clean air displaced from cement and other powder silos.

### *3.2.1 Suitable Applications for Fabric Filtration*

Although fabric filters can be used in many different conditions, there are some factors which limit their application.

- Both the performance and application of fabric filter equipment is very dependent on the type of filter material that is used. The fabric type must also fit the cleaning method, and the stream and particle characteristics.
- The characteristics of the dust are one factor. Some particulates are too adhesive for fabric filters. While such particles are easily collected, they are too difficult to remove from the bags.
- Some fabrics are flammable, and some dusts and stream components may form explosive mixtures. If a fabric filter is chosen to control explosive mixtures, care must be taken when designing and operating the fabric filters to eliminate conditions that could ignite the dust, the stream, and the bags.

- Temperature of the gas stream. There are few fabric filters that can handle temperatures above 300°C for long periods of time. At all temperatures care needs to be taken that the appropriate filter is being used.
- Chemical composition of the gases. While some fabrics have resistance to acid conditions, the most popular fabrics have poor resistance. Lime injection may be necessary to counteract excessive acidity for some applications using Nomex fabric bags.
- Humidity of the gas stream. Gas streams with high humidity can require the bag filter unit to be insulated or heated to maintain temperatures well above the dew point to prevent condensation. Moist gas streams can also clog the bags.
- Spark carryover from the process, which may cause a fire within the bags.

Provided the bag filter units and filters are appropriately designed, bag filter units can be used in most particulate streams including asphalt plants, concrete batching plants, solid fuel-fired combustion processes, metallurgical process, wood and wood product processing and grain milling.

### *3.2.2 Recommended Performance Criteria for Fabric Filtration*

Well-designed and maintained fabric filters that are operated correctly should collect greater than 99 percent of particles ranging in size from sub-micron to hundreds of micrometers. Specialist units, such as cartridge filters with non-woven HEPA and ULPA filters can achieve significantly higher efficiencies. Well-designed and operated bag filter units have been shown to be capable of reducing overall particulate emissions to less than 50 $mg/m^3$ at 25°C, 1 atmosphere pressure, dry gas basis and will with careful design and operation achieve levels as low as 1 - 10 $mg/m^3$ at 25°C, 1 atmosphere pressure, dry gas basis.

The EMB's general design and operating criteria for fabric filtration units are:

- Maximum total particulate discharge of 50 mg/m3 (25°C, 1 atmosphere pressure, dry gas basis). If metals are present in the particulate stream (e.g. foundries, and galvanising plants) maximum particulate emission limit (including metals) of 10 mg/m3 (25°C, 1 atmosphere pressure, dry gas basis);
- Designed to achieve a collection efficiency of at least 99.9% (shakers, pulse jet and reverse air baghouses). Cartridge filters should be designed to achieve a collection efficiency of at least 99.99%. Static fabric filters should only be used for small activities with minor effects should be designed to achieve a collection efficiency of at least 90%;
- Maximum air to cloth ratio of 1.0 $m^3$ per min of gas per $m^2$ of cloth (m/min) (3.5ft.min) for reverse air bag filters and a maximum air to cloth ratio of 3.0 m/min (10 ft.min) for pulse jet bag filter units;
- Appropriate cleaning regimes including a sealed collection unit that does not discharge into the air (if the particulate is not being recycled into the process);
- Bag filter unit compartments able to be isolated from main gas stream for cleaning purposes; and
- Bag filter units, bags and cleaning systems maintained to ensure adequate removal of particulate at all times

EMB's general monitoring requirements for bag filter units include:

- Pressure drop across the bag filter unit. For major or critical bag filter units pressure drop should be continuously monitored and recorded and where necessary alarmed, particularly for metal dusts or hazardous air pollutants. For small, non critical bag filter units pressure drop should be monitored at least weekly and preferably daily;

- For hot gas streams, continuous monitoring and recording of the bag filter unit inlet and outlet temperatures;
- Regular monitoring of the bags within the bag filter unit, this may include visual observations, dye testing or broken bag detectors.
- Particulate sampling will be required for large or critical bag filter units. Sampling of particulate in stack should be undertaken using an appropriate sampling method. EMB prefers USEPA Method 5 .sampling should be undertaken isokinetically to ensure that representative samples are taken.

### 3.3 Electrostatic Precipitators

An electrostatic precipitator (ESP) uses electrical forces to remove particulate matter entrained within a gas stream. Particles are given an electrical charge when they pass through a corona (region consisting of charged ions) and then attach to an opposite-charged collector plate (electrode). Electrodes are maintained at high voltage. Particulate is cleaned from the plates by knocking or rapping so material slides down into the collection hopper without being re-entrained in the gas stream. This process may be assisted in some ESPs by intermittent or continuous washing with water (wet ESP).

A major factor in the performance of the ESP is the resistivity of the particles. In general higher resistivities are preferred because low resistivity particles are held loosely on collection plates and can re-entrain in the exhaust gas during rapping. Very high resistivity is also a problem however, due to a phenomenon known as “back corona”. This is caused by an electric field being formed in particulate layer which can build up on the plates. In general, dry ESPs operate most efficiently with dust resistivities between $5 \times 10^3$ and $2 \times 10^{10}$ ohm-cm. Dust resistivity is generally not such a factor for wet ESPs.

Operating gas temperature and chemical composition of the dust are also key factors and must be carefully considered in the design of an ESP.

The various types of precipitator may be configured as:

- ***Plate-Wire*** — the gas flows between parallel plates of sheet metal and high voltage electrodes in the form of long wires tensioned by weights. The wires hang between the plates. The plate-wire ESP allows for flow lanes in parallel and can handle large volumes of gas. Rapping to remove the collected material is carried out in sequence through the unit. The units normally operate with three or four wire sections in series (often called stages).
- ***Flat-Plate*** — use flat plates instead of wires for the high voltage electrodes. The plates increase the field that can be used to collect the particles and provide an increased surface for collection of particles. Corona generating electrodes are placed ahead of the plates. Flat plate units have an application for high resistivity dusts. Low flow velocities are required to prevent high rapping losses.
- ***Tubular Precipitator*** — essentially a single stage unit and is unique in having all the gas pass through the electrode. This type of unit is normally used only where special requirements demand eg sticky or wet particulate. The units are usually cleaned with water and have very low re-entrainment losses.
- ***Two Stage Precipitator*** — these are normally smaller units ($< 25\ m^3/s$) constructed in package form and delivered to the site. The units are two stages with the discharge electrode preceding the collector electrodes.

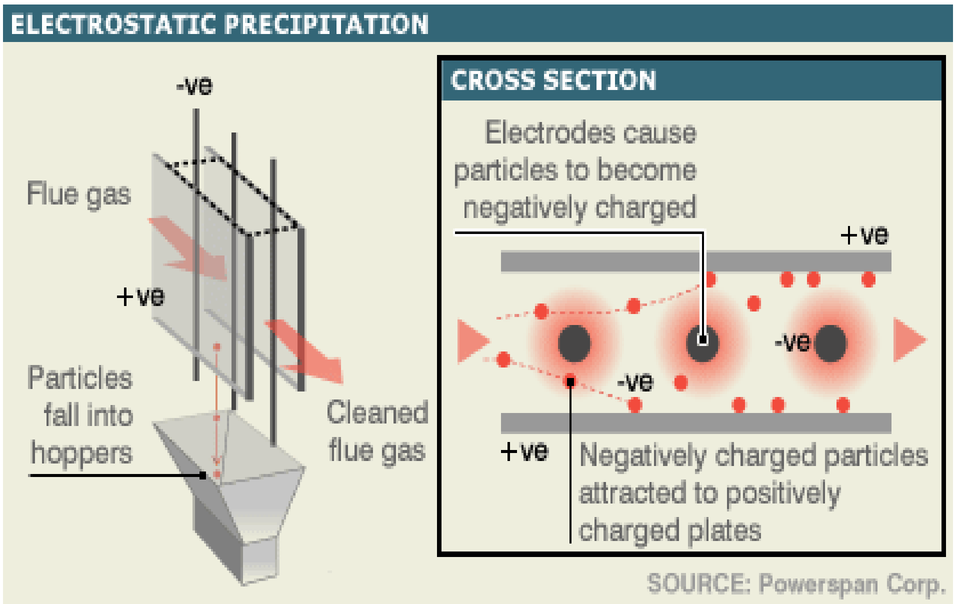



**Figure 4: Schematic of an Electrostatic Precipitator**


**Figure 5: ESP Fitted to a Power Station**

The particle size distribution impacts on the overall performance of an ESP. In general, the most difficult particles to collect are those with aerodynamic diameters between 0.1 and 1.0 µm. Particles between 0.2 and 0.4 µm usually show the most penetration. This is most likely a result of the transition region between field and diffusion charging.

Typical new equipment design efficiencies are between 99 and 99.9%. Good quality existing equipment has a range of actual operating efficiencies of 90 to 99.9%.

### *3.3.1 Suitable Applications for ESPs*

ESPs can be used for the collection of submicron particles such as mists, smoke and fume. Common applications of dry wire-plate ESPs are large solid fuel-fired boilers such as coal-fired power stations or recovery boilers at pulp and paper mills. They are also common in the cement industry and used to some degree in the metallurgical and chemical industries.

Wet ESPs are suitable for the wood products industry to remove blue haze or mist and fume control from sulphonic acid manufacture. In many of these applications using chemical such as sodium hydroxide can enhance the collector washing process. Other applications of wet wire-plate ESPs are similar to dry ESPs and tend to be used when higher control efficiencies are necessary.

ESPs are more common for very large applications. However smaller units are used in the wood processing and chemical industry. Wire-plate ESPs can operate at very high temperatures, up to 700°C.

### *3.3.2 Recommended Performance Criteria for ESPs*

Because of the range of design options it is not possible to stipulate general design criteria for ESPs. However, with the above collection efficiencies, particulate emissions between 50 and 100 $mg/m^3$ adjusted to 25°C, 1 atmosphere pressure, dry gas basis would be expected in many applications. For certain applications, such as ESPs used for fume or aerosol capture, site specific criteria are necessary and should be included as permit conditions.

For large processes such as cement pants and power stations that use ESPs to control particulate emissions, EMB requires that the particulate concentration from the ESP should be continuously monitored using continuous emission monitoring systems (CEMSs).

Alarms shall be installed and monitored to indicate when an ESP unit has tripped out (is not operating). Process shutdown procedures in accordance with the sites Contingency Plan will be instigated after 5 minutes, if the ESP can not be restarted.

Annual particulate sampling should be required of all ESPs. Sampling of particulates in stacks should be undertaken using an appropriate sampling method. EMB prefers USEPA Method 5 and sampling should be undertaken isokinetically to ensure that representative samples are taken.

## 3.4 Cyclonic Separators for Particulates

Inertial separators are the most widely used collectors being suitable for medium to large size particles. They fall into two categories:

- Mechanically aided separators that involve the use of a rotary vane (e.g. radial blade fan) to mechanically impart a centrifugal force on the particles in the gas stream, which causes them to separate from the gas;
- Cyclonic type separators, which have no moving parts, where the mechanical force is generated by the velocity of the gas stream.

Cyclones are also referred to as cyclone collectors, cyclone separators, centrifugal separators, and inertial separators. In applications where many (usually small) cyclones are operating in parallel, the entire system is called a multiple tube cyclone, multiple cyclone, or multi-cyclone. Cyclones use inertia to remove particles from a spinning gas stream. Within a cyclone, the gas stream is forced to spin within a parallel-sided chamber adjoining a second lower conical-shaped chamber. Particles in the gas stream are forced toward the cyclone walls by the centrifugal force of the spinning gas, but are opposed by the fluid drag force of the gas travelling through and out of the cyclone. For the larger particles inertial momentum overcomes the fluid drag force so that the particles reach the cyclone wall. For smaller particles, the fluid drag force overwhelms the inertial momentum and causes these particles to leave the cyclone with the exiting gas. Gravity causes the larger particles that reach the cyclone walls to travel down into a hopper located at the bottom of the cyclone body.

Cyclone collectors can be classified into four types, based on how the gas stream is introduced and how the collected dust is discharged:

- Tangential inlet, axial discharge;
- Axial inlet, axial discharge;
- Tangential inlet, peripheral discharge; and
- Axial inlet, peripheral discharge.

The first two types are the most commonly used cyclones.

Cyclone collectors can be designed for many applications, and they are typically categorized as high efficiency, conventional (medium efficiency), or high throughput (low efficiency). High efficiency cyclones are likely to have the highest-pressure drops of the three cyclone types, while high throughput cyclones are designed to treat large volumes of gas with a low-pressure drop.

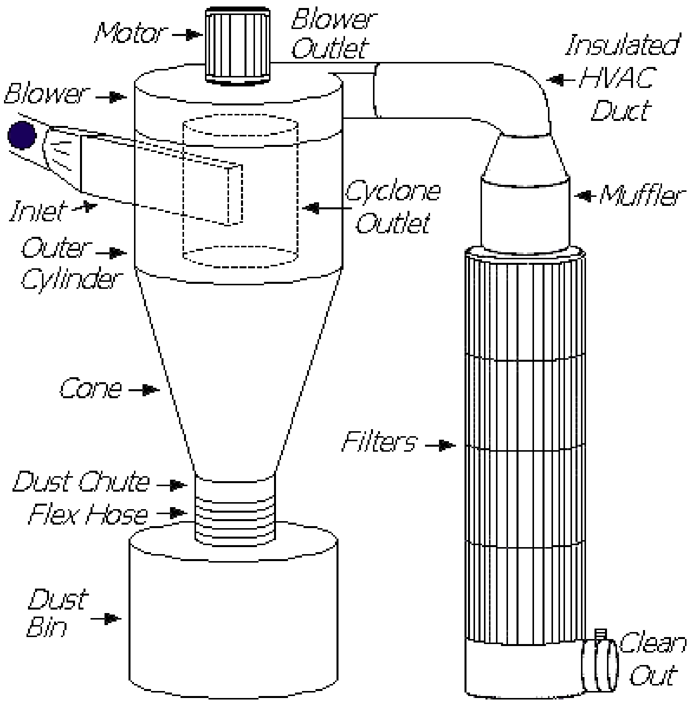



**Figure 6: Schematic of Cyclonic Dist Collector**

Each of these three cyclone types has the same basic design. Different levels of collection efficiency and operation are achieved by varying the standard cyclone dimensions.

The collection efficiency of cyclones varies as a function of particle size, density and cyclone design. Cyclone efficiency will generally increase with increases in:

- Particle size and/or density;
- Inlet duct velocity;
- Cyclone body length;
- Number of gas revolutions in the cyclone;
- Ratio of cyclone body diameter to gas exit diameter;
- Inlet dust loading; and
- Smoothness of the cyclone inner wall.

The cyclone efficiency will decrease with increases in the following parameters:

- Gas viscosity;
- Cyclone body diameter;

- Gas exit diameter;
- Gas inlet duct area;
- Gas density; and
- Leakage of air into the dust outlet.

The efficiency of a cyclone collector is related to the pressure drop across the collector. This is an indirect measure of the energy required to move the gas through the system. The pressure drop is a function of the inlet velocity and cyclone diameter. In general, 18 meters per second is considered to be the optimum operating inlet velocity.

Common ranges of pressure drops for cyclones are:

- 0.5 to 1 kilopascals (kPa) for low-efficiency units and high throughput units;
- 1 to 1.5 kPa for medium-efficiency units; and
- 2 to 2.5 kPa for high-efficiency units.

Control efficiency ranges for single cyclones are often based on four classifications of cyclone. Table 1 gives a summary of expected efficiencies for these cyclones. The collection efficiencies given in Table 1 may indicate possible performance criteria for cyclones but should not be applied as conditions of a permit. Particulate removal efficiencies are relatively expensive to measure, consequently emissions limits are a more commonly applied criteria. The performance of the cyclones and other inertial separators is very specific to application however, and general criteria cannot be specified.

**Table 1: Cyclone Particle Collection Efficiencies**

| Cyclone type | Particle Size | Collection Efficiency (%) |
|---|---|---|
| Conventional | Total | 70 |
| | $PM_{10}$ | 30-90 |
| | $PM_{2.5}$ | 0-40 |
| High Efficiency | Total | 80-90 |
| | $PM_{10}$ | 60-90 |
| | $PM_{2.5}$ | 20-70 |
| High Throughput | > 20 µm | 80-99 |
| | $PM_{10}$ | 10-40 |
| | $PM_{2.5}$ | 0-10 |
| Multiple Cyclones | > 5 µm | 80-95 |

### *3.4.1 Suitable Applications for Cyclones*

The majority of dusts are suitable for collection in mechanical and inertial collectors. The only significant exception being that sticky dust can clog the cyclonic systems. This limitation can be overcome by using a “wet cyclone” where the walls of the cyclone are irrigated with water to assist in the removal of the dust stream. This should not be confused with a wet cyclone associated with a scrubber and designed to remove the water droplets carried forward.

Most applications for inertial separators are for large particulates where moderate collection efficiencies are required. Timber milling and processing, pneumatic conveying, and operations that produce shavings, chips and fibre are generally suitable applications for cyclones. Fossil-fuel and wood-waste fired fuel combustion units are also suitable for multiple cyclones or high efficiency cyclones when moderate collection efficiency is required. However, when high efficiency collection is necessary, wet scrubbers, electrostatic precipitators, or fabric filters are required to collect the remaining fine particulate matter ($PM_{10}$), perhaps with some form or inertial separator as a pre-collector.

Typical gas flow rates are 0.5 to 15 $m^3$/s for single cyclone units, and 50 $m^3$/s or more for multiple cyclones. Inlet gas temperatures are only limited by the materials of construction of the cyclone, and can be as high as 300°C. Particulate inlet concentrations typically range from 2 to 200 g/$m^3$. Outlet particulate concentrations can range from 50 to 400 mg/$m^3$ adjusted to 25°C, one atmosphere and dry gas basis.

### *3.4.2 Recommended Performance Criteria for Inertial Separators*

The performance of cyclones and other inertial separators are activity-specific. A large range of different designs is possible and performance is also very dependent on particle size and type. Therefore a general performance or design criteria has not been specified in these guidelines. Table 1 however, provides a guide to control efficiencies that should be expected for cyclones.

Some general performance criteria will be specified for groups of activities or processes, for example, multiple-cyclones on combustion processes and this will be contained in the permit issued for that particulate stationary source. However, such criteria are as much a function of the process and operational factors as the design of the inertial separator, so it is difficult to set general criteria even for specific industries.

## 3.5 Particulate Scrubbers

Wet scrubbers are particulate control devices that rely on direct and irreversible contact of a liquid (usually water) in the form of droplets, foam, or bubbles. The liquid with the collected particulate is then easily collected. Scrubbers can be very specialized and designed in many different configurations. Wet scrubbers are generally classified by the method that is used to induce contact between the liquid and the particulate, e.g. spray, packed-bed, plate. Scrubbers are also often described as low, medium, or high-energy, where energy is often expressed as the pressure drop across the scrubber.

Wet scrubbers have important advantages when compared to other particulate collection devices. They can collect flammable and explosive dusts safely, absorb gaseous contaminants, and collect mists. Scrubbers can also cool hot gas streams and act as flame arresters. There are also some disadvantages associated with wet scrubbers. For example, scrubbers have the potential for corrosion and freezing, can cause water and solid waste pollution problems, and can have a cool, visible discharge plume.

The collection mechanisms of wet scrubbers are highly dependent on particle size. Inertial impaction is the major collection mechanism for particles greater than approximately 0.1 m in diameter. The effectiveness of inertial impaction increases with increasing particle size. Diffusion is generally effective only for particles less than 0.1 m in diameter, with collection efficiency increasing with decreasing particle size.

The combination of these two principal scrubber collection mechanisms contributes to minimum collection efficiency for particulate approximately 0.1 μm in diameter. The exact minimum efficiency for a specific scrubber will depend on the type of scrubber, operating conditions, and the particle size distribution in the gas stream. The design of the scrubber should ensure a closely packed fine dispersion of droplets is generated to act as targets for particle capture. A variety of methods are used to generate the droplets. These include injecting a liquid and pneumatically shearing the liquid into a fine spray with a high velocity gas stream or using a high pressure liquid spray to create the droplets.

The aim is to cause the particle to be lodged inside the collecting droplet and then to remove the large (relatively) collecting droplet from the gas stream. In general, the smaller the liquid droplet the higher the potential will be to remove smaller particles.

Scrubbing types include:

- ***Spray Chambers***. A spray chamber is a very simple, low-energy wet scrubber. The particulate-laden gas stream is introduced into a chamber where it comes into contact with liquid droplets generated by spray nozzles. The size of the droplets generated by the spray nozzles is controlled to maximize liquid-particle contact and, consequently, scrubber collection efficiency. A de-mister at the top of the spray tower removes liquid droplets and wetted particulate from the exiting gas stream. Scrubbing liquid and wetted particulate matter also drain from the bottom of the tower in the form of slurry.

- ***Packed-Bed Scrubber***. A packed-bed scrubber consists of a chamber containing layers of variously shaped packing material, which provide a large surface area for liquid-particle contact. The packing is held in place by wire mesh retainers and supported by a plate near the bottom of the scrubber. Scrubbing liquid is evenly introduced above the packing and flows down through the bed. The liquid coats the packing and establishes a thin film. The gas stream is forced to follow a circuitous path through the packing, on which much of the particulate impacts. The liquid on the packing collects the particulate and flows down the chamber towards the drain at the bottom of the tower. A mist eliminator (also called a "de-mister") is typically positioned above/after the packing and scrubbing liquid supply. Any scrubbing liquid and wetted entrained material in the exiting gas stream will be removed by the mist eliminator and returned to drain through the packed bed.

**Figure 7 Packed Bed Scrubber**

- ***Impingement Plate Scrubber.*** An impingement plate scrubber is a vertical chamber with plates mounted horizontally inside a hollow shell. Impingement plate scrubbers operate as counter-current collection devices. The scrubbing liquid flows down the tower while the gas stream flows upward. Contact between the liquid and the particle-laden gas occurs on the plates. The plates are equipped with openings that allow the gas to pass through. Gas-liquid-particle contact is achieved within the froth generated by the gas passing through the liquid layer. The bubble caps and baffles placed above the plate perforations force the gas to turn before escaping the layer of liquid. While the gas turns to avoid the obstacles, most particulates cannot and are collected by impaction on the caps or baffles. Bubble caps and the like also prevent liquid from flowing down the perforations if the gas flow is reduced.

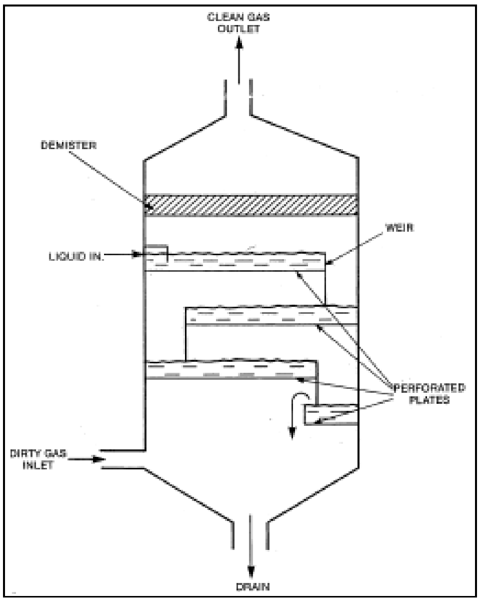



**Figure 8: Impingement Plate Scrubber**

- ***Mechanically-Aided Scrubber.*** A mechanically-aided scrubber (MAS) employs a motor-driven fan or impeller to enhance gas-liquid contact. Generally in MASs, the scrubbing liquid is sprayed onto the fan or impeller blades. Fans and impellers are capable of producing very fine liquid droplets with high velocities. These droplets are effective in contacting fine particulate. Once impacted, the droplets are normally removed by cyclonic motion. Mechanically aided scrubbers are capable of high collection efficiencies, but only with commensurate high energy consumption.

- ***Venturi Scrubber.*** A venturi, or gas-atomised spray, scrubber accelerates the gas stream to atomise the scrubbing liquid and to improve gas-liquid contact. In a venturi scrubber, a "throat" section is built into the duct that forces the gas stream to accelerate as the duct narrows and then expands. As the gas enters the venturi throat, both gas velocity and turbulence increase. The scrubbing liquid is sprayed into the gas stream just before the gas encounters the venturi throat. The scrubbing liquid is then atomised into small droplets by the turbulence in the throat and droplet-particle interaction is increased. After the throat section, the wetted particulate and excess liquid droplets are separated from the gas stream by cyclonic motion and/or a mist eliminator. Venturi scrubbers have the advantage of being simple in design, easy to install, and with low maintenance requirements.

**Figure 9: Venturi Scrubber**

- ***Orifice Scrubber***. Orifice scrubbers, also known as entrainment or self-induced spray scrubbers, force the particle-laden gas stream to pass over the surface of a pool of scrubbing liquid as it enters an orifice. With the high gas velocities typical of this type of scrubber, the liquid from the pool becomes entrained in the gas stream as droplets. As the gas velocity and turbulence increase with the passing of the gas through the narrow orifice,

- the interaction between the particulate matter and liquid droplets also increases. Particulate matter and droplets are then removed from the gas stream by impingement on a series of baffles that the gas encounters after the orifice. The collected liquid and particulate drain from the baffles back into the liquid pool below the orifice. Orifice scrubbers can effectively collect particles larger than 2 µm in diameter. Some orifice scrubbers are designed with adjustable orifices to control the velocity of the gas stream.

- ***Condensation Scrubber***. In a condensation scrubber, particles act as condensation nuclei for the formation of droplets. Generally, condensation scrubbing depends on first establishing saturation conditions in the gas stream. Once saturation is achieved, steam is injected into the gas stream. The steam creates a condition of supersaturation and leads to condensation of water on the fine particulate in the gas stream.

- ***Fibre-Bed Scrubber.*** In a fibre-bed scrubber the moisture-laden gas stream passes through mats of packing fibres, such as spun glass, fibreglass, and steel. The fibre mats are often also wetted with the scrubbing liquid. Depending on the scrubber requirements, there may be several fibre mats and an impingement device for particulate removal included in the design. The final fibre mat is typically dry for the removal of any droplets that are still entrained in the stream. Fibre-bed scrubbers are best suited for the collection of soluble particulate material, i.e. material that dissolves in the scrubber liquid, since large amounts of insoluble material will clog the fibre mats with time. For this reason, fibre-bed scrubbers are more often used as mist eliminators, i.e. for the collection of liquids, rather than for particulate control.

### *3.5.1 Suitable Applications for Particulate Scrubbers*

Particulate scrubbers can be used in a wide range of applications, but wastewater treatment or slurry disposal must be managed effectively, otherwise the pollutant load will be transferred to the water environment.

Venturi scrubbers are suitable for industrial boilers fired with a range of fuels including coal, oil, and wood. They can also be applied to control emissions from chemical, mineral products, wood, pulp and paper, rock products, lead, aluminium, iron and steel, and grey iron production industries; and to municipal solid waste thermal oxidisers. A particularly common application is to control emissions from hot-mix asphalt plants.

Spray towers are comparatively uncommon and tend to be used as pre-conditioners for other control devices or in situations where gas absorption may also be necessary, such as the superphosphate manufacturing industry.

Orifice scrubbers are used in solid fuel combustion processes, food processing (cereal, flour, rice, salt, sugar, etc.), pharmaceutical processing; and the manufacture of chemicals, rubber and plastics, ceramics, and fertilizer. Orifice scrubbers can be built as high energy units, but most devices are designed for low-energy service.

### *3.5.2 Recommended Performance Criteria for Particulate Scrubbers*

Collection efficiencies for wet scrubbers are highly variable. Most conventional scrubbers can achieve high collection efficiencies for particles greater than 1.0 µm in diameter. However, they are generally ineffective collection devices for sub-micron (< 1 µm) particles.

Scrubber collection efficiency is directly proportional to the inlet dust concentration. That is, efficiency will increase with increasing dust loading. This suggests that scrubber removal efficiency is not constant for a given scrubber design, unless it is referenced to a specific inlet dust loading. In contrast, it has been shown that scrubber outlet dust concentration is a constant, independent of inlet concentration, similar to fabric filters described above.

This feature, along with the large potential variety of design options, means that performance criteria for particulate scrubbers are best expressed in the form of discharge limits. These can vary with application and generalised criteria are not recommended by these guidelines. Site specific emission criteria are necessary and should be set based on the particulate concentrations used in the dispersion modelling. For some specific industrial applications general emission concentration limits can be applied. For example, asphalt plants with well managed venturi scrubbers can achieve a discharge less than 100 $mg/m^3$ adjusted to 25°C, one atmosphere and dry gas basis, while orifice scrubbers on solid fuel boilers can achieve 100 $mg/m^3$ adjusted to 25°C, one atmosphere and dry gas basis.

## 3.6 Ceramic Filters

Low density ceramic filter elements can be used for the cleaning of incineration gases and similar high temperature gas streams. A typical ceramic filter is the Cerafil unit; typically these have a diameter of 60 mm, length up to three metres and a wall thickness of 10 mm. The nominal face velocity is 0.03 m/s. A three metre long filter will treat about 150 actual cubic metres per hour.

The ceramic filter offers three main benefits:

- Refractory composition, fire and spark resistance, high porosity, resistance to thermal shock;
- Inert and resistant to attack from both acid and alkali gas streams; and
- Residual dust layer coupled with cake filtration mechanism gives high filtration efficiency.

Ceramic filters accommodate operating temperatures typically up to 900°C. Applications include incineration, secondary metal production, processes with an exhaust temperature above the limitations of conventional filters, and dry scrubbing of acid or alkali gas streams.

### *3.6.1 Recommended Performance Criteria for Particulate Scrubbers*

As ceramic filters are relatively new technology and mainly used for special applications, performance criteria have not be set in the guidelines. Performance criteria should be assessed and set on a case by case basis dependent on the industrial activity.

## 3.7 Particulate Pre-Treatment Systems

The performance of most particulate control devices can often be improved through pre-treatment of the gas stream. Pre-treatment consists of two categories:

- Pre-collection; and
- Gas conditioning.

Pre-collection devices are installed upstream of the main particulate control device and remove large particles from the gas stream, reducing the loading on the primary control device or preventing dangerous situations, such as hot or burning particles entering fabric filters. For example a high efficiency cyclone before a bag filter unit which removes the larger particles including any sparks.

Gas conditioning techniques alter the characteristics of the particles and/or the gas stream to allow the primary control device to function more effectively. Both types of pre-treatment can lead to increased collection efficiency and operating life, while reducing operating costs.

## 3.8 Biofiltration

The term ‘Biofiltration’ is applied to a technology in which vapour phase compounds (generally organic compounds) are passed through a bed of media material (‘biofilter’) and adsorbed onto the exposed surface where they are degraded by micro-organisms in the bed. The bed media is generally soil, bark, compost, scoria or any combination of these materials.

A development of the biofilter is the ‘bioreactor’. This operates in a similar manner to the biofilter but uses an inert support media such as plastic rings, scoria or pumice. The support medium used can vary widely depending on the application. The micro-organisms are cultured as a biofilm on the surface of support media supported by re-circulating water.

The biofilter provides several advantages over conventional absorbers. First, bio-regeneration of the biofilter media keeps the maximum adsorption capacity available constantly; thus, the mass transfer zone remains stationary and relatively short. The filter does not require regeneration, and the required bed length is greatly reduced. These features reduce capital and operating expenses. Additionally, the contaminants are destroyed not just separated, as with activated carbon or similar technologies. In common with other biological treatment processes, biofiltration is dependent upon the biodegradability of the contaminants. Under proper conditions, biofilters can remove virtually all selected contaminants to harmless products. Biofiltration is used primarily to treat hydrogen sulphide, organo-sulphides, organo-nitrogen compounds and non-halogenated hydrocarbons. Halogenated hydrocarbons also can be treated, but the process may be less effective.

Inlet concentrations of contaminants in the gas stream may range from fractions of a part per million (ppmv) up to 1000 ppmv or higher. Efficiency of removal is dependent on the system and contaminant. General odour removal (measured by olfactometry) from waste water treatment plants is expected to be at least 90%. Removal efficiencies for hydrogen sulphide and methyl mercaptan are greater than 99% and 95% respectively (Brenman et al, 1996).

Biofilter design centres on ensuring adequate contact or residence time in the filter bed. This is often expressed in terms of the ratio of treated gas volume to bed cross sectional areas. Values of this ratio typically range from 50 to 100 m3/m2/hr, with bed depths typically 0.8 to 1.2m. The principal disadvantage of biofilters is their large space requirement. However, this can be overcome by using stacked systems with synthetic media, or bioreactors, which have less demanding requirements on residence time and hence size.

The modern biofilter will operate for extended periods with minimal monitoring. However, to maintain maximum efficiency moisture levels must be maintained at higher than 60% and temperature in the 20 – 35°C range. Control of pH is less critical but should be within the range 4 – 8. Bed moisture content is very important and the humidity of the gas stream should be maintained at near to 100% to prevent drying of the underside of the bed. Overhead spray type watering systems are also common. The filter bed should be maintained in an aerobic condition.

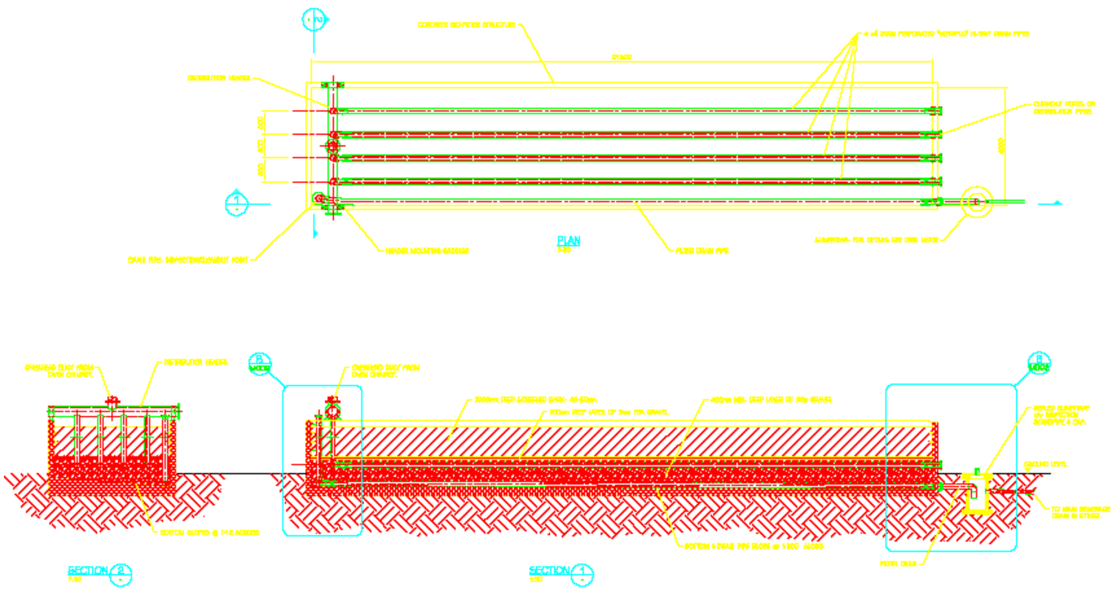


Figure 10: Schematic of a Biofilter

Bioreactors that use an inert bed material normally require the biofilm to be seeded with the most appropriate bacteria and to provide nutrients for food.

Many biofilters in the past have failed due to inadequate design or maintenance. Where a biofilter is used as the primary control device, the design of any associated condenser can be as critical as the design of the actual biofilter. Pilot plants can be used to determine whether a biofilter will provide suitable control.

### *3.8.1 Suitable Applications for Biofilters*

Biofilters and bioreactors are suitable for many applications and the variety of processes using them is growing. Their main uses have largely been confined to wastewater treatment, composting, food and animal products industries including emissions from rendering plants. They have also been used for treatment of VOCs and other contaminants from the surface treatment industry and petrochemical industry.

### *3.8.2 Recommended Performance Criteria for Biofilters*

The EMB's general design and operating criteria for conventional biofilters are:

- Maximum ratio of total gas volume to bed cross sectional area of 50 $m^3/m^2/hr$. Total gas volume includes process air and any necessary dilution air, but excludes flows during maintenance, which will be assessed on a case-by-case basis but should not generally exceed 75 $m^3/m^2/hr$.
- The biofilter must be capable of running with parts of the bed isolated from the incoming gas flow for maintenance purposes;
- Minimum bed depth of filter media of 1.0 m;
- Designed to achieve at least 95% odour removal efficiency;
- Maximum inlet gas temperature of 35°C;
- Humid inlet air stream to maintain the bed moisture content generally above 50%. Bed moisture content is dependent on the media used. Too little moisture causes cracking and decreased microbial activity while too much clogs the media, preventing adsorption and increasing the pressure drop, and leads to undesirable anaerobic activity;
- Pressure drop generally less than 100 mm water gauge;

- pH of bed media generally between 4 - 8 and preferably between pH 7 - 8; and
- Bed distribution system designed and bed maintained to ensure even distribution of flow through the bed and no bypassing (short circuiting) or breakthrough of untreated or partially treated air, particularly for side walls.

The EMB's general monitoring requirements for conventional biofilters are:

- Continuous monitoring and recording of gas inlet temperature;
- Continuous monitoring and recording and if appropriate alarming of the operation of the inlet gas fan;
- At least weekly monitoring and recording of the pressure drop across the bed;
- At least monthly monitoring and recording of bed pH;
- At least weekly monitoring and recording of bed moisture content; and
- Daily visual observations of the state of the biofilter bed, particularly for short circuiting and clogging of the bed.

Odour or contaminant sampling will not be required except in special circumstances. Olfactometry techniques cannot reliably measure below about 50 odour units (i.e. 50 times the odour threshold) and natural odours from bark or soil media can interfere, being of the order of 80 - 150 OUs. Therefore, odour levels need to be quite high before olfactometry can be undertaken and it is likely that these levels of odour will be detected by observations.

## 3.9 Thermal Oxidation of Gaseous Contaminants

Thermal oxidation (incineration) relies on the destruction of air pollutants by the application of heat. It is best applied to carbon and hydrogen-containing contaminants because thermal oxidation renders them into harmless carbon dioxide and water. There are several different types of thermal oxidation devices:

- Thermal
- Recuperative
- Catalytic
- Regenerative
- Flares.

Thermal oxidation may be used as a control option for particulate and/or volatile organic materials in a gas stream. In general, it would only be applied where the volatile material is adsorbed onto the particulate matter or is being carried in the gas stream.

- ***Thermal Oxidisers.*** Thermal oxidisers are probably the most common and are often referred to as '*afterburners*' in some industrial applications. These units rely on thermal oxidation by raising the temperature of combustible materials above the auto-ignition point in the presence of oxygen. A straight thermal oxidiser is comprised of a combustion chamber and does not include any heat recovery of exhaust air by a heat exchanger. Contaminant destruction efficiency in thermal oxidisers depends upon design criteria (i.e., chamber temperature, residence time, inlet concentration, compound type, and degree of mixing). Typical thermal oxidiser design efficiencies range from 98 to 99.99% and above, depending on system requirements and characteristics of the contaminated stream. Typical design conditions needed to meet more than 98% control are:

  870 °C combustion temperature, 0.75 second residence time, and flow velocities of at least 6 – 12 metres/second to ensure proper mixing (Buonicore and Davis, 1992). This criterion

excludes halogenated streams, which may require significantly more demanding conditions and possibly additional devices such as acid scrubbing or carbon adsorption due to the potential to generate acidic gases or even dioxins.

**Figure 11: Thermal Oxidiser**

For vent streams with low contaminant concentrations (typically below approximately 2000 ppmv for VOCs), reaction rates and maximum destruction efficiency decrease. Relatively high destruction efficiencies may also be difficult to measure with low inlet concentrations due to the detection limitations of measurement instruments. Performance criteria may therefore be better expressed as a minimum emission limit, such as outlet concentrations less than 20 ppmv VOCs.

- ***Recuperative Thermal Oxidisers.*** Recuperative thermal oxidiser systems are similar to thermal oxidisers but employ heat exchangers to preheat the waste gas stream, and if appropriate to recover secondary heat for process heating or to generate steam or hot water. Two general types of heat exchangers are used: shell and tube, and plate heat exchangers. Shell and tube units are more common and have advantages when temperatures exceed 540$^{o}$C. Recuperative thermal oxidisers have similar destruction efficiencies to thermal oxidisers, but this can be limited by the need to limit temperatures in the heat exchanger to prevent damage. Care is needed for applications with gases that are difficult to oxidise or when very high destruction efficiencies are necessary. They are usually more economical to operate than straight thermal oxidisers because they can recover 40 to 50% of the waste heat from the exhaust gases, but have higher maintenance costs. To avoid fouling of heat exchangers excessive particulate in the inlet gases must be avoided.

  Suitable design and performance criteria for recuperative thermal oxidisers are similar to those for simple thermal oxidisers discussed above.

- ***Catalytic Thermal Oxidisers.*** Catalytic thermal oxidisers operate very similarly to thermal oxidisers, with the primary difference that the gas, after passing through the flame area, passes through a catalyst bed. The catalyst has the effect of increasing the oxidation reaction rate, enabling conversion at lower reaction temperatures than in thermal oxidiser units. Catalysts typically used for VOC destruction include platinum and palladium. Other formulations include metal oxides, which are used for gas streams containing chlorinated compounds (USEPA, 1998).

  Several different types of catalyst thermal oxidisers are available, largely distinguished by the method of contacting the contaminated gas stream with the catalyst. Both fixed bed and fluid-bed systems are used.

Contaminant destruction efficiency is dependent on the composition of the gas, operating temperature, oxygen concentration, catalyst type and space velocity. Temperature and space velocities are particularly important. High temperatures and low space velocities produce increasing destruction efficiencies. For example, 95% destruction of VOCs can be achieved in a catalytic thermal oxidiser operating at 450°C, with a catalyst bed volume of 0.029 to 0.12 per standard cubic meter per second of off gas (USEPA CACT, 1998). Destruction efficiencies up to 99% are achievable but this requires larger catalyst volumes and/or higher temperatures.

**Figure 12: Catalytic Thermal Oxidiser**

- ***Regenerative Thermal Oxidisers.*** Regenerative thermal oxidisers are similar in principle to recuperative thermal oxidisers, but use direct contact with a high-density media such as a ceramic-packed bed for heat exchange. The bed is heated with exhaust gases before using it to pre-heat and partially oxidise the inlet waste gas. The preheated and partially oxidised gases then enter a combustion chamber where final destruction takes place before the cleaned gases are directed to one or more packed beds cooled by an earlier cycle. Regenerative thermal oxidisers can also employ a catalyst rather than ceramic material in the packed bed. This allows for destruction at a lower oxidation temperature. These units are often called 'regenerative catalytic thermal oxidisers'.

  Contaminant destruction efficiencies of thermal regenerative thermal oxidisers typically range from 95 to 99%, while catalytic units range from 90 to 99%. Catalytic units however have the advantage of being able to remove carbon monoxide from VOC laden air. Both systems are poor at coping with particulate laden waste streams, and the catalytic system in particular may require removal of any particulate to avoid clogging or blinding problems.

  Regenerative thermal oxidisers are expensive and difficult to install, and have a large size and weight and a high maintenance demand for moving parts. Advantages include low fuel requirements, an ability to operate at higher temperatures than recuperative thermal oxidisers and suitability for high flow, low concentration waste streams. Because they are uncommon in the Philippines, standard design and performance criteria are not recommended for regenerative thermal oxidisers.

Figure 13: Schematic of Regenerative Thermal Oxidiser

- ***Flares.*** Flares are a specialist category of thermal oxidiser. They are primarily safety devices, which deal with flows of short duration (generally an upset condition or an accidental release from a process) rather than a control device that treats a continuous waste stream. Flares are generally categorized in two ways:

  - by the height of the flare tip (i.e. ground or elevated), and
  - by the method of enhancing mixing at the flare tip (i.e. steam-assisted, air-assisted, pressure-assisted, or non-assisted).

  Elevating the flare can prevent potentially dangerous conditions at ground level and this also allows the products of combustion to be dispersed. In most flares, combustion occurs by means of a diffusion flame. A diffusion flame is one in which air diffuses across the boundary of the fuel/combustion product stream toward the centre of the fuel flow, forming the envelope of a combustible gas mixture around a core of fuel gas. This mixture, on ignition, establishes a stable flame zone around the gas core above the burner tip. This inner gas core is heated by diffusion of hot combustion products from the flame zone.

  Flares can be used to control almost any VOC stream, and can typically handle large fluctuations in concentration, flow rate, and other characteristics. Flares find their primary application in the petroleum and petrochemical industries but are also common for landfill gas treatment. The majority of chemical plants and refineries have flare systems designed to relieve emergency process upsets that require release of large volumes of gas. These large diameter flares are designed to handle emergency releases, but can also be used to control vent streams from various process operations.

Figure 14: Enclosed Flare

### 3.9.1 *Suitable Applications for Thermal Oxidisers*

Standard thermal oxidisers and recuperative thermal oxidisers can be used to reduce emissions from almost all sources of VOCs. This includes surface coating operations, ovens, dryers, kilns, reactor vents and distillation vents. Both can handle minor fluctuations in flow, but flares are necessary for very large fluctuations. Contaminant concentrations should be well below the lower flammable limit to prevent explosions. A factor of four is usually employed to give an adequate margin of safety.

Catalytic thermal oxidisers can also handle a range of VOC sources and are widely used by the surface coating industry. They are most suited to low volume systems when there is little variation in flow and when there is no potential for fouling from particulate, silicon, sulphur, heavy hydrocarbons and metals such as lead.

Regenerative thermal oxidisers are more suitable for high flow (above 2.5 $m^3/s$) and low VOC concentrations (below 1000 ppmv). They are also suitable for a wide range of sources but cannot handle particulate or condensable material, and catalytic units may be adversely affected by gases containing silicon, phosphorous, arsenic or certain heavy metals.

### 3.9.2 *Recommended Performance and Design Criteria for Thermal oxidisers*

Table 2 presents a summary of performance criteria that could be applied to most activities employing thermal oxidisers as control devices. These criteria are suitable for setting permit conditions.

Table 2 : Summary of Thermal Oxidiser Design and Performance Criteria

| Thermal Oxidiser Type | Recommended Design Criteria | Recommended Performance Criteria |
|---|---|---|
| Thermal<br>Recuperative thermal<br>Regenerative thermal | 750 – 850 $^{o}$C, for 0.5 – 2 second residence time | 98 – 99.99 % removal or < 20ppm VOCs for low concentration inlets |
| Catalytic | Site-specific | 95 – 99 % removal or < 20ppm VOCs for low concentration inlets |

A range of conditions are recommended because higher temperatures and residence times are necessary for those contaminants that are difficult to burn, such as particulates and products of incomplete combustion. Lower temperatures and residence times are suitable for flammable VOCs and most odours.

EMB's general design and operating criteria for thermal oxidisers are:

***Thermal Oxidisers***

- Minimum temperature of between 750 and 850°C, and a minimum residence time of between 0.5-2 seconds. A range of conditions are given because higher temperatures and residence times are necessary for those contaminants that are difficult to burn such as particulates and products of incomplete combustion. Generally EMB consider that a temperature of at least 750°C and a design residence time of at least 0.75 seconds in excess oxygen (and an operational residence time of at least 0.5 seconds) is suitable for flammable VOCs and most odours.
- Designed for at least 99% removal efficiency, or where there is an inlet concentration of less than 400 ppmv VOCs, an outlet concentration of less than 20 ppmv VOCs;
- Cremator thermal oxidisers, a specialised type of thermal oxidiser used on crematoria should have a minimum temperature of 850°C, and a minimum residence time of 2 seconds in at least 6% excess oxygen.

***Catalytic Thermal Oxidisers***

- Minimum temperature and residence time criteria will be assessed on a case by case basis;
- Designed for at least 95% removal efficiency, or where there is an inlet concentration of less than 400 ppmv VOCs, an outlet concentration of less than 20 ppmv VOCs;
- Regenerative and recuperative thermal oxidisers will be assessed on a case by case basis;
- The thermal oxidiser burner must be interlocked so that the process cannot operate until the afterburner is at the appropriate temperature. Where appropriate, interlocks should also shut down the process if the minimum afterburner temperature is not achieved during operation; and
- The afterburner must be designed to ensure suitable turbulence within the main chamber and hence adequate and consistent mixing with oxygen.

EMB's general monitoring requirements for thermal oxidisers are:

- Continuous monitoring, recording and alarming of the thermal oxidiser's operating temperature (note the site of the temperature probe within the afterburner should be considered carefully); and
- For catalytic thermal oxidisers, appropriate monitoring and where necessary replacement of catalyst will be required.

Odour sampling or contaminant sampling may be required in special circumstances. Provided the thermal oxidiser has been correctly designed for the contaminant stream to have adequate mixing, an appropriate residence time and has suitable operating temperatures, EMB will not usually require sampling of the residual emissions exiting the thermal oxidiser unit. If the thermal oxidiser does not have adequate manufacturer guarantees then EMB may require extensive commissioning tests including residence time and odour destruction efficiency tests.

## 3.10 Scrubbing and Adsorption Systems

Many control systems for the removal of gaseous contaminants are based on absorption (gas scrubbing), adsorption or condensation. The selection of the most appropriate method will depend on the contaminants that must be removed, the characteristics of the gas stream and the efficiency required.

### *3.10.1 Gas Scrubbing*

Absorption is the removal of a contaminant from the gas stream by contacting the gas with a liquid phase, where the contaminant either reacts with the liquid or dissolves in the liquid and is removed.

This type of action may take place in all versions of wet scrubbers, however the most common types for the removal of gaseous contaminants are packed or plate absorbers. Packed scrubbers are generally in the form of a tower, with the gas inlet at the base and outlet at the top. The scrubbing liquid flows counter-current to the gas stream. The tower is filled with packing material to increase the surface area where absorption may take place. The packing may be symmetrical in shape such as saddles or rings or random such as coke, plastic scrap, scoria etc. The scrubbing liquid is commonly water or a solution of a chemical in water to promote a removal mechanism. These chemicals can be caustic (sodium hydroxide), acidic (phosphoric acid) or oxidising (hydrogen peroxide or sodium hypochlorite). Other solvents may be used to remove substances having a low solubility in water. The scrubbing liquid should have high gas solubility (or reaction) and low volatility, be chemically stable and non-corrosive, and preferably also have a low toxicity.

Plate scrubbers operate in similar manner to the packed tower and have the same constraints. The scrubbing liquid contacts the gas stream in a series of stages. The liquid enters the top stage, flows across the plate and discharges through holes to the next plate. The gas stream rises through the same holes or openings creating bubbles or froth where removal of the contaminant takes place.

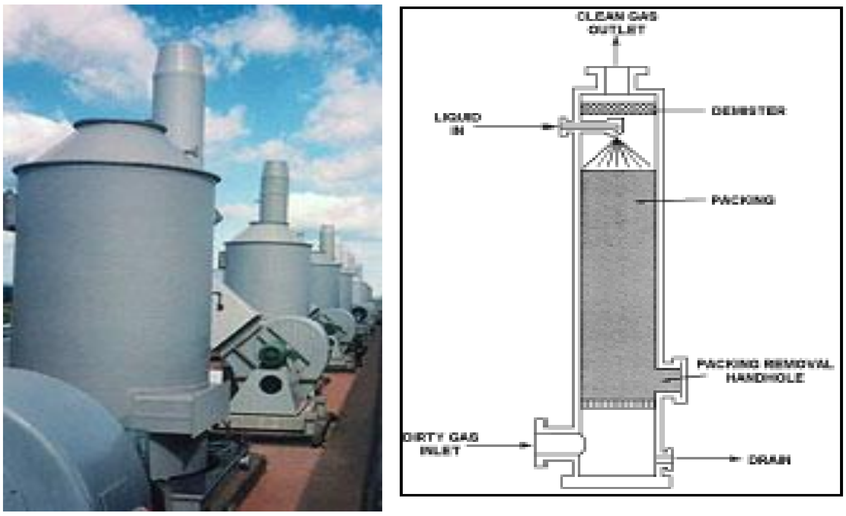



**Figure 15: Counter Current Chemical Scrubber and Packed Tower Scrubber**

Purpose built scrubbing towers designed for a specific duty may reach efficiencies of 99.99% for certain contaminants. Common efficiencies are in the 90 – 99% range. This is very much dependent on there being sufficient residual scrubbing capacity of the liquor being used to remove the gaseous contaminants. The liquor needs to be continuously monitored to ensure the minimum liquor set point is maintained. To achieve this, the scrubbing liquor has to be continually dosed with a concentrated form of the scrubbing chemical being used.

For a caustic scrubber using sodium hydroxide, the pH of the liquor should always be maintained above 8 to ensure adequate chemical residual in the scrubbing liquor. Therefore a constant addition of new solution and bleed-off of spent solution is required. As a result of the bleed off, the discharged liquor needs to be treated prior to disposal to the sewer or re-use. This treatment, and disposal of the spent liquor, will add significant operating costs to these units which must be considered in their selection.

## 3.11 Adsorption Systems

The process of concentrating a substance on the surface of porous solids is known as "adsorption". It may be used for removal of contaminants from an air stream for purification of the discharge or to recover the contaminant for further use. Carbon, zeolite, and polymer adsorbents have each been used to adsorb VOCs and other pollutants from relatively dilute discharge concentrations. Other adsorbents used industrially include alumina, activated clay, silica gel and molecular sieves.

Contaminants are attached or condensed onto the surface of the adsorbent. When the surface has adsorbed nearly as much as it can, the contaminants are desorbed as part of regenerating the adsorbent. When desorbed, the vapours are usually at a higher concentration, after which they are either recovered or destroyed. The principle of adsorption is one of capturing contaminants from a dilute concentration and releasing them in a higher concentration.

The most common adsorption systems used use activated carbon. These range in size and complexity from small systems designed to remove odours from cooking operations to complex solvent recovery systems in the surface coating industry.

Different configurations are available including powder injection and fixed bed systems. In the larger systems it is normal for two fixed bed system to act in parallel, one in adsorption mode, the other in regeneration mode. Regeneration methods include thermal systems, vacuum systems, vapour concentration systems, and steam stripping. Steam is the most common method but care is necessary with removal of water-soluble compounds. If recovery is not practical or is undesirable due to the nature of the substances collected, provision must be made for the removal of the adsorption material and subsequent disposal by incineration or land filling.

Well-designed adsorption devices can achieve control efficiencies of 95 to 98% for input VOC concentrations in the range 500 to 2000 ppmv. This is independent of the recovery or disposal process. If thermal oxidisation is used as the regeneration process at 98% efficiency, total removal efficiencies may be 93 to 96% (USEPA CACT, 1998). Lower efficiencies are achieved with less effective regeneration.

### *3.11.1 Suitable Applications for Gas Scrubbers and Adsorption Devices*

Gas scrubbers are used in a very wide range of applications, almost too numerous to list. Notable activities in the context of this report include: sulphonation plants, electroplating, fertiliser manufacture, general odour control and foundries.

Typical uses of adsorption systems are the removal of hydrocarbons (from storage vents) and odours, solvent recovery units at dry cleaning plants, and solvent extraction processes in the food industry.

### *3.11.2 Recommended Performance Criteria for Gas Scrubbers and Adsorption Devices*

Scrubbers if appropriately designed can have gas removal efficiencies of 90 - 99%.

However, the efficacy of a scrubber is severely impacted by many matters including:

- Maintenance. Scrubber parts can become blocked or corroded, or liquor levels may lower over time;
- Inadequate residence time;
- Maintaining appropriate liquor strength and cleanliness;
- Bypassing or short circuiting within the scrubber, particularly in packed tower or impingement plate scrubbers.

Automatic pH monitoring and dosing systems for caustic and acidic scrubbers should be required as a condition of any permit. And a minimum residual pH should be set that the scrubbing liquor does not fall below. For a caustic scrubber this would be a pH of 8 and for an acid scrubber this would be a pH of 5.5. For oxidiser scrubbers a minimum liquor residual chemical strength may need to be set in the permit, for example for a scrubber using sodium hypochlorite a free available chlorine level of 2.0 ppm should be set.

As a chemical scrubber or adsorption device system needs to be specifically designed for the activity in question, all scrubbers will be assessed on a case by case basis and hence no design criteria or monitoring requirements other than that recommended below have been included. Emission limits should be set based on CAA requirements and the results of dispersion modelling. The level and type of control device monitoring should be assessed on a case by case basis and could include:

- Automatic pH monitoring and dosing systems for caustic and acidic scrubbers. This should be required as a condition of any permit.
- A minimum residual pH should be set that the scrubbing liquor does not fall below. For a caustic scrubber this would be a pH of 9.0 and for an acid scrubber this would be a pH of 5.0.
- For oxidiser scrubbers at liquors a residual chemical level may be set, for example for a scrubber using sodium hypochlorite a free available chlorine level of 2.0 ppm should be set.

## 3.12 Fugitive Dust Control

As well as the point sources at a site, there are fugitive sources of dust and gaseous emissions that need to be considered and adequately controlled. A range of control options are available and should be considered on a case by case basis.

### *3.12.1 Dust Control*

For dust control they include:

- Enclosing all conveyors and bucket elevators;
- Enclosing coal, sand, limestone, and fine solid stockpiles;
- Applying dust suppressant sprays to stockpiles (sprays can be automated, operating on a timer or by a moisture meter located in the stockpile);
- Having solid material dump points enclosed in a building ventilated with the air extracted to a bag filtration system.
- Pneumatic conveying systems (excess air is passed through filtration units before being discharged to air to remove entrained dust).
- Applying dust suppressant sprays to roads and yard areas by automatic spray system or by water carts;
- Removing or accumulated dust and grit on roads and yards by regular vacuuming and sweeping if these areas; and
- Hard paving of all service roads and yards in the site.

Fugitive dust control practices and procedures should be recorded in the establishment's Operation and Management Plan. This means that the prescribed practices in the Plan to control dust can be inspected and checked to see if they are being carried out as intended, either by site management or by EMB inspectors.

### *3.12.2 Gaseous Releases*

Gaseous releases within a building are primarily an occupational safety and health issue. However gaseous releases will eventually leave the building and discharge to atmosphere via roof ridge vents, roof vents, open windows and doors.

If the discharge is visible (e.g. steam, mist, smoke can be seen clearly discharging from the building opening) and occurs on a frequent basis, then under 'best practice' the site operator should install a device to first collect the fume/gaseous release using some form of hood arrangement over the process causing the release. From the hood the pollutants should be extracted to air pollution control devices for treatment before being discharged to atmosphere. The type of treatment required will be dependent on the chemical parameters of the collected fume/gaseous release. The appropriate control devices should be selected and installed.

# 4 MANAGEMENT OF FUEL BURNING

## 4.1 Introduction

As well as installing air pollution control devices to control and reduce emissions from industrial sources to air, there are a number of management, maintenance and efficiency measures that can be applied to emissions sources. This is particular relevant to small to medium-sized fuel burning equipment operating on liquid fuels. Set out in this section are best practice guidelines on how to reduce emissions from fuel burning equipment (external and internal) operating in the Philippines.

## 4.2 Boiler Combustion Efficiency Testing and Tuning

### *4.2.1 Why Efficiency Test and Tune?*

The simplest and easiest control to apply to fuel burning equipment is to ensure the appliance is operating efficiently and is therefore well tuned. As well as reducing emissions an efficient and well tuned boiler will provide significant savings in fuel consumption.

A boiler at an industrial or commercial site is probably the single largest user of heating fuel (natural gas or distillate fuel oil) at the site. Boiler systems are inefficient users of fuel. At best, they may be 85% efficient and on average they are probably 60 to 75% efficient. This means that upwards of 40% of the energy in your heating fuel is wasted (goes up the stack). It also means that upwards of 40% of your heating bill is also wasted.

Any heat lost by the system lowers the efficiency of the boiler (or heater). These losses include radiant loses from heat escaping through the surfaces of the boiler, heat lost through boiler blowdown, frequent cycling of the burners, and combustion efficiency losses.

Combustion efficiency may be defined as the ratio of the usable energy generated by the boiler to the energy actually contained in the fuel. Combustion loses are a large portion of total boiler efficiency losses. It makes good economic sense to maximize combustion efficiency before more costly capital improvements to improve boiler efficiency are considered. The best way to maximize combustion efficiency is to measure oxygen and unburned fuel in the flue gases on a regular basis (as a minimum annually) and to tune the burner to ensure optimum combustion efficiency for that appliance is being achieved.

### *4.2.2 Factors that Affect Combustion Efficiency*

There are three basic factors, which affect the combustion efficiency of fuel burning equipment. These are:

- Excess air,
- Unburned fuel in the stack gases and
- Environmental concerns.

Ideally, the combustion of fuel in fuel burning equipment should be carried out with just the right amount of air to completely burn the fuel (stoichiometric combustion). However, typically, the inconsistency in the fuel/air mix results in incomplete combustion, so more air is required. On the other hand, heat is wasted due to the presence of too much excess air, and emissions of harmful oxides of nitrogen (NOx) are generated and vented to the atmosphere. Issues that can reduce combustion efficiency are discussed below.

***1) High Oxygen Content***

When the $O_2$ content of the flue gas is high, more than 12 percent, heat is lost up the chimney and the operation is inefficient.

High oxygen content may be caused by:

- Too small a burner nozzle;
- Air leakage into the furnace or boiler; and
- Underfiring in the combustion chamber.

In order to prevent high oxygen levels, the fuel burning equipment and the chimney flue should be well maintained with all holes that are potential for air leakage plugged. Inspection of the boiler and flue for holes and poor joints should be undertaken as part of the boiler annual inspection process.

***2) Low Oxygen Content***

When the $O_2$ content of the flue gas is too low it is common to have excess smoke in the flue gas.

Low oxygen content may be caused by:

- Insufficient draught; and
- Over-fired burner.

Smoke in flue gas indicates poor burner performance or excess fuel. The amount of smoke can be measured with a smoke tester where smoke particles set on a filter paper are interpreted according a Bacharach scale. Alternatively the smoke exiting the chimney can be evaluated using Ringelmann smoke opacity assessment procedure.

***3) Smoky Combustion***

Smoky combustion can be caused by:

- Soot formation on the heating surfaces;
- Insufficient draught, incorrectly adjusted draught regulator, improper fan delivery;
- Poor fuel supply, malfunctioning fuel pump;
- Defective firebox;
- Oil-burner nozzle defect, for example the wrong size;
- Excessive air leaks in boiler or furnace; and
- Wrong fuel-air ratio.

The amount of smoke can be measured with a smoke tester where smoke particles set on a filter paper are interpreted according a Bacharach scale. Alternatively the smoke exiting the chimney can be evaluated with the Ringelmann procedure. To prevent excess smoke the burners need to be assessed against the caused listed above and any faults found should be rectified. This assessment should be carried out as part as the annual inspection of the combustion appliance.

***4) High Stack Temperatures***

The "net stack temperature" is the difference between the flue gas inside the chimney and the room temperature outside the burner. Net stack temperatures above 370$^{o}$C are in general too high. Typical values are between 180 - 260$^{o}$C.

High stack temperatures may be caused by:

- Undersized furnace;
- Defective combustion chamber;
- Incorrectly sized combustion chamber;
- Excessive draught;
- Over-fired burner;

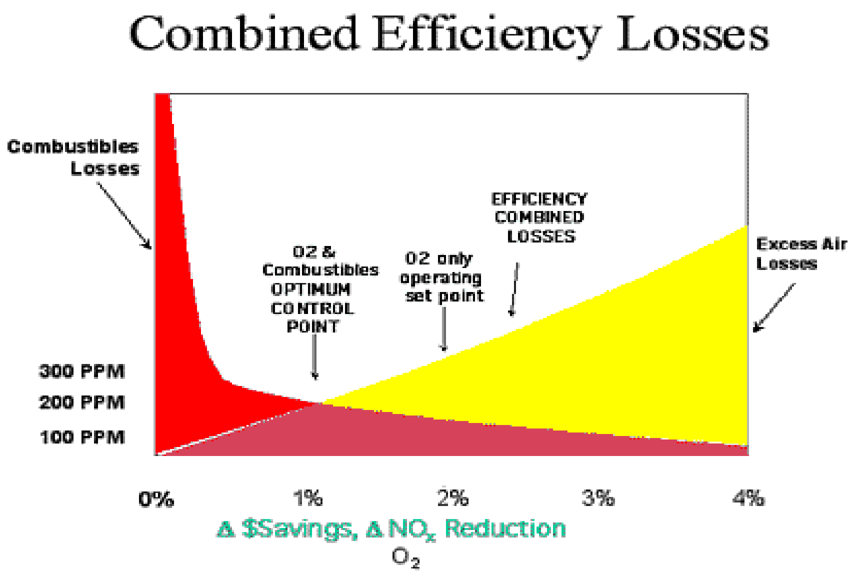
- Draught regulator improperly adjusted; and
- Soot formation on the heating surfaces.

To prevent high temperatures the combustion system need to be assessed against the caused listed above and any faults found should be rectified. This assessment should be carried out as part as the annual inspection of the combustion appliance.

### *4.2.3 Combustion Analysis and Tuning*

Modern combustion analysers (monitors) are used to measure oxygen, oxides of nitrogen, hydrogen and carbon monoxide in the flue gases. These measurements allow the boiler to be tuned so that it maintains high combustion efficiency. Combustibles decrease with an increase in excess air, however, flue gas heat loss increases with the same increase in excess air. Therefore, the total combustion efficiency is maximized when the amount of excess air supplied results in the sum of the unburned fuel loss and the flue gas heat loss being minimized.

On average, poorly tuned boilers may have combustion efficiencies of 60% or lower. A well-tuned boiler or heater can dramatically lower the fuel cost of operating a boiler or industrial process heater. For example the cost of natural gas in northern Illinois ranges from 27 to 95 cents per therm (100,000 Btus) depending on the season of the year. At an average of 60 cents/therm, a 10,000-lb/hr boiler with an average annual capacity factor of 50% would save about $26,000 per year in fuel costs with a 10% increase in combustion efficiency. Even a 1% increase in efficiency would save about $2,600 per year. The following figure illustrates the levels of fuel savings, which may be realized by tuning the combustion efficiency of a boiler or heater.




For fuel burning equipment the best and simplest cleaner production technique that can be applied to reduce emissions and reduce fuel consumption is to have the combustion appliance tuned on a regular basis. The tuning should occur on an annual basis as a minimum and EMB will include this requirement as a condition of any permit issued for fuel burning equipment.

Before costly capital improvements are undertaken, the combustion efficiency should be maximized. With the improved combustion efficiency there is a corresponding reduction in fuel consumption, which is a benefit to the operator, given the increasing cost of fuel.

## 4.3 Fuel Switching

### *4.3.1 Use of Cleaner Fuels*

Another method regarded as 'best practice' for reducing emissions to air is to use a cleaner fuel. Emissions can be reduced by the use of better quality fuels which burn more cleanly or contain lower levels of fuel contaminants. The classic change was to convert to natural gas combustion from oil or coal, thereby dramatically reducing particulate and sulfur oxide emissions.

In the Philippines there is a need for industrial site operators to use fuels in their fuel burning equipment that have low sulfur content in order to comply with the emission standard for sulfur dioxide, and very often also the standard for particulate emissions. The first step is to get industrial sites to use lighter fuels which have lower sulfur content and have less contaminants as the refining process means they are a cleaner fuel. Bunker C Fuel Oil has a sulfur content of 3% whilst marine diesel has a sulfur content of 0.3%. Converting the boiler to run on marine diesel will reduce sulfur emissions by a factor of 10 and will reduce the need to heat storage tanks and fuel lines. By decreasing sulfur levels in the diesel fuel used in stationary fuel burning equipment, as well as reducing the sulfur dioxide emission rates, it will prevent damage to the emission-control systems. In addition, reducing sulfur levels will provide immediate public health benefits by reducing particulate matter from these sources.

The use of fuels containing lower sulfur content can also be applied to fuel burning equipment fired on coal. For large fuel burning equipment above 50MW there may be still a need to install flue gas desulfurisation control equipment.

It is probable that current sulfur levels in diesel produced by refineries around the world will over time reduce to 15 ppm when new refinery technologies are fully and widely implemented (a reduction of greater than 99 percent).

Should voluntary 'best practice" changes to lower sulfur content fuel fail to occur then EMB may need to set conditions in new Permits about the sulfur content that can be used in fuels burnt in fuel burning equipment

### *4.3.2 Fuel Switching*

With natural gas supplies becoming available in the Philippines, industry should be encouraged to use this fuel subject to availability and cost in order to reduce emissions from fuel burning equipment. Other fuels on the market that also have low sulfur content and are suitable for fuel burning equipment include the use of LNG and LPG.

### *4.3.3 Biomass and Biofuels*

An area of fuel switching which is being followed throughout the world is the use of biomass and biofuels to replace fossil fuels in combustion processes. EMB encourages industrial plants to investigate and where appropriate use biomass or biofuels in combustion processes as long as specific emissions associated with the combustion of these fuels such as particulate matter are adequately controlled.

Biomass is defined as any organic matter that is available on a renewable or recurring basis (excluding old growth timber), including dedicated energy crops and trees, agricultural food and feed crop residues, aquatic plants, wood and wood residues, and other waste materials.

Bioenergy means biomass used in the production of energy – electricity; liquid, solid and gaseous fuels; and heat.

Biofuel is defined as any fuel that is derived from biomass — recently living organisms or their metabolic byproducts, such as manure from cows. It is a renewable energy source and includes oils, fats and greases (landfill gas and digester gas from wastewater treatment).

Biomass can be used for the production of electricity, heat, or both. Biomass fuels include:

- Wood residues – from the sawmill industry, plantations and powerline trimmings;
- Energy crops – crops that may be grown for energy, other than bioliquid crops, including short rotation woody crops and grasses;
- Crop wastes – waste material (straw) from existing crops;
- Bagasse – sugar cane residue from processing cane into sugar;
- Landfill gas – gases emanating from landfill/waste dumps;
- Municipal wastewater – gas derived from the treatment of human waste; and
- Food and agriculture byproducts– this includes the fats and oil byproducts as a result of processing plants and animals by these industries

Bioenergy can be utilised by two methods:

- Direct combustion – of solids or biomass-derived gases, including cogeneration with coal or peat, which includes the use of circulating fluidized bed boilers
- Gasification – converting biomass to combustible gases that may be used in a burner, a gas turbine or an internal combustion engine.

As the use of biofuels/biomass is, apart from the use of bagasse and wood residues in boilers, a developing technology world wide, EMB wants industry to consider the use of biomass fuels as one of the options available to industry in terms of ‘best practice’ to help in the reduction of industrial emissions, and reduce the reliance on fossil based fuels.

## 4.4 Control of NOx

### *4.4.1 Low NOx Burners*

For a number of larger fuel burning equipment above 20 MW, oxides of nitrogen (NOx) emissions can be reduced by the installation of low NOx burners. This practice is commonly applied in Europe to processes such as cement kilns, large boilers, and thermal power stations.

Low NOx burners are designed to control fuel and air mixing at each burner in order to create larger and more branched flames. Peak flame temperature is thereby reduced, and results in less NOx formation. The improved flame structure also reduces the amount of oxygen available in the hottest part of the flame thus improving burner efficiency. Combustion, reduction and burnout are achieved in three stages within a conventional low NOx burner. In the initial stage, combustion occurs in a fuel rich, oxygen deficient zone where the NOx are formed. A reducing atmosphere follows where hydrocarbons are formed which react with the already formed NOx. In the third stage internal air staging completes the combustion but may result in additional NOx formation. This however can be minimised by completing the combustion in an air lean environment.

Low NOx burners can be combined with other primary measures such as overfire air, reburning or flue gas recirculation. Plant experience shows that the combination of low NOx burners with other primary measures is achieving up to 74% NOx removal efficiency. A large number of low NOx burners have been developed and are currently used in over 370 coal-fired units (125 GWe). Nevertheless, developmental work continues to enhance the design, and improve the performance of existing burners and engineer and develop new and advanced low NOx burners.

### *4.4.2 Flue gas recirculation for NOx control*

Flue gas recirculation for NOx control includes gas recirculation into the furnace or into the burner. In this technology 20-30% of the flue gas (at 350-400°C) is re-circulated and mixed with the combustion air. The resulting dilution in the flame decreases the temperature and availability of oxygen therefore reducing thermal NOx formation. When flue gas recirculation into the burner is used in low NOx burners, the flue gas is usually re-circulated subject to the operational constraints of flame stability and impingement, as well as boiler vibration. Flue gas recirculation in combination with other primary measures for NOx control is installed at 49 pulverised coal-fired units on a total capacity of >15 GWe.

Retrofitting an existing coal-fired unit with flue gas recirculation involves installation of a system to extract the flue gas from the boiler unit, additional ductwork and a fan, and a fly ash collecting device. The fly ash control device is necessary in order to clean the flue gas of particulate matter prior to recirculation. Heat distribution in the furnace may be affected due to the increase in throughput. Excessive flue gas recirculation can also result in flame instability problems and increased steam temperatures.

Flue gas recirculation alone in coal-fired boilers achieves a low NOx reduction efficiency (< 20%). This is because the ratio of thermal NOx to total NOx emissions is relatively low in coal-fired plants. The technique is being used on coal-fired units in combination with other primary measures for NOx control.

NOx is one of the precursors of photochemical smog, and technologies to reduce NOx are regarded as ‘best practice’. EMB may place conditions on establishments requiring them to install technologies to lower their NOx emissions.

# 5 OPERATION AND MANAGEMENT PLANS

## 5.1 Introduction

Section 3 of these Guidelines covered the selection of air pollution control devices and their operating performance criteria. This section provides guidance on how to develop an environmental management framework under the CAA regulatory regime to ensure that installed air pollution control devices are operated in accordance with manufacturer's instructions and well maintained, and their performance is adequately monitored to ensure that they are operating correctly. EMB's EIS and enhanced permitting systems should require significant or priority industries to develop and implement Operation and Management Plans to achieve improved environmental outcomes.

As part of a total environmental management system for an industrial undertaking there is a need to develop an Operation and Management Plan and procedures to ensure that the emissions to air remain at the levels for which the permit was granted, or which were assessed in the Environmental Impact Statement. The Operation and Management Plan should contain procedures and instructions developed specifically for each site in order to ensure that emission control devices installed at the site are adequately maintained, and monitored so that they are operating correctly. It should also contain Contingency Plans designed to manage failures of the installed controlled devices and to reduce the impacts from these failures. The preparation of Contingency Plans and what should be contained in them is covered in Section 6.

The Operation and Management Plan should be tailored to fit the size and scale of the industrial activity, taking into account the level of impact from its emissions to air. EMB can set permit conditions requiring the site to develop an Operation and Management Plan (OMP) and to operate in accordance with the parameters set out in the Plan, in particular in relation to maintenance, inspection and monitoring of air pollution control devices.
An OMP is a means of setting out what can be regarded as good process management and housekeeping practices at the facility in relation to the operation and management of air pollution control equipment. It also provides a basis for auditing in terms of its environmental management performance. The OMP is just one of the controlled documents in a facility's environmental management system.

## 5.2 Contents of Operations and Management Plan

A range of operation and management requirements for specific air pollution control devices is provided in the following sections. This information can be used in the development of an establishment's Operation and Management Plan (OMP). EMB may require a permit applicant or permit holder to develop and implement an OMP.

An OMP will usually contain the following sections:

***1) Introduction***

This should set out the intent of the OMP and describe the regulatory requirements set by the IRR or the permit that the site must meet. This may include emission limits, testing and monitoring requirements, reporting requirements, etc.

***2) Process Description***

This section should briefly describe the processes at the site and the air pollution control devices or systems fitted.

***3) Operation and Management Procedures***

This section should set out for each air pollution control unit installed details of:

- Its proper and effective operation, including its expected emission control performance or efficiency;
- The daily or continuous monitoring of the unit and the relevant monitoring systems (e.g. meters, alarms) that will be used to ensure it is operating correctly;
- The regular or periodic inspections that are required to ensure the unit continues to operate efficiently; and
- The ongoing maintenance requirements for the unit.

***4) Contingency Plans***

This should describe the procedures that will be followed for each emission control device installed at the site to ensure, in the event of breakdown or failure of the control devices, that the air discharges and resulting impacts are minimised. The procedures should establish how the process connected to the failed air pollution control unit should be shutdown. The development of this Plan should be based on a risk assessment exercise (as outlined below in Section 6), and incorporate the resulting risk management measures in the Contingency Plan.

***5) Complaint Records***

This section sets out how any complaints received from the public by the permitted establishment are recorded and investigated, and how the results of the investigation will be documented.

***The Importance of Corrective Action Arising from the OMP***

The following parts of Section 5 contain details of operating, inspection/maintenance and monitoring procedures, and the performance indicators to be monitored, for the range of air pollution devices described in Section 3. These procedures and performance indicators should be incorporated in the relevant OMPs.

For an OMP to operate successfully the facility must make a commitment to take timely corrective action during periods of excursion, where the indicators are out of range for the devices being regularly monitored in accordance with the requirements set out in the OMP. This commitment to take the necessary corrective action should be documented in the OMP, and followed throughout the operating life of the permitted facility.

A corrective action may include an investigation of the reason for the excursion, evaluation of the situation and necessary follow-up action to return operational performance within the indicator range.

Many of these indicators are operating parameters for the processes or devices that generate or control emissions (e.g. temperature, pressure drop, pH), rather than the emissions themselves. So an excursion beyond specified limits does not necessarily mean an exceedance of emission standards or limits. But it does indicate a need to take corrective action so that any exceedance that might be occurring can be rectified.

If the corrective measures taken fail to return an indicator to the appropriate level or range, the facility should conduct source testing to assess compliance with applicable requirements. If the test demonstrates non-compliance with emission limits, then the facility should report the exceedance to EMB, and discuss what additional actions should be taken to bring the source into compliance.

## 5.3 Bag Filter Unit

Key OMP requirements include:

- Inspect annually all components that are not subject to wear or plugging, including structural components, housing, ducts and hoods. Maintain a written record of the inspection and any action resulting from the inspection.

- Inspect quarterly all components that are subject to wear or plugging. Maintain a written record of the inspection and any action resulting from the inspection.
- Check differential pressure through the control device once per week. Verify that it is within acceptable range. Record the results.
- Check visible emissions from the unit once per week. If visible emissions exist, inspect devices for evidence of malfunction, including broken bags. Record the results of the inspection and any corrective action taken.
- Calibrate mercury pressure switch annually and maintain a written record of the calibration and any action resulting from the calibration. Maintain pressure switch alarms with both horn and light in the control room if pressure loss to the bag puffer is detected.

Set out below are the recommended maintenance and monitoring requirements for bag filtration units operated at a site.

***Daily Maintenance***

1) Check pressure drop (cite manufacturer maximum pressure drop and normal operating range).
2) Monitor gas flow rate.
3) Observe stack outlet visually or with a continuous monitor, during material handling.
4) Monitor cleaning cycle; pilot lights or meters on control panel.
5) Check compressed air on pulse jet bag filter units.
6) Monitor discharge system; make sure dust is removed as needed.
7) Walk through bag filter unit to check for normal or abnormal visual and audible conditions.

***Weekly Maintenance***

1) Check all moving parts on the discharge system; screw-conveyor bearings.
2) Check damper operation; bypass, isolation, etc.
3) Spot check bag tensioning; reverse air and shake bags.
4) Check compressed air lines including oilers and filters.
5) Blow out manometer lines.
6) Verify temperature-indicating equipment.
7) Check bag-cleaning sequence to see that all valves are seating properly.
8) Check the drive components on fan.

***Monthly Maintenance***

1) Spot check bag-seating condition.
2) Check all moving parts on shaker bag filter units.
3) Check fan for corrosion and blade wear.
4) Check all hoses and clamps.
5) Spot check for bag leaks and holes.
6) Inspect bag filter units housing for corrosion.

***Quarterly Maintenance***

1) Thoroughly inspect bags.
2) Check duct for dust build-up.
3) Observe damper valves for proper seating.
4) Check gaskets on all doors.
5) Inspect paint on bag filter unit.
6) Calibrate opacity monitor or particulate monitor if one is fitted.
7) Inspect baffle plate for wear.

*Annual Maintenance*

1) Check all welds and bolts.
2) Check hopper for wear.
3) Replace high-wear parts on cleaning system.

### 5.3.1 Routine Monitoring

*General*

Periodic monitoring is not required during periods of time greater than one day in which the source does not operate.

*Weekly*

1) The exit of the bag filter unit shall be checked for visible emissions on a daily basis to ensure no visible emissions during the material handling operation of the unit. If visible emissions are observed action will be taken as soon as possible, but in no later than eight (8) hours, to investigate the cause and to rectify. If weather conditions prevent the observer from conducting an opacity observation, the observer shall note such conditions on the data observation sheet. At least three attempts shall be made to retake opacity readings at approximately 2 hour intervals throughout the day. If unsuccessful that day due to weather, an observation shall be made the following day.
2) Check and document the bag filter unit pressure drop on a per shift basis (e.g. 2 shifts per day - two checks of the pressure drop). If the pressure drop falls out of the normal operating range specified by the manufacturer, corrective action will be taken within 8 hours to return the pressure drop to normal.
3) Maintain a written record of the observation and any action resulting from the inspection.
4) For large bag filter units or where the exit of the bag filter unit cannot be easily observed continuous particulate monitoring devices such as the Triboflow will need to be installed. The units should be fitted with high and high/high alarms to alert the operator of a higher than normal release of particulate matter. The readout should be recorded once per shift.

*Monthly*

1) Check the cleaning sequence of the bag filter unit. For pulse jet bag filters - check the air delivery system.
2) Check the hopper functions and performance. If leaks or abnormal conditions are detected the appropriate measures for remediation will be implemented within eight (8) hours.
3) Maintain a written record of the inspection and any action resulting from the inspection.

*Quarterly*

1) Thoroughly inspect bags for leaks and wear. (Look for obvious holes or tears in the bags.) If leaks or abnormal conditions are detected the appropriate measures for remediation will be implemented within eight (8) hours. Bag replacement should be documented by identifying the date, time and location of the bag in relationship to the other bags. The location should be identified on an overhead drawing of the bag layout in the bag filter unit.
2) Maintain a written record of the inspection and any action resulting from the inspection.

*Six-Monthly*

1) Inspect every 6 months all components that are not subject to wear or plugging, including structural components, housing, ducts and hoods. If leaks or abnormal conditions are detected the appropriate measures for remediation will be implemented within eight (8) hours.
2) Maintain a written record of the inspection and any action resulting from the inspection.

*Record Keeping and Reporting*

Maintenance and inspection records will be kept for five years and made available upon request.

***Quality Control***

The filter devices will be operated and maintained according to the manufacturers' recommendations. An adequate inventory of spare parts shall be kept.

## 5.4 Electrostatic Precipitators (ESP)

Set out in this section is the recommended practices for operating, maintaining and monitoring an Electrostatic Precipitator.

### *5.4.1 Operating Procedures*

Operating procedures will vary depending on the site processes undertaken and the operating requirements for the site. Actions that should be covered in setting out operating procedures should be developed in accordance with the manufacturers instructions and should include the following actions.

***Start-Up Practices***

The following ESP start-up procedures shall be used during plant re-start activities:

1) When preparing for start-up, assure that all tools and safety devices (including lock out/tag out) have been removed from or taken off of the controls of the ESP. The plant superintendent or his designated representative shall be responsible for final inspection of the ESP to determine that the unit is ready for start-up.
2) During the final pre-start-up inspection, the inspector shall ensure that the ESP has been properly closed up and the keys for the interlock system have been returned to their appropriate locations.
3) Conduct an air load test for each T-R set and if possible, for each bus section. This activity is used to determine that maintenance has been completed, all foreign matter has been removed and the ESP is ready for operation.
4) If the insulator heaters have been inspected during the shut-down, make sure that they have been turned back on at least 2 - 12 hours prior to ESP start-up. Purge air systems will also be activated at this time. Be aware of the potential for particulates to pass through the system and be emitted to the atmosphere when the purge air is activated.
5) The rapping system will be in operation during start-up to remove any settled dust.
6) Energize the ESP according to procedures established during previous plant turnarounds.

***Shutdown Practices***

Except in the instance of an emergency shutdown, this process should be essentially the reverse of the start-up procedure.

1) Deenergization usually begins at the inlet fields and progresses toward the outlet. At the point that the boiler is off-line, the fields (T-R sets) should be deenergized. This should be done sequentially toward the ESP outlet and as quickly as possible to prevent unnecessary sparking, condensation or insulator build-up.
2) The rappers should be allowed to operate for several hours to remove residual dust.

***Routine Operations***

Daily operating requirements include parameter monitoring and record keeping (hourly recording of voltage and amp levels during ESP operations), preventative maintenance, evaluation of applicable data for malfunctions and response to any malfunctions. The appropriate corrective measures for remediation will be implemented within a specified time period (maximum eight (8) hours) plus the period of time required to shutdown the process without damaging the process equipment or control devices. In some instances immediate shut down of the processing equipment will be required

### 5.4.2 Preventative Maintenance

***Daily Inspection and Maintenance***

This activity will be a follow up to the hourly recording of voltage and amp levels at the ESP and observation of other relevant operating data. A review of several of the hourly data sets will give the inspector an indication of any abnormal conditions. If the operating voltages or amperages of any of the ESP fields show considerable variation, the inspection should focus on identifying a cause for reading fluctuations.

The following items will be checked during a routine daily inspection:

1) Operation of the dust discharge system: All conveyors, airlocks, valves and other associated equipment should be operating so that ash removal is continuous.
2) Vacuum system: Check vacuum gauges. This gauge will be used as a reference during ash and dust removal with the ash equipment system (ash removal occurs 3 times per day).
3) Check indicator lights on the hopper level alarm system.
4) Check hopper access doors for air leaks or dust discharge.
5) If possible, check the operation of each rapper.
6) Check for air leaks around the ESP.
7) Check for sparking or arcing in the T-R high voltage bus duct and localized sparking (usually reflected by T-R readings).
8) Maintain a written record of the inspection and any action resulting from the inspection.

***Weekly Inspection and Maintenance***

Begin this activity with a review of the daily and/or shift inspection data. Any apparent adverse trends in operating parameters need to be noted and a determination made as to whether or not an operating procedure needs changing or maintenance/repair is necessary. This review will also confirm that all requested or required maintenance has been completed or scheduled. Weekly operating data will be checked and compared to normal/baseline values. Physical inspection of the ESP will include:

1) Check, clean or replace T-R cabinet air filters. Also check circuit boards and heat sinks for dust build-up and clean if necessary.
2) A thorough check of rapper operation will be conducted. Each rapper or rapper system should activate. Those that do not will need to be scheduled for repair or replacement.
3) Changes in rapper operating parameters can be made at this time. All new settings need to be recorded and special attention paid to performance during the following week.
4) Check the operating temperature and oil level in the high voltage transformer.
5) Check insulator purge air and heating systems. Clean or replace air filters as necessary.
6) Check insulator pressurization and heating system in negative pressure systems.
7) Check all access hatches for air leaks, make sure that the hatch door is fully closed and locked. Inspect the door gasket for cracks or tears.
8) Maintain a written record of the inspection and any action resulting from the inspection.

***Semi-Annual Inspection and Maintenance***

During the semi-annual inspection quarterly and annual inspection activities will be conducted.

1) Before anyone enters the ESP, conduct an air load check of each field. This data will be compared with the post maintenance air load check to assure that proper maintenance has been performed.
2) Clean control cabinets for rappers and T-R sets. Check the gaskets on the rapper control cabinet for cracks and tears. Clean all switch contacts in the rapper control cabinet.
3) Check and clean all T-R sets. All contacts will be removed, cleaned and adjusted. After replacement all electrical connections will be checked for proper tightness.

4) Check and clean high voltage lines, bushings and insulators. Check and replace surge arrestors as necessary. Check the high voltage bus duct for dust build up and corrosion. Check and replace bus duct insulators as necessary. Check and tighten high voltage bus duct connections. Clean and adjust transformer switch gear.
5) Check all rappers for proper operation. Check the rapper rod connections (anvils) for loose, broken or bent connections. Check anvils for proper lift, energy transfer and striking. Adjust pneumatic systems and vibrators to assure a proper amount of rapping energy is applied to the collection or discharge system.
6) Empty the ash hopper and remove any residual build-up of ash on internal parts. Check and repair all level detectors. Check, clean and repair dust discharge valves.
7) Check and calibrate ESP instrumentation, including all voltage and current meters. The transmissometer will also be cleaned and realigned.
8) Conduct an interior inspection of the ESP during the initial walk through, check the collection and discharge electrode system. Look for the presence of ash build-up. Generally there will be 1/8 to 1/4 inch of material build-up.
9) Check the alignment of the wires and plates. Any bowing or skewing of their alignment will need correction. This check must be conducted for each lane of each field within the ESP.
10) If a short circuit has been detected in a field, check for a broken wire. The broken wire will be removed or replaced as necessary.
11) Check the upper and lower discharge guide frame assembly for alignment so that equal spacing is maintained. Spacing should be equal from top to the bottom of the plate and from the leading edge to the trailing edge of the plates. The frames should be level in both parallel and perpendicular planes to the gas flow.
12) Check and clean all insulators while looking for insulator tracking. Be sure to include the inside of the large support bushing insulators at the top of the ESP and the discharge rapper insulators. Any insulators that are broken, chipped, cracked, or glaze damaged will be removed and replaced.
13) General maintenance items can include: Checks of door gaskets for proper seal, check the inlet and outlet system including duct work for plugging and dust build-up, inspect expansion joint seals for integrity, lubrication of door hinges and closure mechanisms, cleaning and lubrication of key interlocks, check all ground connections, sampling and testing of transformer oil for dielectric strength.
14) Maintain a written record of the inspection and any action resulting from the inspection.

### *5.4.3 Monitoring*

Continuous monitoring of the performance of the ESP is required and this monitoring should include:

1) The voltage and amps at each T-R set being recorded hourly during ESP operation.
2) Continuous particulate monitoring takes place via a stack continuous emissions monitoring system (CEMS). Data from this CEMS is produced as a rolling 10 minute average, a one hour average and a 24 hour average.
3) Calibration of the CEMS will need to be recorded (frequency and results).
4) A report will be prepared every three months and submitted to EMB.

## 5.5 Cyclones and Multi-cyclones

Set out in this section is the recommended practices for inspecting and monitoring cyclones and multi-cyclones. Due to their construction maintenance requirements are not as critical as for ESP and bag filter units. However, cyclones and multi-cyclones should be included in the plants annual maintenance schedule.

### 5.5.1 Performance Monitoring

***General***

1) Periodic Monitoring is not required during periods of time greater than one day in which the source does not operate.
2) The facility will maintain a written record of the observation, deficiencies, and any action resulting from the inspections.
3) Verify the rated gas flow rate for the cyclone and the actual gas flow rate for the system.
4) Rated gas flow rate for the cyclone.
5) System gas flow range.

***Daily***

1) Visible emissions shall be observed on a daily basis to ensure no visible emissions during the material handling operation of the unit. If visible emissions are observed and corrective action will be taken as soon as possible, but no later than 8 hour after the occurrence. If weather conditions prevent the observer from conducting an observation, the observer shall note such conditions on the data observation sheet. At least three attempts shall be made to retake the visual assessment at approximately 2 hour intervals throughout the day. If unsuccessful that day due to weather, an observation shall be made the following day.
2) Maintain a written record of the observation and any action resulting from the inspection.
3) The facility will record the daily pressure drops across the cyclone.
4) Corrective action measures will be taken when the pressure drop deviates from its normal operating range. The normal operating ranges is (Select one):
5) Low Efficiency cyclones: 2 - 4 inches of water
6) Medium Efficiency cyclones: 4 - 6 inches of water
7) High Efficiency cyclones: 8 - 10 inches of water
8) Other (list your own range).

***Weekly***

1) Inspect the solids discharge valve for proper operation.
2) Valve Type (Select one):
   - Manual Slide (list operating schedule for removal of solids from collecting tube)
   - Rotary Valve
   - Screw Feeder
   - Double Flap
   - Other (indicate what type)
3) The facility will maintain a written record of the observation, deficiencies, and any action resulting from the inspection.
4) If leaks or abnormal conditions are detected the appropriate measures for remediation will be implemented within eight (8) hours.

***Quarterly***

1) Inspect the structural components including the cyclone ductwork and hoods for leaks or component failure.
2) The facility will maintain a written record of the observations, deficiencies, and any action resulting from the inspection.
3) If leaks or abnormal conditions are detected the appropriate measures for remediation will be implemented within eight (8) hours.

***Annually***

1) Inspect the hopper unloading components.
2) Check for leaks in the system to ensure the airflow from the dirty side doesn't infiltrate the clean side. Verify that the inlet and outlet ductwork is in good operating condition.

3) Check the barrel and collecting tube for deposits and/or excess wear and clean/repair as needed. Dents in the barrel or collecting tube must be removed to ensure proper operation.
4) Clean cyclone inlet vanes (ramps or spinners) and ensure they operate according to manufacture specifications.
5) The facility will maintain a written record of the observations, deficiencies, and any action resulting from the inspection.
6) If leaks or abnormal conditions are detected the appropriate measures for remediation will be implemented before the system is returned to service.

***Record Keeping and Reporting***

1) The facility will maintain a written or electronic record of all inspections and any action resulting from the inspections.
2) The facility will keep maintenance and inspection records for five (5) years and will be available upon request.

***Quality Control***

All instruments and control devices will be calibrated, maintained, and operated according to the manufacture specifications.

## 5.6 Venturi Particulate Scrubber

Set out in this section are the recommended practices for inspecting and monitoring venturi particulate scrubbers.

### *5.6.1 Performance Monitoring*

***General***

Periodic monitoring is not required during periods of time greater than one day in which the source does not operate.

***Daily***

1) Visible emissions shall be observed on a daily basis to ensure no visible emissions during the material handling operation of the unit. If visible emissions are observed, corrective actions will be taken as soon as possible, but no later than 8 hours. If weather conditions prevent the observer from conducting an observation, the observer shall note such conditions on the data observation sheet. At least three attempts shall be made to retake readings at approximately 2 hour intervals throughout the day. If unsuccessful that day due to weather, an observation shall be made the following day.
2) Check and document the pressure drop across the scrubber. If the pressure drop falls out of the normal operating range, to be specified by the facility, corrective action will be taken within 8 hours to return the pressure drop to normal.
3) Conduct observations of the stack and areas adjacent to the stack to determine if droplet re-entrainment is occurring from an improperly operating mist eliminator. The signs of droplet re-entrainment may include fallout of solid-containing droplets, discoloration of the stack and adjacent surfaces, or a mud lip around the stack. If droplet re-entrainment is occurring, the appropriate measures for remediation will be implemented within eight (8) hours.

***Weekly***

Check liquid pressure gauges on supply headers to the scrubber to monitor for problems such as nozzle pluggage, header pluggage, and nozzle erosion. Pluggage problems are indicated by higher than normal pressures and erosion problems are indicated by less than normal pressures. If the liquid pressure is out of the normal operating range, to be specified by the facility, corrective action will be taken within eight (8) hours to return the pressure to normal.

***Quarterly***

Conduct a walk-around inspection of the entire system to search for leaks. If leaks in the system are detected, the appropriate measures for remediation will be implemented within eight (8) hours.

***Semi-Annually***

Conduct an internal inspection of the scrubber to search for signs of erosion, corrosion, or solids deposits in ductwork, spray nozzles, and adjustable throat dampers. If any of these conditions exist the appropriate measures for remediation will be implemented within eight (8) hours.

***Record-Keeping***

1) Maintain a record of all inspections and any action resulting from the inspection.
2)  Maintenance and inspection records will be kept for five (5) years and made available upon request.

***Quality Control***

All instruments and control devices will be calibrated, maintained, and operated according to the manufacturers' specifications.

## 5.7 Biofilter

Set out in this section are the recommended practices for inspecting, maintaining and monitoring biofilter.

Set out below are the parameters are to be monitored and recorded, and records retained for sufficient time to provide a good historical record of biofilter operation.

### *5.7.1 Monitoring and Maintenance*

***Daily***

1) Biofilter Inlet Gas Temperature. The temperature of inlet gases should not exceed 50°C at any time, and preferably should be maintained at 20 - 40°C. Inlet gas temperatures shall be recorded at least once every shift and logged.
2) Biofilter Static Pressure. The static pressure (back pressure) of the biofilters determined in the inlet duct, and whether or not significant rain fall occurred within about two hours or is occurring, to be recorded at least once every day that processing is being carried out and logged.
3) Static pressure should not, under normal moisture conditions (four hours after significant rainfall), exceed 100 mm water gauge (wg). High static pressure with normal media moisture indicates excessive compaction of the media, excessive breakdown of media (excessive fines), blocked gas distribution laterals, or blocked drainage system (water build-up in the distribution system and in the lower section of the media). If media compaction is excessive rotary hoe the bed as deep as practicable. If excessive fines are the cause then the media requires replacement. Excessive build-up of biological growth in the distribution laterals can be removed by water blasting, rodding, etc via the laterals end caps and from the header. Blocked drainage invariably results from excessive sediment in the sediment trap/trap inlet pipe. Clean out accordingly.
4) If static pressure is less than 20 mm wg this suggests insufficient media moisture; significant tracking (short-circuiting of gas through fissures in the media or through the media/wall interface - generally through low media moisture causing shrinkage of media); or inspection covers, manhole covers, and ducting end caps being dislodged. Low media moisture can be rectified by turning on media sprinklers for 2 - 3 hours per day until media moisture increases to within specification. Dislodged ducting covers and caps must be replaced and sealed as appropriate.
5) Biofilter Media Moisture. Media moisture should be checked daily during dry periods (weekly during partially dry periods), with observations, and use of sprinkler system, recorded. Media moisture content should be maintained at about 40 to 60% dry weight basis through its depth. As a guide to satisfactory moisture content, media, when squeezed in the hand, should feel damp without significant free water (not soggy). Upper bed moisture content is estimated by scraping a

hole in the media about 400 mm deep (or by coring) in four random locations and assessing accordingly.

6) Biofilter Inlet Gas Moisture. The relative humidity of inlet air should exceed 95% to prevent media being de-hydrated during dry weather periods. The water spray system fitted to the fan discharge transition is operated at all times the ventilation fan is operating. Stop spray when the fan is shut-down. Record fan/spray on and off.
7) A qualitative assessment of biofilter odour should be made once every operating day by assessing odour down-wind of each biofilter: odour should consist of a light compost/earthy smell if detected at all, and should not have a `rendering' and/or a `burnt' smell at or beyond the site's premises.

***Weekly***

1) Biofilter Media Moisture. Media moisture should be checked weekly during partially dry periods, with observations, and use of sprinkler system, recorded. Media moisture content should be maintained at about 40-60% dry weight basis through its depth. As a guide to satisfactory moisture content, media, when squeezed in the hand, should feel damp without significant free water (not soggy). Upper bed moisture content is estimated by scraping a hole in the media about 400mm deep (or by coring) in four random locations and assessing accordingly.
2) Biofilter Drainage. The biofilter drainage receiver (sediment/water trap) to be kept sufficiently free of sediment to enable the trap to operate according to design and maintained in a gas-tight condition and this should be checked weekly.

***Monthly***

1) Biofilter Inlet Over-Temperature Sensor (Process Biofilter only). This is checked once each month and recorded.
2) Media Acidity (pH). The pH of the media to be maintained between about 7 and 8 (mean pH should not be less than 6.5). Media pH should be estimated every month from sampling the liquid collecting in the biofilter drainage receiver (sediment trap) - pH determined by digital meter or by indicator strips. (Note: this method only provides a reasonable estimate of media pH if sufficient (but not excessive) moisture percolates through the bed to provide a representative sample. This will not be the case if media moisture during dry periods is lower than optimum - any liquid in the drainage receiver could mainly be condensate and droplets from inlet gas.)
3) Media Appearance and Consistency. As a minimum once each month the appearance and consistency of the media should be noted and recorded. The media should have a friable consistency, not be compacted, and not contain excessive fines.
4) The surface of biofilter media is to be maintained in a reasonably level condition, and be kept free of gross weeds. The media surface should be rotary hoed every four to six months.
5) Media to remain firmly packed against biofilter containment to minimise tracking.

***Six Monthly***

1) Media Acidity (pH). Every six months media pH to be determined from four samples randomly spaced and collected through the media depth by coring. The core sample to be divided into four sections (samples) with approximately 50 g of each section added to beakers, distilled water added to the top of the bark, and pH of the liquid determined about 30 minutes after water addition. The sample pH results to be summed and a mean pH then determined.

   Excessive acidity may be corrected by `washing-through' the media by heavy rain, or by continuous use of water sprinklers at a time when the plant is not processing, followed by re-checking media pH. If `washing-through' is not effective to correct excessive acidity, lime may be added by top-dressing and rotary hoeing surface followed by watering as necessary.

   If mean media pH cannot be corrected to the recommended range media replacement is indicated but expert advice should be sought if doubt exists.

2) Media Micro-organism content. Micro-organism total viable counts are carried out on a media core sample every six months. Typical total micro-organism counts should be > $10^4$. A composite

sample of cores should be sent to an appropriate microbiological laboratory for assessment and reporting, with date of sampling and results recorded and retained for five years.

***Media replacement***

The media should be routinely replaced every 5 - 7 years or when monitoring indicates the media condition is poor and needs replacing.

## 5.8 Packed Tower Chemical Scrubber

This section provides general requirements on the monitoring and maintenance of packed tower scrubbers. It should be noted that the parameters selected to monitor the condition of the chemical being used in the scrubber is very dependent on the chemical being used in the scrubber and the contaminants being treated by the scrubber unit. For further information reference should be made to the manufacturer's instructions and specifications for the unit.

### *5.8.1 Performance Monitoring*

***General***

1) Periodic Monitoring is not required during periods of time greater than one day in which the source does not operate.
2) The appropriate measures and/or action plan for remediation, if pressure drop levels are occurring outside the normal operating range, are:
   -Either the control devices causing the problem shall be repaired in an expeditious manner, or
   - the process generating the emissions shall be shutdown within a reasonable period of time.

'An expeditious manner' is the time necessary to determine the cause of the problem and to correct it within a reasonable period of time. A reasonable period of time is eight hours plus the period of time required to shut down the process without damaging the process equipment or control devices.

***Daily***

1) Check and document the pressure drop across the scrubber. If the pressure drop falls out of the normal operating range, to be specified by the manufacturer, corrective action will be taken within 8 hours to return the pressure drop to normal.
2) Conduct observations of the stack and areas adjacent to the stack to determine if droplet re-entrainment is occurring from an improperly operating mist eliminator. The signs of droplet re-entrainment may include fallout of solid-containing droplets, discoloration of the stack and adjacent surfaces, or a mud lip around the stack. If droplet re-entrainment is occurring, the appropriate measures for remediation will be implemented within eight (8) hours.
3) Check the scrubber reagent flow pressure once each shift and record in scrubber log book.
4) Scrubber pH. Automatic dosing system for caustic solution the target pH is 9 - 10. Manual monitor using a calibrated pH meter at least daily when unit operating and record in log book. Alarms set should be checked daily.
5) Hydrogen Peroxide Reagent Strength for an Automatic dosing system should be checked. Minimum hydrogen peroxide concentration is not less than 150ppm v/v. Manual monitoring using a Pallin Test Photometer at least daily when unit operating and record in log book. Alarms set should be checked daily.
6) Reagent Tank Levels are monitored at least daily and volumes recorded in log book.

***Weekly***

Check liquid pressure gauges on supply headers to the scrubber to monitor for problems such as nozzle pluggage, header pluggage, and nozzle erosion. Pluggage problems are indicated by higher than normal pressures and erosion problems are indicated by less than normal pressures. If the liquid pressure is out of the normal operating range, to be specified by the manufacturer, corrective action will be taken within eight (8) hours to return the pressure to normal.

***Quarterly***

Conduct a walk-around inspection of the entire system to search for leaks. If leaks in the system are detected, the appropriate measures for remediation will be implemented within eight (8) hours.

***Semi-annually***

Conduct an internal inspection of the scrubber to search for signs of:

- Corrosion and erosion
- Solids deposits in packed beds or tray orifices
- Solids accumulation in mist eliminators
- Plugged or eroded spray nozzles

If any of these conditions exist the appropriate measures for remediation will be implemented within eight (8) hours.

Also check internal condition of the reagent tanks, looking in particular for signs of corrosion.

***Record Keeping***

1) Maintain a record of all inspections and any action resulting from the inspection.

2) Keep maintenance and inspection records.

***Quality Control***

All instruments and control devices will be calibrated, maintained, and operated according to the manufactures specifications.

# 6 CONTINGENCY PLANNING

Some industrial processes have the potential to emit contaminants in quantities which can have serious environmental impacts if the plant or air pollution control devices fail. These failures may develop over time, or may result from a serious failure of a process or discharge control. For processes where such releases are possible, some minimum level of process and equipment monitoring is required to warn of the potential for, or existence of, an accidental release. This does not prevent the permit holder from installing more sophisticated monitoring equipment than that required by EMB. However, in the event of air pollution control device failure, the management of the plant needs to have put in place procedures (Contingency Plans) for managing the situation.

Contingency Plans for air pollution control device failure provide procedures as what to do in the event of a failure. In most circumstances total failure of air pollution control devices on a process will require that the process be shut down, but in an orderly manner.

Operators of air pollution control devices need to be trained in the procedures contained in the Contingency Plans and on how to shut the processes they are operating down in the event of a major failure of the installed air pollution control devices.

## 6.1 Contents of a Contingency Plan

A contingency plan should be developed for each type of air pollution control devices installed at the site. The Plan should:

- Be based on an environmental **risk assessment**. This should identify likely modes of failure and the level of impact risk for these failure scenarios for that process and air pollution control device. This includes the likelihood of the failure mode to occur, the consequence of the discharge (size of the release, duration, pollutants contained in the release and the area affected), and identification of who would be affected (on-site and off-site) by the release by these failures. This risk assessment process allows the relative risk of the failure of each piece of air pollution control devices to be assessed, and compared to each other. It also allows the requirements Contingency Plans to reflect the relative level of risk posed by each failure scenario. A typical qualitative risk assessment that can be used to evaluate the level of risk for different failures of emission control equipment at a site is provided in Appendix B. The scenarios can be grouped into those only have on-site consequences and those having both on-site and off-site consequences.
- For off-site consequences, contain a contact list of sites and personnel that could be affected, and in some instances may need to be evacuated from there premises.
- Develop a set of procedures that sets out the actions that must be followed in the event of the failure of a specific piece of air pollution control devices. They usually include the following steps:
    1) Identify the scale and level of failure;
    2) Advise supervisor of the failure;
    3) Decide whether the failure requires to process to be shutdown or that the fault can be fixed without having to shut the plant down;
    4) Implement actions to close process/plant and if a major failure;
    5) Decide in consultation with supervisor whether off-site consequences will occur and whether evacuation is required; and
    6) Complete all actions.
- Assign the responsibilities and actions of key personnel who will implement the Contingency Plan in respect to the investigating the cause of failure and the scale of the failure, and whether shutting down the process and control devices is appropriate action.

- Once the failure and immediate effects have been managed, define procedures/steps to follow to conduct an investigation into the failure and to put into place corrective actions to prevent future failures. As part of this investigation the effective of the Contingency Plan should also be assessed and recommendations for changes to it made.
- Define the frequency of tests for seeing that the Contingency Plan will be followed in the event of a failure, and also the frequency that the Contingency Plan should be reviewed for its appropriateness and ensured that it is up to date.

For a number of the air pollution control devices described in Section 3 of the guidelines, the Contingency Plans will be relatively simple and, if the devices failed, would result in the process being shutdown if the problem can not be rectified within 5 – 10 minutes.

A Contingency Plan can also address wider emergency response issues, such as evacuation procedures in the event of a major incident. Some examples of evacuation procedures for a Contingency Plan are presented in Appendix C.

# 7 COMPLAINTS

All site that hold a Permit to Operate should as a condition of the permit be required to maintain a Complaints Register. The complaints register should record all complaints that the plant receives from the public in relation to their operations and in particular their emissions to air.

The Complaints Register should record the following:

1) Name and contact details of complainant (or enquirer)
2) Date and time of receipt of the complaint (or enquiry)
3) Name and designation of the person who received the complaint
4) Details of the complaint
    - a description of the pollution incident, event or subject matter
    - the place, time and duration of the incident or event
    - the alleged or suspected source of the pollution
    - the weather conditions at the time of the incident or event
    - the complainant’s assessment of the seriousness of the incident or event
    - any other pertinent comments or information provided by the complainant
5) Results of the facility’s investigations of the incident or event
6) Mitigation actions or measures (if any) adopted
7) Advice to complainant of the outcome (date & time advised)
8) Advice to EMB of the outcome (date & time advised)

The Complaints Register is to be retained as a part of facility operational log and should be made available to EMB inspectors who visit the site.

# 8 REFERENCES


1) Auckland Regional Council, *Performance Criteria for Air Pollution Control Equipment*, August 2000, a report prepared by Sinclair Knight Merz Limited.

2) Auckland Regional Council, Assessing Risk from Potential Air Discharges Following Industrial Incidents, A Discussion, June 2000, a report prepared by Sinclair Knight Merz Limited.

3) Auckland Regional Council, Technical Publication 152, Assessing Discharges of Contaminants into Air (Draft), April 2002

4) Brenman B. M., Donlan M. and Bolton E., 1996, Peat Biofiltration as an Odour Control Technology for Sulphur Based Compounds J.CIMEM, June 1996.

5) Buonicore A. J. and Davis W. T., 1992, *Air Pollution Engineering Manual* AWMA, Van Nostrand Rienhold, New York.

6) USEPA, 1996, *Compilation of Air Pollutant Emission Factors* AP-42 Fifth Edition, Volume 1: Stationary and Point Sources. http//www.epa.gov/ttn/chief/

7) USEPA, 1998. U.S. EPA, Office of Air Quality Planning and Standards, *Stationary Source Control Techniques Document for Fine Particulate Matter*, EPA-452/R-97-001, Research Triangle Park, NC., October.

8) USEPA, CACT, 1998 Clean Air Technology Centre, Technology Fact Sheets. http//www.epa.gov/ttn/catc/

9) World Bank - Low NOx Burners.htm.

# Appendix A Example of Air Pollution Control Inspection Checklist

# Air Pollution Control Field Inspection Checklist

1. Company Name:
2 Permit number(s)
3. Site Address:
4 Pollution Control Officer's Name:
5 Name and Designation of EMB Officer:
6 Date of Site Inspection:

## Air Discharges

☐y☐n Industry complies with all current permit emission discharge conditions – if **n**, generate a report details and consider enforcement action

☐y☐n All discharge sources are included in the permit? - if **n**, report details, draft new conditions and amend permit

☐y☐n Industry has changed processes/operations/pollution control equipment at the site since the last inspection? - if **y** require written report from permit holder and amend permit and consider enforcement action

☐y☐n Are there odours, solid particulates, liquid droplets or mist detectable off-site? - if **y** report details and amend permit

☐y☐n Are the permit monitoring conditions adequate in terms of the parameters and testing frequency? - if **n** report details and amend permit

☐y☐n Is the emission control equipment installed at the site effective in controlling emissions? - if **n** report details and amend permit

## Operation and Management Plan

☐y☐n Does the site have an Operation and Management Plan (OMP) to inspect, monitor and maintain the air pollution control devices installed at the site? - if **n** report and amend permit

☐y☐n Are monitoring records held for each air pollution control device installed at the site? – if **n** report and amend permit to include effective OMP conditions

☐y☐n Have corrective actions required in the OMP been carried out? - if **n** report and consider enforcement action

☐y☐n Is maintenance being carried out in accordance with the OMP? – if **n** report and consider enforcement action

## Contingency Plans

☐y☐n Does the industry have an effective Contingency Plan with procedures to manage any accidental or unexpected releases of emissions? - if **n** report and amend permit

☐y☐n Have there been accidental or unexpected releases to the environment? – if **y** report details of causes and action taken/needed and amend Contingency Plan if necessary

## Complaints

☐y☐n Does the industry have an up to date complaints register? - if **n** report and amend permit

☐y☐n Is the company's response to complaints appropriate? – if **n** report and consider enforcement action

# Appendix B Risk Management Principles and Procedures

## B.1 Introduction

The term *risk assessment* can be confusing, particularly in the context of air pollution assessments. This document describes a risk-based approach to assessing potential events or incidents in industrial facilities.

A risk-based approach is a methodology that takes account of the probabilistic nature of unintended events. Tools that aid the identification of accidental or unexpected events and an understanding of the potential consequences are also discussed. The probabilistic approach of risk assessment contrasts with the more recognised assessment methods used for air quality impacts. These are usually deterministic in nature and do not facilitate the identification of hazards or the resulting failure combinations or sequences.

In most circumstances, normal or expected air discharges are compared to a specific guideline or criterion, such as an ambient air quality standard. However, many criteria used in deterministic assessments have been developed by way of a risk-based approach that includes a probabilistic element. For example, ambient air concentration limits for many contaminants have been determined by health risk assessments, which deal with evaluating long-term exposures in relation to an acceptable likelihood of illness or death.

### *What is Risk?*

The fundamental concept of risk always involves two elements: the frequency or probability with which a hazardous event may occur, and the consequence of that event. A risk analysis deals with both elements, while risk assessment is the process used to determine risk management priorities by comparing the level of risk against predetermined standards or other criteria.

### *Individual and Societal Risks*

It is necessary to define the most appropriate way of measuring risk. In some cases it will be necessary to investigate and measure the risk posed to an individual or a defined receiving environment. In other cases the important element may be seen as risk to society or the environment as a whole. When referring to human safety risk it is normal to define risk in terms if the individual or society; “societal risk” or “individual risk”.

Put simply, societal risk is the likelihood of a disaster. It can be defined as:

“the relationship between frequency and the number of people suffering from a specified level of harm in a given population from the realisation of specified hazards”.

Societal risk is difficult to express as a single probability figure as it is necessary to consider the size of the disaster as well as its probability. In reality there would be a range of possible sizes, each with a different probability.

### *Hazard and Hazard Identification*

A hazard is a source of risk or potential harm and a hazard identification process -

*“involves a systematic review of the system under study to identify the type of inherent hazards that are present together with the ways in which they could be realised”.*

In the context of these guidelines, it may involve a review of what can cause an incident, e.g. the failure of an air pollution control device. This can involve a range of methods and some of these are described in later sections. The hazard identification process is without doubt the most important step of any risk-based study. Risks cannot be assessed or managed if they remain unknown.

### *Risk Analysis*

As discussed above, risk analysis is the process of determining how often incidents may occur and the severity of the associated consequences so as to establish the actual, as opposed to the perceived, level of risk. This process can be carried out using detailed mathematically-based tools or by a more general process involving the extensive use of judgement-based data. The first methodology is known as ‘quantitative’, and the latter ‘qualitative’. An example of a qualitative method that can be followed in presented Section B.2.

A quantitative risk analysis provides a measure of risk by using estimates of frequency or probability of the undesired events that are based upon historical data or calculations based upon an analysis of failure sequences. This work is then supported by the calculation of the impact of the consequences.

Quantitative risk analysis can be very demanding and, in practice, there is a potential for a very large range of accident scenarios. It therefore may not be feasible to undertake a detailed frequency and consequence analysis for each one. In these circumstances it may be better to rank the scenarios qualitatively and then concentrate on those events that are assessed as having the highest risk. Thus, risk estimation techniques provide a useful approach for ensuring the quantitative effort is focused on events of greatest concern.

### *Frequency Analysis*

A frequency analysis forms part of a risk analysis described above. It involves the quantitative determination of the likelihood or frequency of events identified at the hazard identification stage.

### *Consequence Analysis*

Consequence analysis involves methods for calculating or estimating the impact of the incident. This could include a study of the effects of any harm caused such as on people, property or the environment and must relate the sensitivity of the local environment to the event.

In general terms, consequence analysis determines the effects from fires, projectiles, falling structures etc. However, in the context of assessing air emissions, the focus is on the consequence of the release of contaminants to air. A range of tools are available for assessing the consequence including atmospheric dispersion modelling.

### *Cumulative Risk*

The total risk faced by an individual or society is the sum of all individual risks. Therefore, when considering the calculated risk from a facility, it is necessary to also consider any existing risks posed by other nearby facilities. Even when the new facility may present a small risk relative to an existing one, the total or cumulative risk will still be increased, possibly to a level that may be deemed intolerable.

### *Uncertainty*

As risk is a function of both probability and what may actually happen in the future, there will invariably be a level of uncertainty associated with any analysis of risk. This uncertainty relates to the inability to know exactly how and when events may occur.

The uncertainties may arise in various parts of an assessment, including failure rate estimates, consequences, or assumptions about human error. In many cases, therefore, quantitative evaluation criteria may have limited value and more qualitative criteria may be more appropriate. In some cases the appropriate approach will be to consider the worst case, thereby adding an element of precaution.

Furthermore, it may be very difficult to derive quantitative criteria for ecological risk. For example, the environmental values being protected are often not well understood. As a result any data derived from risk analysis must be interpreted with a full understanding of the associated uncertainties. Those tasked with risk-based decision making need to be aware of the inherent uncertainties associated with the information used in making a judgement or decision. Thus any risk analysis presented as part of an application for a discharge to air, will need to, at the very least, make comment on the level of uncertainty associated with the critical data.

## B.2 Qualitative Risk Analysis Procedure

In order for sites to plan for, and achieve effective management of their discharges to air and the associated hazards and impacts, a structured risk identification and assessment approach, based on the qualitative risk assessment methodology of Australian Standard AS/NZS 4360:2003 Risk Management can be followed. The risk assessment process is a management tool that allows resources to be applied to control emission sources that pose the highest level of risk.

This risk assessment approach combines (qualitative) estimates of the likelihood of a certain hazard event or environmental impact occurring, with the consequence of that impact or hazard. The qualitative rankings of likelihood and consequence used in this assessment are based on those in AS4360:2003 and are described in **Tables B-1** and **B-2**, respectively.

### Table B-1: Likelihood Descriptor Criteria and Scale

| Likelihood Descriptor | Scale | Descriptor Criteria |
|---|---|---|
| Almost certain | 5 | Is expected to occur in most circumstances |
| Likely | 4 | Will probably occur in most circumstances |
| Possible | 3 | Might occur at some time |
| Unlikely | 2 | Could occur at some time |
| Highly Unlikely | 1 | May occur only in exceptional circumstances |

### Table B-2: Consequence Descriptor Criteria and Scale

| Consequence Descriptor | Scale | Descriptor Criteria |
|---|---|---|
| Catastrophic | 16 | ▪ Multiple fatality<br>▪ Irreversible environmental damage and prosecution<br>▪ Financial loss over US $5M |
| Major | 8 | ▪ Single fatality or permanent disability<br>▪ Environmental damage leading to potential prosecution<br>▪ Financial loss over US $1M but less than US$5M |
| Significant | 4 | ▪ Serious injury or long-term illness<br>▪ Non-compliance with licence/agreement conditions or emission having significant adverse environmental impact<br>▪ Financial loss over US $500,000 but less than US $1M |
| Moderate | 2 | ▪ Injury requiring medical attention and several days off work<br>▪ Community complaint or emissions having adverse offsite environmental impact<br>▪ Financial loss over US $250,000 but less than US $500,000 |
| Minor | 1 | ▪ First aid needed<br>▪ Localised on-site impact such as oil staining over a small area of the site<br>▪ Financial loss less than US $250,000 |

The potential effects in terms of harm to the environment, on-site personnel or the local community should be taken into consideration for realistic worst case scenarios for potential hazard events and exposures. The assessment should be based on current site operations and management strategies (which may or may not be best practice).

An assessment of the overall risks associated with the hazards is then made based on the perceived likelihood of a hazard occurring and the potential realistic worst case effects associated with the hazard. Each hazard has been assigned a qualitative risk ranking based on the Risk Calculation Matrix shown in Table B-3.

**Table B-3: Risk Calculation Matrix**

| | **Almost Certain 5** | **Likely 4** | **Possible 3** | **Unlikely 2** | **Highly Unlikely 1** |
|---|---|---|---|---|---|
| **Catastrophic 16** | 80 | 64 | 48 | 32 | 16 |
| **Major 8** | 40 | 32 | 24 | 16 | 8 |
| **Significant 4** | 20 | 16 | 12 | 8 | 4 |
| **Moderate 2** | 10 | 8 | 6 | 4 | 2 |
| **Minor 1** | 5 | 4 | 3 | 2 | 1 |

The numerical risk ranking has been translated into a low, medium to high risk ranking using the criteria provided in Table B-4.

**Table B-4: Risk Ranking**

| **HIGH** | **MEDIUM** | **LOW** |
|---|---|---|
| 20-80 | 10-16 | 1-8 |

The risk rankings, and the degree of management planning or response appropriate to each risk ranking, are generally:

- **H:** High risk, senior management attention required
- **M:** Moderate risk, management responsibility must be specified
- **L:** Low risk, management by routine procedures.

# Appendix C Example of Evacuation Procedures for a Site Contingency Plan

## General Responsibilities

Evacuation provisions are applicable to fires and all other occurrences for which evacuation of staff from buildings to Assembly Areas (assembly points) is appropriate, such as major plant failure, fire, etc.

All building emergency exits are labelled with the green sign **EXIT**.

All personnel should familiarise themselves with the locations of ALL emergency exits from their work area and the location of their nearest Assembly Area (assembly point).

All Safe Briefing Areas are sign posted ‘Assembly Areas’ and are allocated a distinct letter for identification purposes. (These tie up with marked areas on site layout maps.)

Always assemble at the designated Assembly Area closest to your point of work.

## Evacuation Procedures

In the event of a fire, major plant failure, explosion, bomb threat or the need to evacuate the plant, the actions listed below should be followed.

- On the continuous sound of the alarm siren (bells), STOP all activities and vacate the building or area without delay, by the nearest exit.
- Plant Operators to initiate appropriate Emergency Operating Procedures (EOP), and where possible, confirm plant is in safe state prior to vacating buildings.
- Move quickly, but do not run.
- Do not return to a work area to collect belongings.
- Keep left in corridors and stairs.
- Do not overtake others along the route.
- Assemble in the designated Assembly Area.
- At Assembly Area report to the responsible Warden.
- Do not enter the building or work area under any circumstances until the all clear is given.

All new staff, as part of their induction into the company, shall be given instructions on the evacuation procedures for the site.

All visitors and contractors are to be advised of the site’s Evacuation Procedure and the location of Assembly Areas when they are admitted to the site.

## Specific Responsibilities

***Duties of Warden (Fire)***

- Study and become familiar with evacuation procedure.
- Turn-off power and gas supplies.
- Check department including toilets, showers, offices, etc to ensure that all personnel are evacuated from their area/department. DO NOT try to account for individuals; just clear all personnel from the department or area.
- Ensure all doors are closed but not locked to partitioned areas, strong rooms, and main doors. Do not turn off lights.
- Advise Control Centre whereabouts of fire, or threat in your area.
- Check all personnel from your area are at the Assembly Area (assembly point).
- Mark Evacuation Control Board at Control Centre that the area of responsibility is clear.

***Duties of Control Officer***

- Report to designated control centre area.
- Await wardens to report.
- Review Evacuation Control Board status.
- Direct personnel accordingly.
- On all clear, issue instructions to return to work.

### Assembly Areas (Assembly Points)

Designated Assembly Areas are marked on site layout maps, and are displayed on noticeboards throughout the site next to the Evacuation Procedure.

For some sites, wind socks are placed throughout the site. Observe the wind direction (sock direction) during the evacuation. Personnel should assemble at the safe upwind Briefing Areas.

### All Clear

Instructions to return to work will be given by the Control Officer.

### Control Centre

- The most senior staff member of the shift will be the Control Officer. All Area Wardens will report to the Control Officer.
- The Evacuation Control Board will be held at the Control Centre.

A flow diagram showing the Evacuation Procedure is presented in Figure 1. This flow diagram can be placed on notice boards throughout the site next to the site plan showing designated Assembly Areas.

Regular drills (once every six months) are held to ensure that staff are familiar with the Evacuation Procedures.

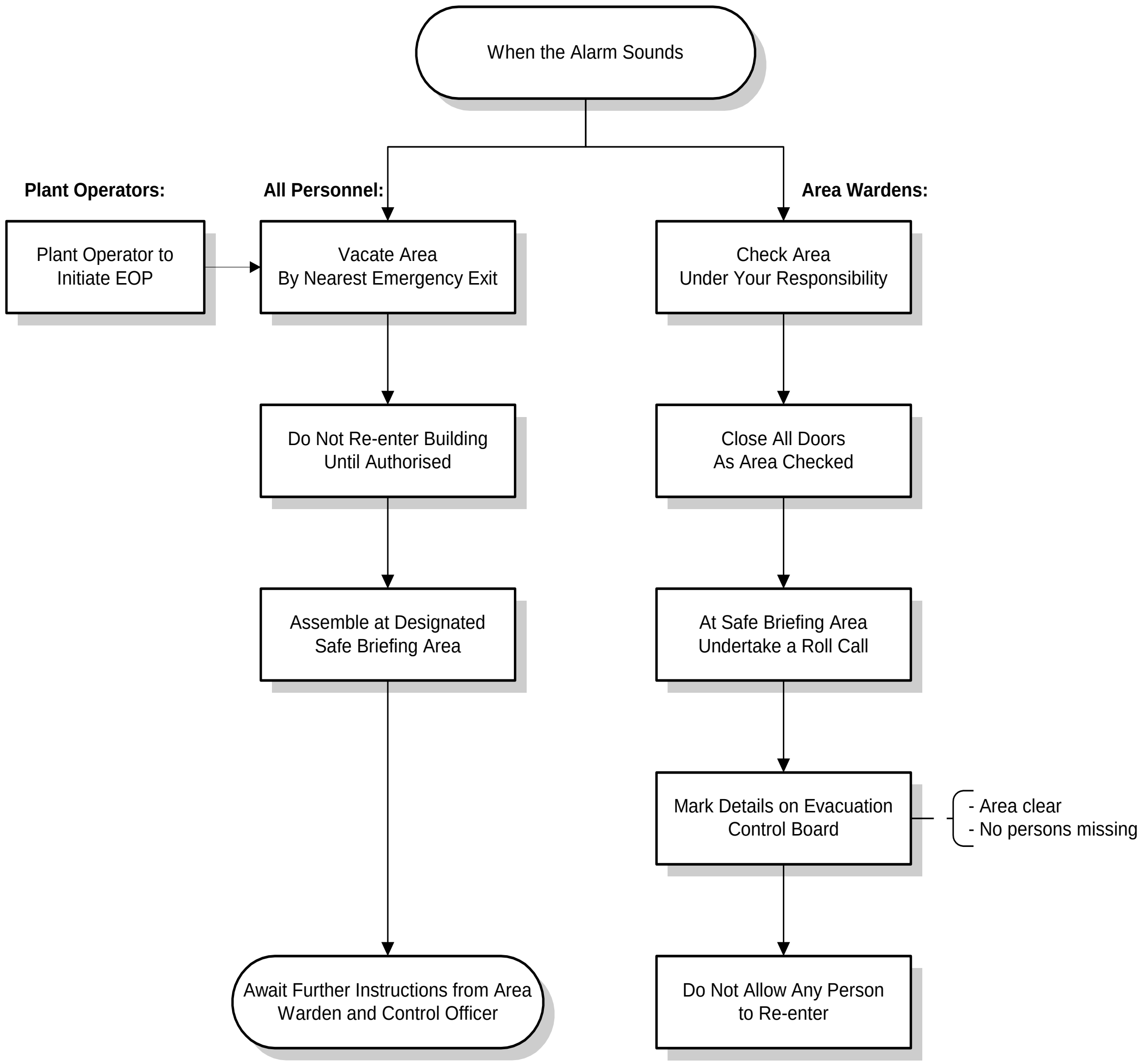
### Training

All personnel, visitors and contractors will be trained on how to use the emergency plans set out in this section.

Emergency procedures will be included in induction training for all new staff and contractors to the site.

**Figure 1 : Evacuation Procedures**

## In the Event of a Fire or the Need to Evacuate the Plant the Following Actions Should Be Taken:



# Appendix D Guidance on Costs of Pollution Control Equipment

The costs contained in this section are provided for indicative purposes and are sourced from the US EPA Air Pollution Control Technology Fact Sheets. For full details the reader should refer to the fact sheet itself. The following costs for the various air pollution control devices covered below are ranges in US dollars (circa 2002) and are based on typical operating conditions found in US situations. In some instances an allowance for duct work, etc has not been included in the estimate of costs.

## D1. Filtration Equipment

### Shaker Bag Filter

| | |
|---|---|
| **Capital Costs** | \$17,000 to \$153,000 per sm$^3$/sec \$1,000 to \$1,300 per sm3/sec extra for sonic horns |
| **Operation and Maintenance Costs** | \$9,300 to \$51,000 per sm3/sec, annually |
| **Annualised Costs** | \$11,000 to \$95,000 sm3/sec, annually |
| **Cost Effectiveness** | \$41 to \$334 per tonne, annually |

### Reverse Air Bag Filter

| | |
|---|---|
| **Capital Costs** | \$19,000 to \$180,000 per sm3/sec \$1,000 to \$1,300 per sm3/sec extra for sonic horns |
| **Operation and Maintenance Costs** | \$14,000 to \$58,000 per sm3/sec, annually |
| **Annualised Costs** | \$71,000 to \$106,000 sm3/sec, annually |
| **Cost Effectiveness** | \$58 to \$372 per tonne, annually |

### Pulse-jet Bag Filter

| | |
|---|---|
| **Capital Costs** | \$13,000 to \$55,000 per sm3/sec |
| **Operation and Maintenance Costs** | \$11,00o to \$50,000 per sm$^3$/sec, annually |
| **Annualised Costs** | \$13,000 to \$83,000 sm3/sec, annually |
| **Cost Effectiveness** | \$46 to \$293 per tonne, annually |

**Cartridge Collectors**

| | |
|---|---|
| **Capital Costs** | \$15,000 to \$28,000 per $sm^3$/sec |
| **Operation and Maintenance Costs** | \$20,000 to \$52,000 per $sm^3$/sec, annually |
| **Annualised Costs** | \$26,000 to \$80,000 $sm^3$/sec, annually |
| **Cost Effectiveness** | \$94 to \$280 per tonne, annually |

## D2. Electrostatic Precipitators

**Dry ESP – Wire Pipe Type**

| | |
|---|---|
| **Capital Costs** | \$42,000 to \$260,000 per $sm^3$/sec |
| **Operation and Maintenance Costs** | \$8,500 to \$19,000 per $sm^3$/sec, annually |
| **Annualised Costs** | \$19,000 to \$55,000 $sm^3$/sec, annually |
| **Cost Effectiveness** | \$47 to \$710 per tonne, annually |

**Dry ESP – Wire Plate Type**

| | |
|---|---|
| **Capital Costs** | \$21,000 to \$70,000 per $sm^3$/sec |
| **Operation and Maintenance Costs** | \$6,400 to \$74,000 per $sm^3$/sec, annually |
| **Annualised Costs** | \$9,100 to \$81,000 $sm^3$/sec, annually |
| **Cost Effectiveness** | \$38 to \$260 per tonne, annually |

**Wet ESP- Wire Pipe Type**

| | |
|---|---|
| **Capital Costs** | \$85,000 to \$424,000 per $sm^3$/sec |
| **Operation and Maintenance Costs** | \$12,000 to \$21,000 per $sm^3$/sec, annually |
| **Annualised Costs** | \$25,000 to \$97,000 $sm^3$/sec, annually |
| **Cost Effectiveness** | \$73 to \$720 per tonne, annually |

## D3. Cyclonic Separators

**Conventional Cyclones**

| | |
|---|---|
| **Capital Costs** | \$4,600 to \$7,400 per $sm^3$/sec |
| **Operation and Maintenance Costs** | \$1,500 to \$18,000 per $sm^3$/sec, annually |
| **Annualised Costs** | \$2,800 to \$29,000 $sm^3$/sec, annually |

**Cost Effectiveness** $0.47 to $40 per tonne, annually

## D4. Particulate Scrubbers

### Spray Chamber - Spray Tower Wet Scrubber

| | |
|---|---|
| **Capital Costs** | $4,200 to $13,000 per $sm^3$/sec |
| **Operation and Maintenance Costs** | $3,200 to $64,000 per $sm^3$/sec, annually |
| **Annualised Costs** | $5,300 to $102,000 $sm^3$/sec, annually |
| **Cost Effectiveness** | $50 to $950 per tonne, annually |
| | Does not include the costs for used solvent or waste disposal. |

### Packed Bed Spray Tower

| | |
|---|---|
| **Capital Costs** | $4,200 to $13,000 per $sm^3$/sec |
| **Operation and Maintenance Costs** | $3,200 to $64,000 per $sm^3$/sec, annually |
| **Annualised Costs** | $5,300 to $102,000 $sm^3$/sec, annually |
| **Cost Effectiveness** | $50 to $950 per tonne, annually per tonne per year of pollutant control |
| | Does not include the costs for used solvent or waste disposal. |

### Impingement Plate

| | |
|---|---|
| **Capital Costs** | $8,500 to $23,000 per $sm^3$/sec |
| **Operation and Maintenance Costs** | $6,500 to $93,000 per $sm^3$/sec, annually |
| **Annualised Costs** | $11,000 to $150,000 $sm^3$/sec, annually |
| **Cost Effectiveness** | $104 to $1,400 per tonne, annually |

Does not include the costs for used solvent or waste disposal.

**Mechanically Aided Scrubber**

| | |
|---|---|
| **Capital Costs** | \$5,500 to \$37,000 per $sm^3$/sec |
| **Operation and Maintenance Costs** | \$6,400 to \$167,000 per $sm^3$/sec, annually |
| **Annualised Costs** | \$7,200 to \$172,000 $sm^3$/sec, annually |
| **Cost Effectiveness** | \$66 to \$6,600 per tonne, annually<br>Does not include the costs for used solvent or waste disposal. |

**Venturi Scrubber**

| | |
|---|---|
| **Capital Costs** | \$5,300 to \$45,000 per $sm^3$/sec |
| **Operation and Maintenance Costs** | \$9,300 to \$254,000 per $sm^3$/sec, annually |
| **Annualised Costs** | \$12,000 to \$409,000 $sm^3$/sec, annually |
| **Cost Effectiveness** | \$77 to \$2,600 per tonne, annually<br>Does not include the costs for used solvent or waste disposal. |

**Orifice Scrubber**

| | |
|---|---|
| **Capital Costs** | \$10,000 to \$36,000 per $sm^3$/sec |
| **Operation and Maintenance Costs** | \$8,000 to \$149,000 per $sm^3$/sec, annually |
| **Annualised Costs** | \$9,500 to \$154,000 $sm^3$/sec, annually |
| **Cost Effectiveness** | \$88 to \$1,400 per tonne, annually<br>Does not include the costs for used solvent or waste disposal. |

**Condensation Scrubber**

| | |
|---|---|
| **Capital Costs** | \$13,000 per $sm^3$/sec |
| **Operation and Maintenance Costs** | \$5,300per $sm^3$/sec, annually |
| **Annualised Costs** | \$7,000 $sm^3$/sec, annually |
| **Cost Effectiveness** | \$65 per tonne, annually.<br>Does not include the costs for used solvent or waste disposal. |

**Fibre-Bed Scrubber**

| | |
|---|---|
| **Capital Costs** | \$2,100 to \$6,400 per $sm^3$/sec |
| **Operation and Maintenance Costs** | \$3,500 to \$76,000 per $sm^3$/sec, annually |
| **Annualised Costs** | \$4,300 to \$77,000 $sm^3$/sec, annually |

| | |
|---|---|
| **Cost Effectiveness** | $40 to $7100 per tonne, annually |
| | Does not include the costs for used solvent or waste disposal. |

## D5. Thermal Oxidation

### Thermal Oxidiser

| | |
|---|---|
| **Capital Costs** | $53,000 to $190,000 per $sm^3$/sec |
| **Operation and Maintenance Costs** | $11,000 to $160,000 per $sm^3$/sec, annually |
| **Annualised Costs** | $17,000 to $208,000 $sm^3$/sec, annually |
| **Cost Effectiveness** | $44 to $3,600 per tonne, annually per tonne per year of pollutant control |

### Recuperative Thermal Oxidiser

| | |
|---|---|
| **Capital Costs** | $25,000 to $212,000 per $sm^3$/sec |
| **Operation and Maintenance Costs** | $10,000 to $53,000 per $sm^3$/sec, annually |
| **Annualised Costs** | $17,000 to $95,000 $sm^3$/sec, annually |
| **Cost Effectiveness** | $105 to $2,000 per tonne, annually per tonne per year of pollutant control |

### Catalytic Thermal Oxidiser

| | |
|---|---|
| **Capital Costs** | $47,000 to $191,000 per $sm^3$/sec |
| **Operation and Maintenance Costs** | $8,500 to $53,000 per $sm^3$/sec, annually |
| **Annualised Costs** | $17,000 to $106,000 $sm^3$/sec, annually |
| **Cost Effectiveness** | $105 to $5,550 per tonne, annually per tonne per year of pollutant control |

### Regenerative Thermal Oxidiser

| | |
|---|---|
| **Capital Costs** | \$85,000 to \$320,000 per $sm^3$/sec |
| **Operation and Maintenance Costs** | \$8,500 to \$21,000 per $sm^3$/sec, annually |
| **Annualised Costs** | \$17,000 to \$70,000 $sm^3$/sec, annually |
| **Cost Effectiveness** | \$115 to \$21,000 per tonne, annually per tonne per year of pollutant control |

### Flare

| | |
|---|---|
| **Capital Costs** | \$37,000 to \$4,000,000 per $sm^3$/sec |
| **Operation and Maintenance Costs** | \$2,000 to \$20,000 per $sm^3$/sec, annually |
| **Annualised Costs** | \$6,000 to \$650,000 $sm^3$/sec, annually |
| **Cost Effectiveness** | \$17 to \$6,500 per tonne, annually per tonne per year of pollutant control |

## D6. Chemical Scrubbing

### Packed Tower Bed Scrubber

| | |
|---|---|
| **Capital Costs** | \$23,000 to \$117,000 per $sm^3$/sec |
| **Operation and Maintenance Costs** | \$32,000 to \$104,000 per $sm^3$/sec, annually |
| **Annualised Costs** | \$36,000 to \$155,000 $sm^3$/sec, annually |
| **Cost Effectiveness** | \$110 to \$550 per tonne, annually |

Note: Pollutant is hydrochloric acid and the scrubbing liquor is caustic soda. Costs do not include the costs for used solvent or waste isposal.