GUIDELINES FOR THE UTILISATION AND DISPOSAL OF WASTEWATER SLUDGE

Volume 5 of 5

Requirements for thermal sludge management practices and for commercial products containing sludge

water & forestry
Department:
Water Affairs & Forestry
REPUBLIC OF SOUTH AFRICA

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Environmental Affairs and Tourism
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TT 351/09

Water Research Commission

GUIDELINE VOLUMES

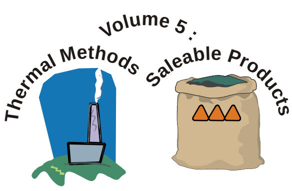
These Guidelines were developed to encourage the beneficial use of wastewater sludge. Rather than trying to develop a single guideline to address all the management options, a separate Guideline Volume deals with each of the management options. This Volume deals with the management, technical and legislative aspects associated with thermal treatment of sludge and manufacturing commercial products containing sludge.

Volume 1: Selection of management options

Volume 2: Requirements for the agricultural use of sludge

Volume 3: Requirements for the on-site and off-site disposal of sludge

Volume 4: Requirements for the beneficial use of sludge at high loading rates



Volume 5: Requirements for thermal sludge management practices and for commercial products containing sludge

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Guidelines for the Utilisation and Disposal of Wastewater Sludge

Volume 5: Requirements for thermal sludge management practices and for commercial products containing sludge

Prepared for the
Water Research Commission
by

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DISCLAIMER

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FOREWORD

Traditional practices related to wastewater sludge management include dedicated land disposal, waste piling, landfill disposal and to a lesser degree use in agricultural practices. However due to varying reasons, on-site land disposal and waste piling have become the standard management options for many wastewater treatment plants in South Africa today. With sludge production increasing on a daily basis, it has however become apparent that current practices are unsustainable with sludge management becoming a problem for many municipalities in South Africa. Innovative solutions need to be sought to create opportunities that provide a wide spectrum of options to the management of wastewater sludge.

Seeking innovative solutions requires a paradigm shift in our perception and understanding of wastewater sludge from a waste product to one of a resource. Such a shift creates an opportunity for local authorities and municipalities to generate a range of economic and social spin-offs to the benefit of their local communities thereby taking a small step towards achieving the goal of sustainable development.

Volumes 2, 3, 4 and 5 of the Sludge Guidelines Series aim to provide options and opportunities for this innovation and to encourage the beneficial use of wastewater sludge. Where wastewater sludge cannot be used as a resource, the guidelines also provide for its disposal in a responsible manner.

The potential benefits of the nutrients (nitrogen, potassium and phosphorus) and the high carbon content of sludge have been well demonstrated and have led to the beneficial utilization of sludge in many countries. Beneficial use of sludge is seen as an appropriate cost-effective management option for South Africa, both for the sludge user and wastewater industry.

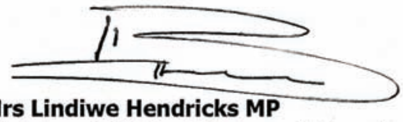
Sludge can also be used beneficially as raw material in the manufacture of various commercial products, e.g. bricks, cement, pellets, fertilizers, etc. In many instances the manufacture of the commercial products requires that the sludge undergo some form of thermal treatment before being used as a raw material. This heating step ensures that pathogens are destroyed and metals are converted to the insoluble fraction so that these products will not pose an environmental or health risk. A common form of thermal treatment used is incineration.

The incineration process itself can provide valuable energy both in the form of heat and electricity. This renewable energy source can be re-used by incinerators as well as by the wastewater treatment plant and third parties. The ash produced is less than 25% of the sludge volume incinerated and can be used as raw material for commercial products used in the construction industry. The negative effects of sludge incineration on air quality need to be managed to ensure protection of the environment and human health. The use of the final ash should also be restricted for this purpose. This Guideline Volume (Volume 5) has specifically been developed to encourage the responsible incineration and beneficial use of the ash while still protecting the receiving environment.

Commercial fertilizer and compost can also be manufactured from sludge. Since these products will be distributed to the general public, management of the product is out of the hands of the producer. Therefore, these products should be of such quality that it can be used without restrictions and adverse environmental and human health implications. This Guideline Volume 5 has also been developed to provide the requirements and restrictions for fertilizer products containing sludge.

The Guidelines were developed as a user-friendly document for regulatory authorities, managers, practitioners and operators responsible for sludge management. The development of the Sludge Guidelines were also supported by an extensive stakeholder consultation process (two consultative workshops and a training workshop in each province) which included sector stakeholders, regulatory authorities, government departments, industry experts, professional service providers, and interested individuals whose inputs significantly enhanced the final product. In the interest of transparency, the scientific basis, assumptions, thought processes and stakeholder consultation were documented as separate documents available from the Water Research Commission (WRC).

The Sludge Guidelines are living publications, and will be reviewed periodically based on comments received on the current requirements and approaches. All users are urged to take a critical view regarding the Guidelines in terms of usefulness and appropriateness. It is believed that valuable feedback will ensure continual improvement. Comments should be directed to the Director: Resource Protection and Waste, Department of Water Affairs and Forestry, Private Bag X313, Pretoria, 0001.



Mrs Lindiwe Hendricks MP
Minister of Water Affairs and Forestry

Mr Marthinus van Schalkwyk MP
Minister of Environmental Affairs and Tourism

ACKNOWLEDGEMENTS

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"DEVELOPMENT OF THE SOUTH AFRICAN WASTEWATER SLUDGE DISPOSAL GUIDELINES DEALING WITH LAND AND OCEAN DISPOSAL, BENEFICIAL USE, USE IN COMMERCIAL PRODUCTS AND THERMAL TREATMENT"

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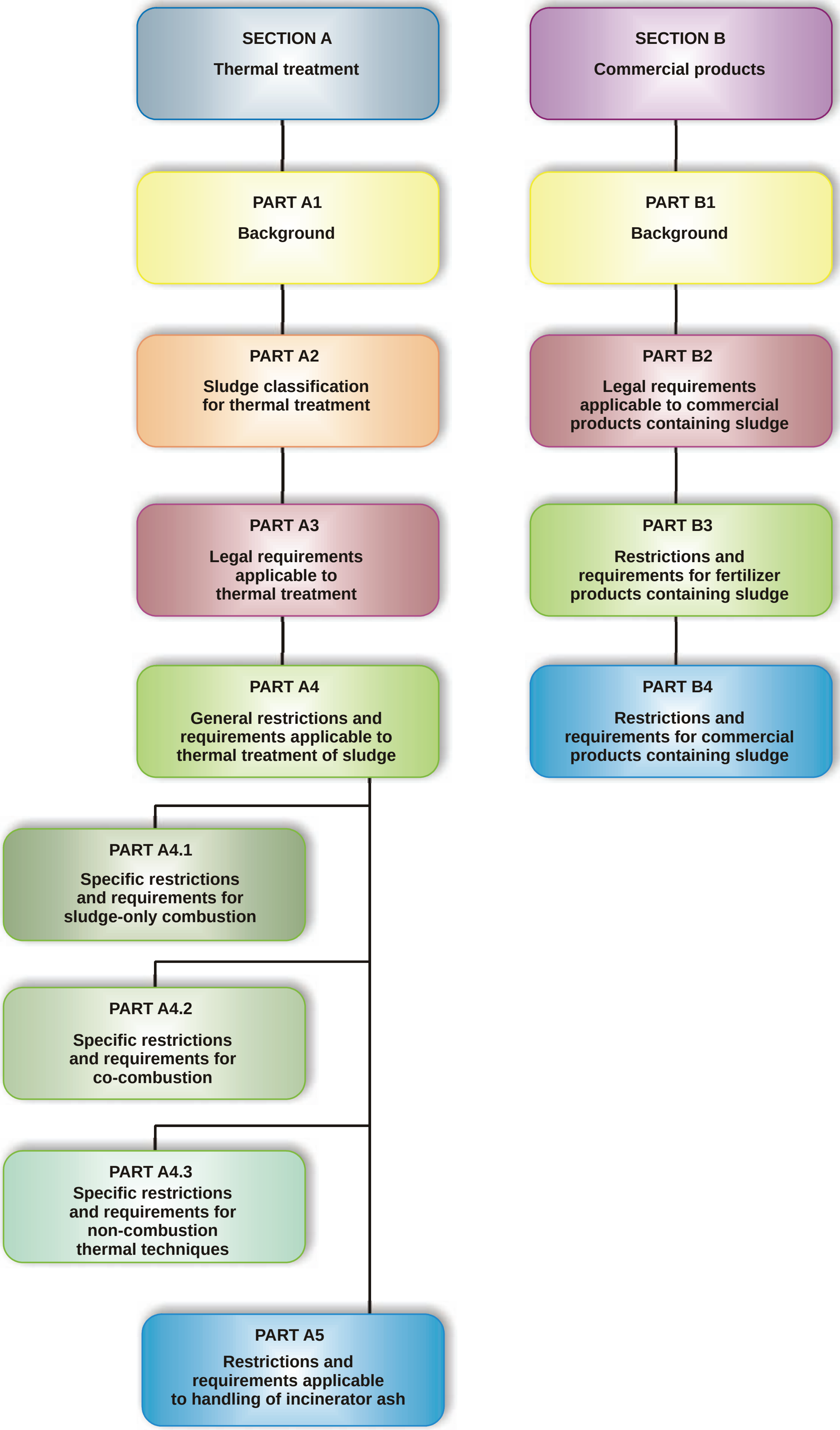
The financing of the project by the Water Research Commission and the Department of Water Affairs and Forestry as well as the contribution of the members of the Reference Group and all Stakeholders are gratefully acknowledged.

The project team also want to acknowledge Tiaan van Niekerk (cover page design) and Beulah Sanders (graphics design) for their assistance.

STRUCTURE OF THIS GUIDELINE VOLUME



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LIST OF ACRONYMS

APC	Air Pollution Control
APPA	Atmospheric Pollution Prevention Act
CO	Carbon monoxide
DEAT	Department of Environmental Affairs and Tourism
DWAF	Department of Water Affairs and Forestry
ECA	Environment Conservation Act 73 of 1989
ESP	Electrostatic precipitator
HCl	Hydrogen chloride
NEM-AQA	National Environmental Management Air Quality Act
Nox	Nitrogen oxides
PAH	Polycyclic aromatic hydrocarbons
SO_2	Sulphur dioxide
TEQ	Toxic equivalence
THC	Total hydrocarbons
TOC	Total organic carbon
WWTP	Wastewater treatment plant

INTRODUCTION

The New Sludge Guidelines were developed to encourage the beneficial use of wastewater sludge. Sludge has well known beneficial soil conditioning and fertilizing properties as well as potentially harmful substances and can therefore not be used as normal fertilizer. Volume 2 of the Sludge Guidelines covers the beneficial use of sludge in agricultural practices at agronomic rates, not exceeding 10 ton/ha/year, while the fundamental premise of Volume 4 is that sludge can be used beneficially at high loading rates, provided that there is adequate management and control.

Volume 5 of the Guidelines (this Volume) addresses thermal treatment and commercial products containing sludge and consists of 2 sections, namely:

- **Section A** – Thermal treatment where the aim is to give guidance on the restrictions and requirements for the combustion of sludge and the handling of the resulting ash, and
- **Section B** – Commercial products containing sludge/incinerator ash, with the aim of giving guidance on the use of sludge as commercial fertilizer (compost and pellets) as well as other commercial products including construction materials. There are other commercial products that may be developed from sludge or incinerator ash that is not discussed in this document. However, the principles put forward in this document can be applied to other products as well.

PURPOSE OF THIS VOLUME

The purpose of this Volume is:

- To create an understanding of the operational and legal requirements for thermal treatment of sludge and commercial products containing sludge;
- To present guidelines for monitoring of thermal treatment process emissions as well as guidelines for ash handling;
- To present operational guidelines for composting of sludge and restrictions and requirements for other commercial products to be used as fertilizer; and
- To present restrictions and requirements applicable to the use of sludge for commercial products applied in construction (bricks, cement, etc.).

WHO SHOULD USE THIS VOLUME?

Volume 5 was developed to inform the user of the restrictions and requirements applicable to the thermal treatment of sludge and to enable beneficial use of sludge as a commercial product (or part thereof) without harming the receiving environment. Any person who effectively applies the Guidelines will comply with all the environmental requirements. This Guideline was developed for:

- **Wastewater treatment plant operators** – to implement acceptable good practice pertaining to thermal treatment, ash handling and composting of sludge as well as the use of sludge to create commercial products.
- **Wastewater treatment service providers** – to implement beneficial use of sludge as a commercial product and/or to implement thermal treatment as a management strategy while managing the environmental impact.

- **Local authorities and town/city councils that own and operate wastewater treatment plants** – to design, operate and maintain a sustainable beneficial sludge use strategy that would not negatively impact on the receiving environment.

- **Landfill site owners/operators** – to manage the ash resulting from sludge thermal treatment accepted on the site.

- **Wastewater engineers/scientists** – to design and develop improved treatment methods and monitoring protocols which will ensure sustainable beneficial use of sludge.

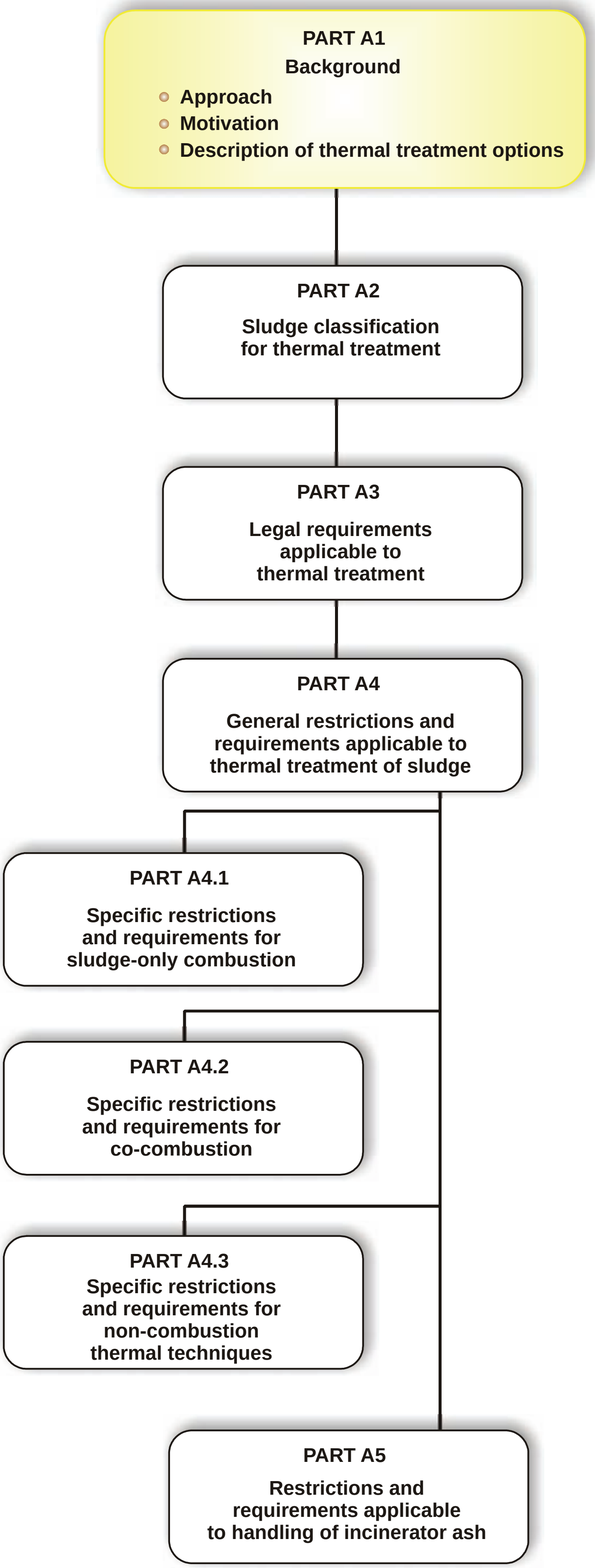
- **Technical advisors** – to encourage beneficial use of sludge and provide appropriate advice on management and monitoring requirements for thermal treatment and commercial products.

- **Regulators** – to assess compliance in cases where the Sludge Guideline Volumes have been referred to in a water use authorisation or waste disposal site permit.

- **Sludge users** – to effectively and responsibly utilise sludge in beneficial use options.

- **Educators** – to build capacity and create awareness.

SECTION A: THERMAL TREATMENT ROADMAP



PART A1:

BACKGROUND

Volume 5: Section A –Thermal treatment of the Guidelines was developed with a view to guide the sludge producer/user to the different thermal treatment options available for sludge. The aim of incineration, also called combustion, is mainly to reduce the sludge volume through the conversion of the organic complexion of sludge to more basic compounds like carbon dioxide, oxides of nitrogen, water vapour, methane and hydrogen. Established thermal treatment processes include, but are not limited to:

- Total or partial combustion of organic solids to oxidised end products (carbon dioxide and water) through incineration;
- Partial oxidation and volatilisation of organic solids by pyrolysis or starved-air combustion to produce end products with energy content (e.g. methane, hydrogen, carbon monoxide); and
- Co-incineration of sludge with other materials (municipal solid waste, wood waste and coal) in industrial processes such as industrial furnaces and cement kilns.

This Section deals specifically with the legislative and technical aspects of thermal treatment, including air emission limits and air quality monitoring. These restrictions and requirements are presented to protect the receiving environment and the general public from any potential constituents of concern present in the sludge that may be present in air emissions.

APPROACH FOLLOWED TO DEVELOP VOLUME 5: THERMAL TREATMENT

The scientific premise of the Guidelines for thermal treatment of sludge is based on the following information:

- International research findings;
- Local legislative and guiding documents;
- International guidelines and legislative trends; and
- Practical considerations.

Air quality at thermal treatment plants should be managed to eliminate any negative effects that constituents present in the exit gas may have on the environment and public health. The final ash produced should also be managed according to its potential hazard to the environment.

> It was assumed that the employers comply with the provisions of the Occupational Health and Safety Act (OSH Act) and workers are equipped with personal protective equipment (PPE). The impact of the sludge on workers would therefore be covered by this Act and is not considered to be a sludge issue.

The conceptual thinking, development process and assumptions are presented in separate documents which are available from the WRC[1 & 2].

[1] Herselman, J.E. and Snyman, H.G. 2008. Guidelines for the utilisation and disposal of wastewater sludge: Literature review and technical support document for Volumes 3-5. WRC Report 1622/1/09, 1622/2/09 and 1622/3/09.

[2] Snyman, H.G. and Moodley, P. 2008. Guidelines for the utilisation and disposal of wastewater sludge: Legal review. WRC Report 1622/4/09.

MOTIVATION FOR DEVELOPING GUIDELINES FOR THERMAL TREATMENT OF SLUDGE

The beneficial use of sludge is encouraged throughout the Sludge Guidelines to ensure sustainable sludge management and Volume 2 (Agricultural use), Volume 4 (Beneficial use) and Volume 5 (Thermal treatment and Commercial products) deal with these aspects. The major **benefits** of thermal treatment are:

- Use of sludge as an energy resource;
- Reduction of waste volume;
- Destruction of pathogens and toxic compounds; and
- The remaining ash can be used in the production of commercial products (Section B).

The major **disadvantages** of thermal treatment are:

- High capital and operational costs;
- Potential presence of metals, organic pollutants (PAHs), dioxins and furans in air emissions and residual ash; and
- Waste and/or wastewater from air pollution control (APC) devices.

Due to these disadvantages, the benefits of thermal treatment should always be weighed against the restrictions.

DESCRIPTION OF THERMAL TREATMENT OPTIONS

Sludge-only combustion

Sludge combustion/incineration is the firing of sludge at high temperatures in an enclosed device (Figure 1). The combustible fraction in sludge solids is characterised as volatile or char (fixed carbon). The amount of char produced depends on the sludge solid composition and volatile combustible burning characteristics. While efficient combustion at high temperatures with plenty of air minimises char production, poor combustion with smaller amounts of air yields higher amounts of fixed carbon. If the temperature of the hearth above the burning zone is too low for the destruction of the distilled organics, some or all of the volatilised organic matter may escape the combustion zone unburned. These organics usually are the cause for odour problems, especially with polymer conditioned sludge.

Co-combustion

Virtually any material, that can be burned, can be combined with sludge in a co-combustion process. Common materials for co-combustion are coal, municipal solid waste (MSW), wood waste and agricultural waste (Figure 2). Thus, municipal or industrial waste can be disposed of while providing a self-sustaining sludge feed, thereby solving two disposal problems. There are two basic approaches to combusting sludge with MSW: use of MSW combustion technology by adding dewatered or dried sludge to the MSW combustion unit, and use of sludge combustion technology by adding processed MSW as a supplemental fuel to the sludge furnace. The amount of sludge that can be incinerated depends on the speed of vaporisation of the large quantity of water contained in the sludge. This increases the volume of flue gas (exhaust gas) and contributes to the local cooling of the gas temperature.

Utilising sludge in cement kilns or power plants involves drying the sludge, transporting it to the kiln or power plant and then burning it. The fossil fuel energy saved by burning sludge must be balanced against that utilised in first drying and then transporting the sludge. This option is highly reliant on the willingness of the company operating the power plant or cement works to burn the sludge and therefore it is a relatively high-risk disposal strategy.

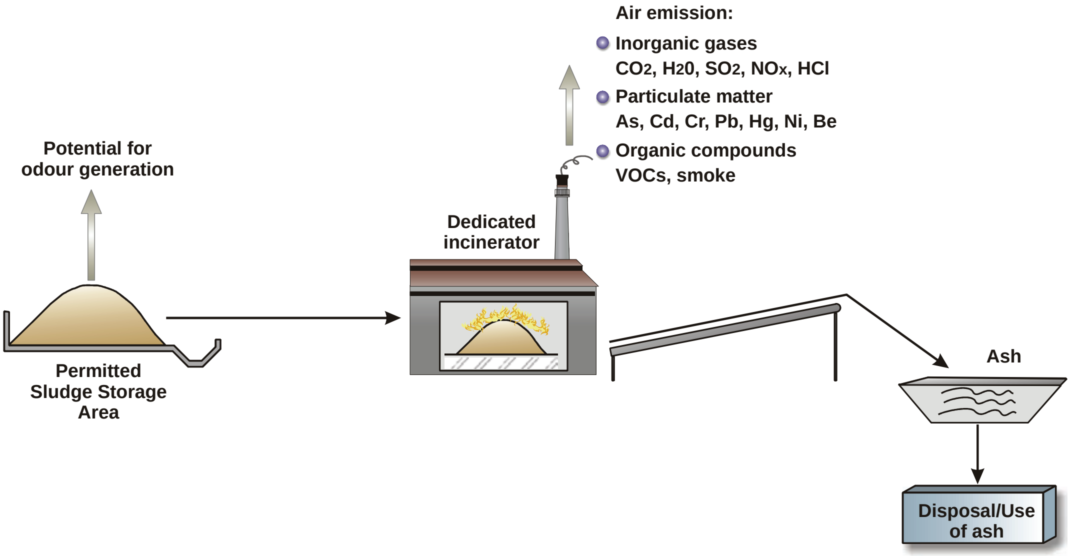


Figure 1: Schematic presentation of sludge combustion in a dedicated incinerator

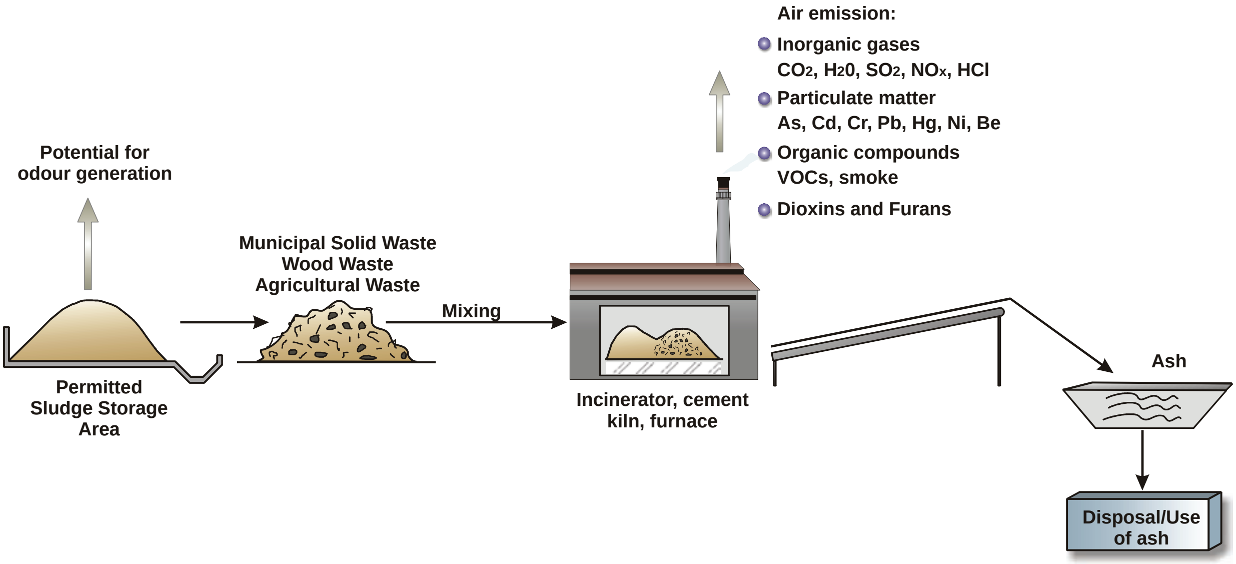


Figure 2: Schematic representation of co-combustion of sludge with other waste

Non-combustion techniques

Pyrolysis

Pyrolysis is the thermal decomposition of organic materials by heating in the absence of oxygen and water, splitting the organic substances into gas, liquid and solid phases (Figure 3). In contrast to combustion, which is highly exothermic, the pyrolytic process is endothermic. The characteristics of the three major components of pyrolysis are:

- Gas stream containing hydrogen, methane, carbon monoxide, carbon dioxide and other gases;
- Fraction that consist of a tar and/or oil stream which is liquid at room temperature and contains acetic acid, acetone and methanol; and
- Char consisting of carbon plus any inert material that may have entered the process.

Thermo-chemical conversion processes offer the following environmental benefits:

- Complete destruction of all pathogens and viruses;
- Control of heavy metals, including mercury (recovered as processed sludge);
- Destruction of organo-chlorine compounds; and
- Odour control.

Consequently, gas cleaning is very simple and cheap. Emission standards are therefore easily attainable. The disadvantage of the technology is its capital-intensiveness and the relative complexity of the plants.

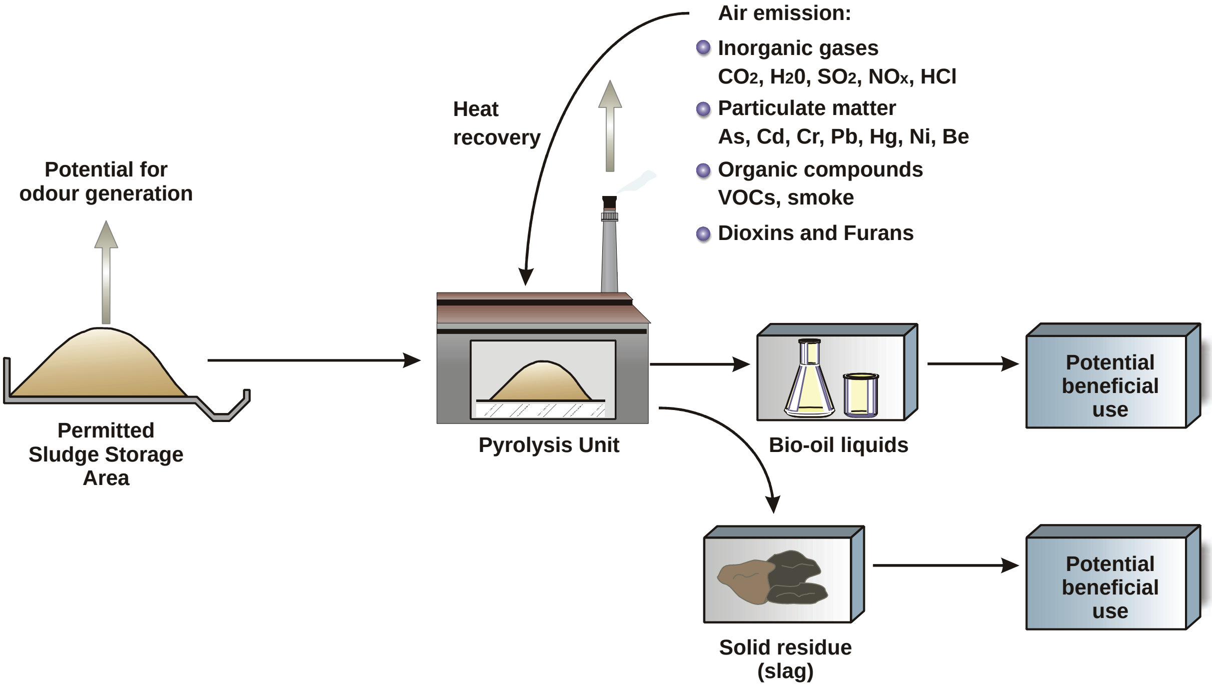
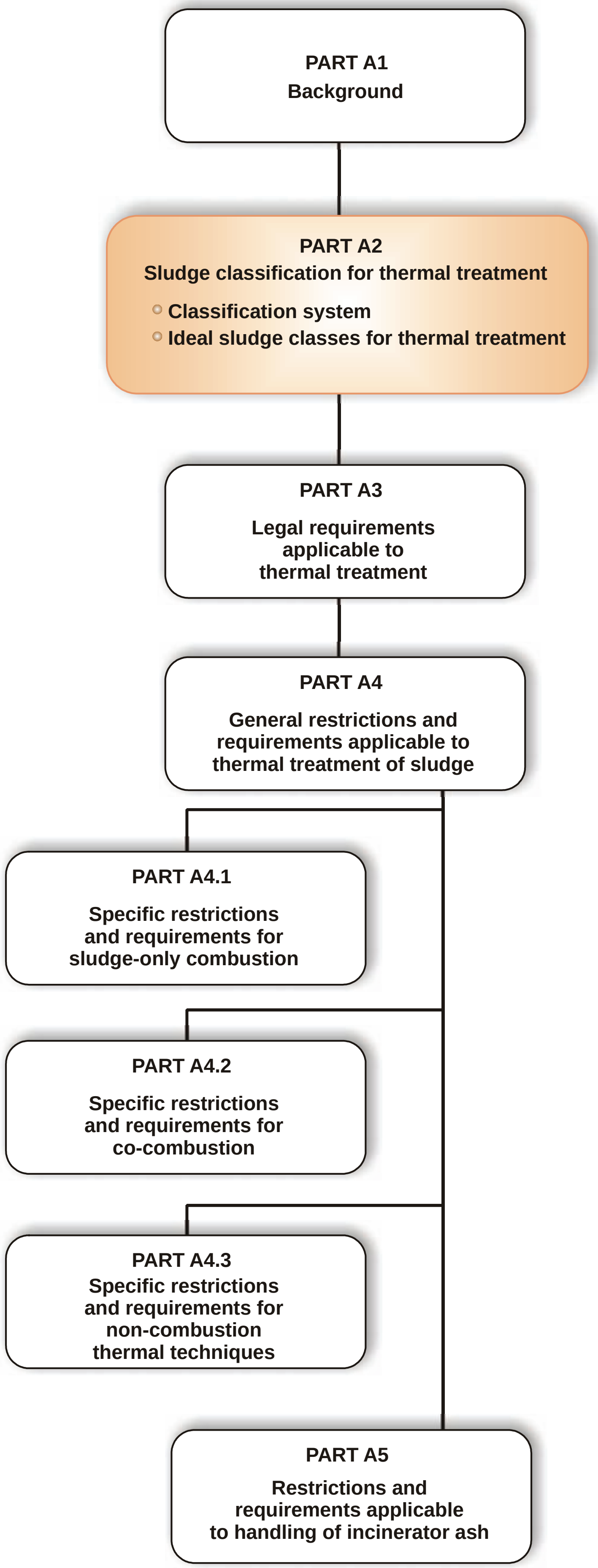


Figure 3: Schematic presentation of pyrolysis process

SECTION A: THERMAL TREATMENT ROADMAP



PART A2:

SLUDGE CLASSIFICATION FOR THERMAL TREATMENT

Sludge classification is discussed in detail in Volume 1 of the Sludge Guidelines. It is not necessary to repeat the classification process, but the sludge producer/user should confirm that the sludge class is suitable for thermal treatment. Therefore, the classification system is repeated here for guidance purposes only.

CLASSIFICATION SYSTEM

The preliminary analytical data of sludge samples as classified in terms of Volume 1 of the Sludge Guidelines can be used (Table 1). It is not necessary to reclassify the sludge unless the characteristics of the wastewater have changed.

TABLE 1: CLASSIFICATION SYSTEM FOR SLUDGE

Microbiological class	**A**	**B**	**C**
Stability class	**1**	**2**	**3**
Pollutant class	**a**	**b**	**c**

Ideal sludge classes favourable for thermal treatment

Not all sludge types are suitable for incineration. Table 2 shows the colour coded index that can be used to assess the appropriateness of thermal treatment as a management option based on the Microbiological class, Stability class and Pollutant class of a specific sludge as discussed in Volume 1 of the Sludge Guidelines. The potential for incineration based on sludge classification is presented in Table 3.

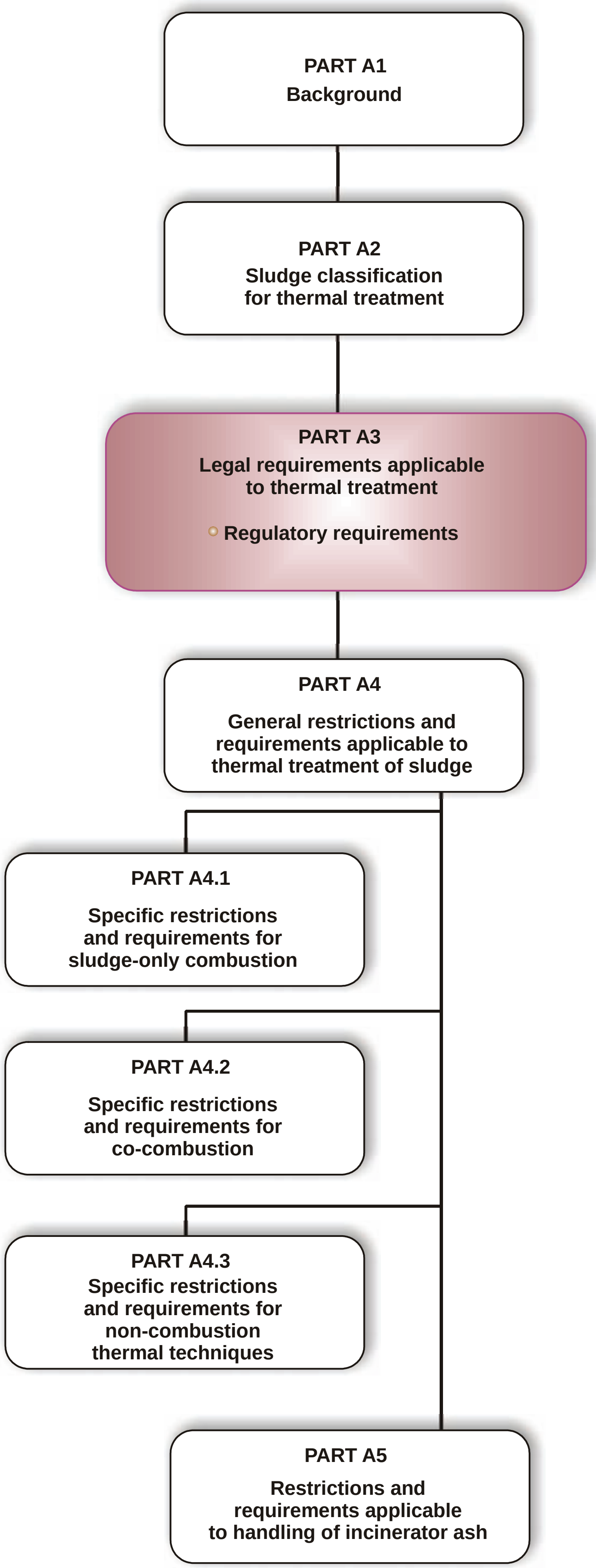
TABLE 2: COLOUR CODED INDEX TO ASSESS APPROPRIATENESS OF THERMAL TREATMENT FOR SLUDGE

(i)	Yes	Recognising that no management option can ever truly be applied without any restrictions, these options only have minor restrictions.
(ii)	Qualified yes	The restrictions that apply do not have major complications and can be managed using good management practices.
(iii)	Maybe	This can only be effectively applied under strict conditions and major management and cost implications apply.
(iv)	Qualified no	Only under unique conditions can this management option be applied for this class of sludge
(v)	No	This management option should not be considered for this class of sludge.

TABLE 3: POTENTIAL FOR THERMAL TREATMENT BASED ON SLUDGE QUALITY

South African Sludge Classification		Is thermal treatment an option?	Notes
Microbiological Class	A	No (v)	Costly to achieve, could be used as a commercial product without thermal treatment
	B	Qualified no (iv)	Costly to achieve, could be used beneficially without thermal treatment, restrictions will apply
	C	Yes (i)	Appropriate technology for this Microbiological class
Stability Class	1	Maybe (iii)	A dewatering step should be applied as pre-treatment before incineration
	2	Qualified yes (ii)	A dewatering step should be applied as pre-treatment before incineration
	3	Yes (i)	Ensure that options used are reliable to prevent odours or other nuisances
Pollutant Class	a	Yes (i)	Will have limited environmental impacts with respect to metals
	b	Qualified yes (ii)	Emissions of gaseous contaminants and the ash should be monitored as managed
	c	Qualified yes (ii)	Emissions of gaseous contaminants and the ash should be monitored as managed

SECTION A: THERMAL TREATMENT ROADMAP



PART A3:

LEGAL REQUIREMENTS FOR THERMAL TREATMENT

The Department of Environmental Affairs and Tourism (DEAT), Directorate: Air Pollution Control developed a set of guidelines for the 72 Scheduled Processes which are included in the Atmospheric Pollution Prevention Act (APPA) (Act No. 45 of 1965, Second Schedule). In terms of this regulation, sludge incineration is classified as Class 2A: Incinerators for the disposal of waste that contains hazardous or potentially hazardous waste. The APPA of 1965 has subsequently (September 2005) been replaced by National Environmental Management Air Quality Act (NEM-AQA) (Act No. 39 of 2004) with the exclusion of a few sections including the air emission limits. The aim of NEM-AQA is to reform the law regulating air quality in order to protect and enhance the quality of air in South Africa, taking into account the need for sustainable development, to provide for national norms and standards regulating air quality monitoring, management and control by all spheres of government, for specific air quality measures and for matters incidental thereto.

The DEAT is the lead authority in terms of the implementation of the NEM-AQA. However, regulation of activities such as combustion has been delegated to provincial and local government level. Thus the licensing authority is the metropolitan or district municipality or a provincial organ of state where this function has been delegated. Air quality is no the only aspect related to incineration with legal requirements. These aspects include:

- Sludge handling and storage area – sludge may only be present at these areas for short periods at a time, but on a continuous basis. Therefore, in effect these areas are considered disposal areas and must have the applicable permits according to the Environmental Conservation Act
- Ash handling – the residual of incineration is ash. The ash may have elevated concentrations of metals, depending on the quality of the sludge that was incinerated, and should be considered as hazardous waste until proven otherwise.

REGULATORY REQUIREMENTS

The regulatory requirements applicable to thermal treatment of sludge and ash handling is presented in

Table 4.

The following legal requirements for thermal treatment will be expected as a minimum:

- The producer must have a legal contract with the user if the sludge is incinerated by a third party
- For thermal treatment

  The producer/user must comply with Volume 5 of the Sludge Guidelines

  The producer/user must have an Air Pollution Certificate
- Sludge handling and storage

  The producer/user must comply with Volume 5 of the Sludge Guidelines

  The producer/user must have a Disposal site Permit

- For ash handling

  Ash disposal – The producer/user must comply with the Minimum Requirements Waste Management Series (Latest edition)

  Use of ash as raw material in commercial products – The producer/user must comply with Volume 5 Section B

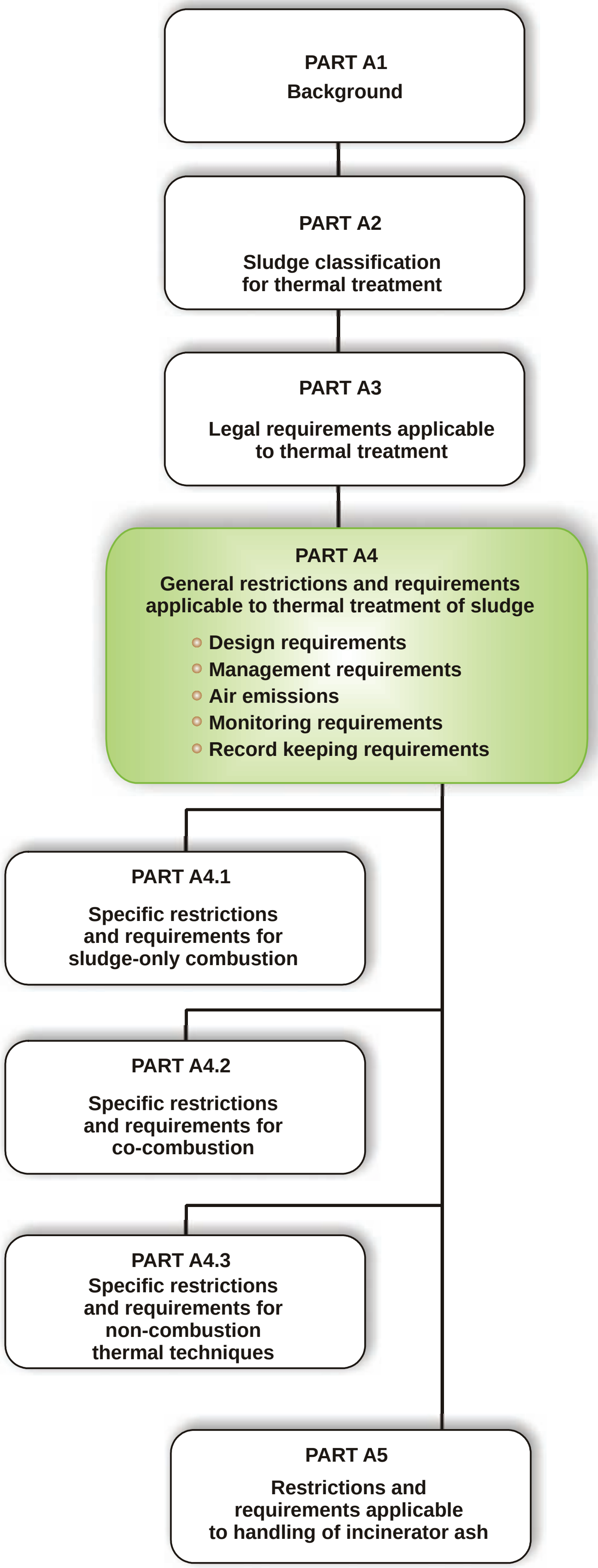
TABLE 4: REGULATORY REQUIREMENTS APPLICABLE TO INCINERATION

	Air quality	Sludge storage area	Ash handling
Applicable Act Governing Practice	Atmospheric Pollution Prevention Act (APPA) (Act No. 45 of 1965, Second Schedule). National Environmental Management Air Quality Act (NEM-AQA) (Act No.39 of 2004)	Environmental Conservation Act (Act No. 73 of 1989) National Environmental Management: Waste Management Act	Environmental Conservation Act (Act No. 73 of 1989) National Environmental Management: Waste Management Act
Authorisation Required	Air Pollution Licence	Disposal site Authorisation (Section 20 permit or exemptions or directions)	Disposal site Permit (Facility bound)
Lead Authority	DEAT (or delegated organ of State, Provincial or Local municipality)	DEAT	DEAT
Regulatory Instrument	Air Pollution Registration Certificate	Disposal site Permit	Disposal site Permit
Regulatory Guidelines	Sludge guidelines (Volume 5) and/or Ambient Air Quality Guidelines and/or Minimum Requirements (Latest edition)		

Note: For existing incinerator plants the current APPA certificates will apply.

New incinerator plants will receive certificates under the new NEM-AQA.

SECTION A: THERMAL TREATMENT ROADMAP



PART A4:

GENERAL RESTRICTIONS AND REQUIREMENTS APPLICABLE TO THERMAL TREATMENT

Part A4 deals with the general restrictions and requirements for all incinerator plants where sludge is treated. It includes guidance on site design, management, air emissions and monitoring requirements.

DESIGN REQUIREMENTS

Important design requirements include site selection, the adherence to appropriate buffer zones and stack height of the incinerator.

Site selection

The incinerator plant should be sited in accordance with the relevant town planning scheme, the topography of the area and have to be compatible with the land-use in the neighbourhood. It should also be an optimum distance from the supplying WWTP. The following aspects should be considered in conjunction with the relevant planning and environmental legislation (e.g. district or municipal Air Quality Management Plan) when a site is selected:

- Careful examination of the proposed site with respect to sensitive receptors (hospitals, schools, etc.)
- Type of treatment plant and installation requirements
- Spatial development plan objectives and principles. Allowance should be made for the possibility of future expansion on a site when setting up initial separation distances, otherwise the expansion could be prevented by the lack of available buffers.
- Details of existing land uses in the vicinity. The compatibility of neighbouring industries themselves needs to also be considered, for example, food and beverage preparation premises would be incompatible. The reasons for incompatibility could often be highly individual, and need to be addressed on a case by case basis to ensure that sensible planning solutions are reached.

Buffer zones

The establishment of a separation distance between the incinerator and sensitive receptors should be viewed as a distance which would protect sensitive receptors from the impact of non-routine and upset emissions, or air emissions following accidental spills or fires.

The recommended buffer zone for incinerators is 350 m, as measured from the site boundary to the nearest sensitive land use.

Note: Where the buffer zone is less than 350 m, the plant owner/operator must be able to demonstrate why the shorter distance would be appropriate.

The advice of the relevant air pollution authority should be obtained if site specific circumstances (e.g. local topography, state of the art technology, etc.) indicate a reason for relaxation of the recommended buffer zone.

Combustion Chambers

- The primary combustion chamber shall be accepted as the primary combustion zone and should be equipped with a burner/s burning gas or low sulphur liquid fuel. Other combustion methods will be judged on merits. Primary air supply is to be controlled efficiently.
- The secondary combustion chamber shall be accepted as the secondary combustion zone and should be fitted with a secondary burner/s burning gas or low sulphur liquid fuel or any suitable fuel. Secondary air supply is to be controlled efficiently. Flame contact with all the gases should be achieved.
- The residence time in the secondary chamber should be > 2 seconds.
- The gas temperature as measured against the inside wall in the secondary chamber, not in the flame zone, should be > 850°C.
- The oxygen contents of the emitted gases should be > 11%.
- Both the primary and the secondary temperatures should be maintained until all the waste has been completely combusted.

Stack height

- The chimney should have a minimum height of 9 m above ground level and clear the highest point of the building by not less than 6 m for flat roofs or 3 m for pitched roofs. The topography and height of adjacent buildings (i.e. closer than 5 times chimney height) should be taken into account.
- The addition of dilution air after combustion in order to achieve the requirements of emission limits is unacceptable.
- The minimum exit velocity should be 10 m/s.
- The stack shall be insulated to maintain the maximum outlet temperature.
- Point for the measurement of emissions should be provided.

MANAGEMENT REQUIREMENTS

The management of sludge incinerators include:

- Monitoring instrument operation and maintenance;
- Temperature requirements;
- Efficient operation of air pollution control devices; and
- Prevent or limit negative effects on the environment and the risks to human health.

Feeding

The following feeding requirements are applicable to incinerators:

- Controlled, hygienic mechanical or automatic feeding methods which will not negatively influence the air supply and temperature in the primary and secondary chambers of the incinerator, have to be used.
- No waste is to be fed into the incinerator under the following circumstances:

  at start up and until the minimum combustion temperatures have been reached,

  whenever the minimum combustion temperatures are not maintained,

  whenever the previous charge has not been completely combusted in the case of a batch loader,

  until such time as the addition of more waste will not cause the design parameters of the incinerator to be exceeded.

Minimum solids content

Ideally, sludge considered for thermal treatment must have a low moisture content which would allow less energy input or recovery of energy in a form of steam (boilers) or electricity (generators). Sludge of up to 80% moisture can potentially be incinerated, but this would require the addition of energy. For example, the incineration of raw sludge at 850°C would theoretically require about 8.9 $MJ/kg_{dry\ solids}$ energy input, assuming 40% excess air. Similarly, for digested sludge the theoretically energy requirement would be about 14.9 $MJ/kg_{dry\ solids}$. The energy required for other moisture levels of sludge (raw sludge and digested sludge) is shown in Figure 4. From the figure it can be seen that the energy balance (no external heat required) for digested sludge would be at about 38% moisture. For raw sludge, this point is at about 66% moisture.

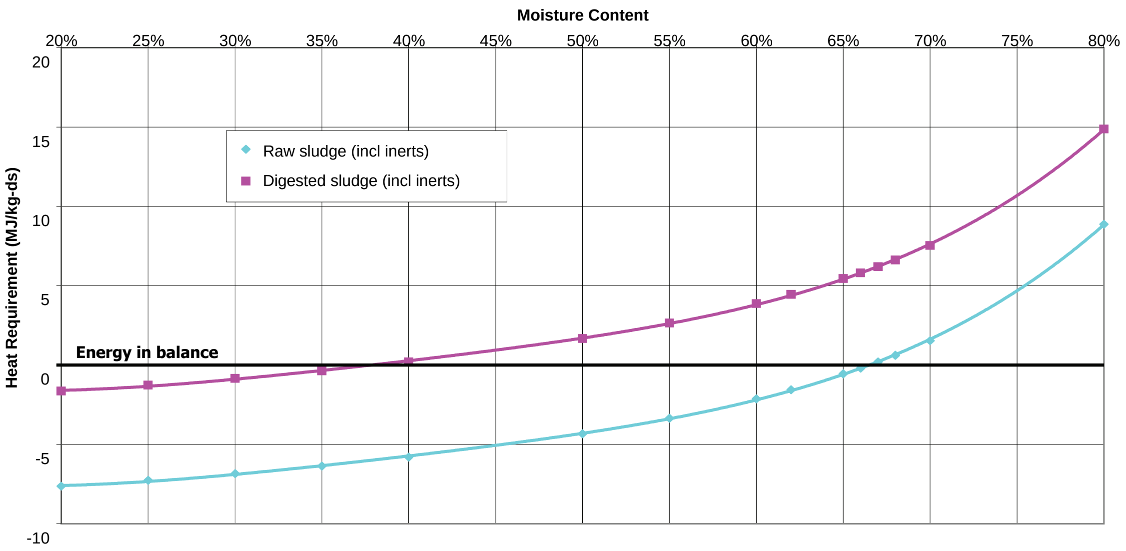


Figure 4: Calculated external heat demand for incinerators based on moisture content of raw sludge and digested sludge

Performance

A 99.99% destruction and removal efficiency (DRE) for each principle organic hazardous constituent (POHC) in the waste feed should be achieved. The DRE can be calculated as follows:

$$DRE = [(W_{in} - W_{out})/W_{in}] \times 100$$

Where:

W_{in} = mass feed rate of the POHC in the waste stream fed to the incinerator, and

W_{out} = mass emission rate of POHC in the stack prior to the release to the atmosphere

Operation

- Sludge may only be incinerated in a furnace that is registered for this purpose
- The incinerator should be preheated to working temperature before sludge is fed to the incinerator
- Overloading of the incinerator should be avoided at all times
- The incinerator should be kept in good working order at all times and should not be used if any component fails. Any malfunction should be recorded in a log book and reported to the relevant authority
- The incinerator operator and all relevant staff should be trained to the satisfaction of the relevant control authority
- A list should be displayed at or near the control panel which identifies all trained operators
- The incinerator and its surrounds should be kept in a clean and neat condition at all times
- In cases where noxious or offensive gases are emitted that cannot be destroyed by secondary combustion, additional control equipment, e.g. scrubbers, bag-filters or electrostatic precipitators will be required.

Temperature Requirements

Combustion conditions must be maintained at the temperatures during which performance testing was conducted. Temperatures in excess of this may result in increased metal emissions form the stack. The sludge must be maintained at a temperature of 850 °C for two (2) seconds (as measured near the inner wall or at another representative point of the combustion chamber).

Furthermore, each line of the incineration plant shall be equipped with at least one auxiliary burner. This burner must be switched on automatically when the temperature of the combustion gases after the last injection of combustion air falls below 850 °C. It shall also be used during plant start-up and shut-down operations in order to ensure that the temperature is maintained at all times during these operations and as long as unburned sludge is in the combustion chamber.

AIR EMISSIONS

The emission of air pollutants during thermal treatment is inevitable. The extent of its impact (health and odour) can be minimised and controlled with a well-designed and properly operated process. Different air pollutants would be generated depending on the thermal treatment technology, i.e. whether the process is oxidising (e.g. combustion and wet air oxidation) or starved air (e.g. pyrolysis and partial pyrolysis). Although the gaseous products from pyrolysis differ from those produced in an incinerator, these gases are often also combusted in afterburners or boilers, and hence producing similar air pollutants. The pollutants generated can be grouped into:

- Inorganic gases – During the combustion process, oxygen reacts with carbon, hydrogen, sulphur, nitrogen and halides to form combustion products such as carbon dioxide (CO_2), water (H_2O), sulphur dioxide (SO_2), oxides of nitrogen (NO_x) and acid gases (e.g. HCl).
- Particulate matter – A fraction of the sludge ash and heavy metals present in the sludge feed will elutriate into the gas stream. An increase in furnace temperature will result in increasing releases of heavy metals. The heavy metals of greatest concern in the sludge incineration process are arsenic, cadmium, chromium, lead, mercury and nickel.
- Organic compounds – Volatile organic compounds (VOCs) are undesirable in furnace off-gas. These gases are visible, generate smoke, can be toxic and could result in odours.

Sludge quality limitations

The following general risk-based equation can be used for determining the pollutant limits for sludge destined for complete combustion and co-combustion:

$$C = CRSC \times \frac{86400}{DF \times (1 - CE) \times SF}$$

Where:

C = The pollutant limit (allowable daily concentration of As, Be, Cd, Cr, Pb, Hg or Ni in sludge, in mg/kg of total solids, dry-weight basis)

CRSC = Chronic Risk Specific Concentration of a pollutant [(the allowable increase in the annual average ground-level ambient air concentration for a pollutant at or beyond the property line of the site in µg/m³ (see Table 5)]

DF = Dispersion Factor (in µg/m³/g/s, based on an annual average air dispersion model) (see Figure 5)

CE = Sewage sludge incinerator control efficiency for As, Be, Cd, Cr, Pb, Hg or Ni (in hundredths, based on a performance test) (see Table 6))

SF = Sludge feed rate (in ton_{dry}/day)

86 400 = Time conversion factor (number of seconds per day)

Application of the equation requires the Chronic Risk Specific Concentration (CRSC; Table 5), the dispersion factor (Figure 5) and a control efficiency (estimates from Table 6).

Note: This equation does not apply to non-combustion techniques.

Example 1:

If the fence line is 100 m from the incinerator and the stack is 10 m, then from Figure 5, the DF = 9.7 µg/m³/g/sec. **Note the maximum DF is beyond 100 m and therefore this value needs to be used.** If the maximum occurred before 100 m, then the value at 100 m could have been used.

For arsenic the CRSC = 0.007

The air pollution control is a fabric filter, CE = 0.95 (95%)

And the sewage sludge feed rate is 20 ton_{dry}/day

Then: $$C_{arsenic} = \frac{0.007\mu g/m^3 \times 86400}{9.7(\mu g/m^3/g/s)\times(1-0.95)\times 20\,dmt/day}$$

$$C_{arsenic} = 63\,mg/kg$$

If the fence line was at 350 m, the dispersion factor would have been 4.6 µg/m³/g/s and the allowable concentration for arsenic would be 132 mg/kg.

TABLE 5: CHRONIC RISK SPECIFIC CONCENTRATIONS FOR SELECTED ELEMENTS

Pollutant	Chronic Risk Specific Concentrations (CRSC) (μg/m³)
Arsenic (As)	0.007
Beryllium (Be)	0.042
Cadmium (Cd)	0.006
Chromium (Cr)	0.002/*R**
Lead (Pb)	1.19
Mercury (Hg)	1.0
Nickel (Ni)	0.26

* *R* = fraction of hexavalent chromium in total chromium emission.

An air pollution control device is a mechanism or piece of equipment used to clean the emissions generated by an incinerator by removing pollutants that would otherwise have been released into the atmosphere. A number of Air Pollution Control (APC) devices are available to collect the range of pollutants emitted from incinerators. The effectiveness of these devices is characterised as control efficiency, i.e. the % of the uncontrolled emission which is collected. Table 6 indicates the control efficiencies of the most popular APC used in South Africa (Fabric filters, ESP and venturi scrubbers) in terms of selected pollutants.

TABLE 6: AIR POLLUTION CONTROL (APC) DEVICE EFFICIENCIES

Pollutant	Air Pollution Control (APC) device	Control Efficiency (CE) %
Chromium, Nickel, Beryllium, Copper, Lead	Fabric filter	95
	Electrostatic precipitator (ESP)	90
	Venturi quench/Venturi scrubber	90
Cadmium	Fabric filter	92
	Electrostatic precipitator (ESP)	88
	Venturi quench/Venturi scrubber	88
Arsenic, Mercury, Magnesium oxide	Fabric filter	30
	Electrostatic precipitator (ESP)	25
	Venturi quench/Venturi scrubber	50
Polychlorinated Dioxins & Furans	Fabric filter	50
	Venturi quench/Venturi scrubber	50

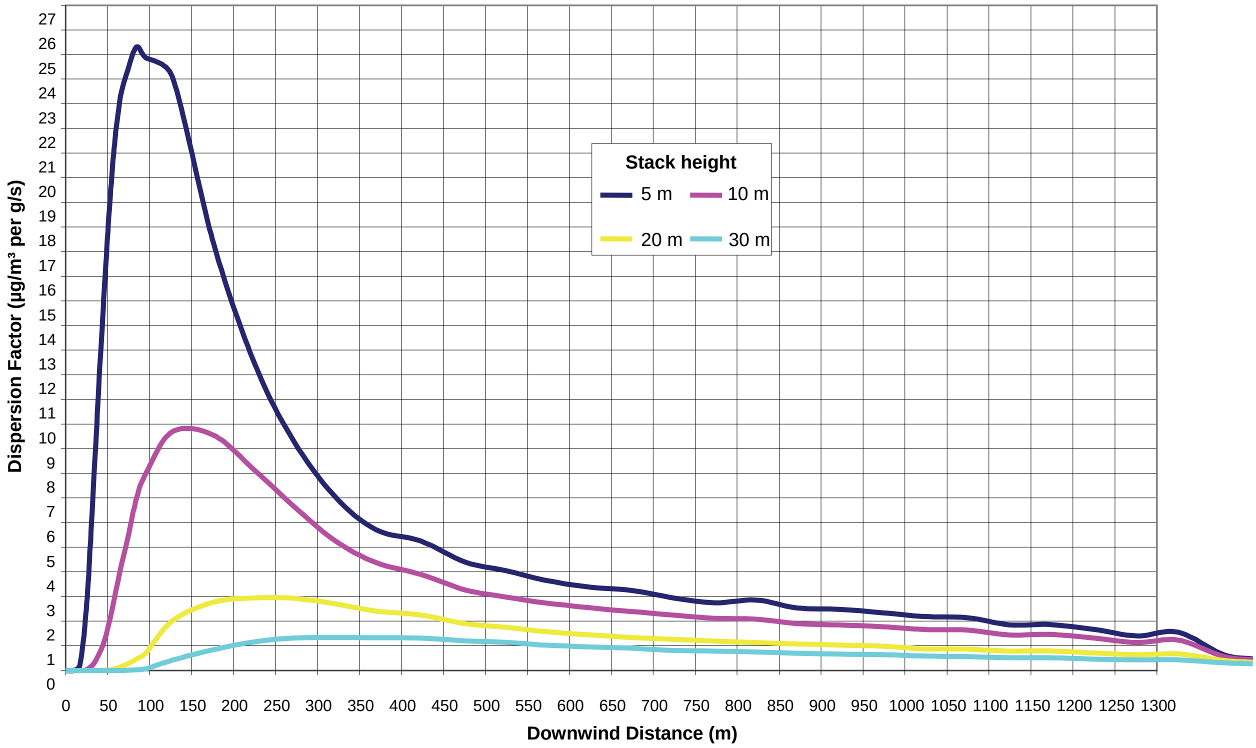


Figure 5: Annual average dispersion factors (DF) at various downwind distances and for different release heights.

The methodology for chromium is slightly different since it is necessary to determine the hexavalent (Cr(VI)) fraction of the chromium emission (Table 7). These fractions can be used in Table 5 to substitute *R* when the chromium content in sludge is calculated.

TABLE 7: HEXAVALENT CHROMIUM FRACTIONS ASSOCIATED WITH INCINERATOR EMISSIONS

Type of incinerator	Risk Specific Concentrations (RSC) (μg/m³)
Fluidized bed with wet scrubber	0.013
Fluidized bed with wet scrubber and wet electrostatic precipitator	0.037
Other types with wet scrubber	0.133
Other types with wet scrubber and wet electrostatic precipitator	0.531

Example 2

For the same site as described in Example 1 the following will apply for the Cr concentration:

The fraction of Cr(VI) (*R*) in the total Cr emission of the site is 5% (0.05)

The CRSC for Cr(VI) = 0.002 / 0.05

The air pollution control is a fabric filter, CE = 0.95 (95%)

And the sewage sludge feed rate is 20 ton_{dry}/day

Then: $$C_{totalCr} = \frac{0.04\mu g/m^3 \times 86400}{9.7(\mu g/m^3/g/s)\times(1-0.95)\times 20\,dmt/day}$$

$$C_{totalCr} = 356\,mg/kg$$

Emission guidelines

The air emission guidelines depend on the type of thermal treatment technology (Figure 6). If the incineration involves total combustion of sludge, producing combustion products like carbon dioxide, water, sulphur dioxide and oxides of nitrogen, the emission guidelines are risk-based. Emission guidelines for non-combustion thermal techniques and co-combustion of sludge with other waste are based on emission standards only.

MONITORING REQUIREMENTS

Monitoring requirements include the substances to be measured, the frequency at which they should be measured and reported, the methods to be used, compliance criteria, calibration methods and the standards to be used.

It is required that the:

- Operator shows that the proposed measurement techniques for emissions to air will comply with the requirements of monitoring standards;
- Sampling and measurement procedures would satisfy the conditions imposed;
- Location of the sampling or measurement points must be laid down by the regulator; and

- Calibration of continuous monitoring equipment and the periodic measurements of the emissions into the air must be carried out representatively and according to applicable standards.

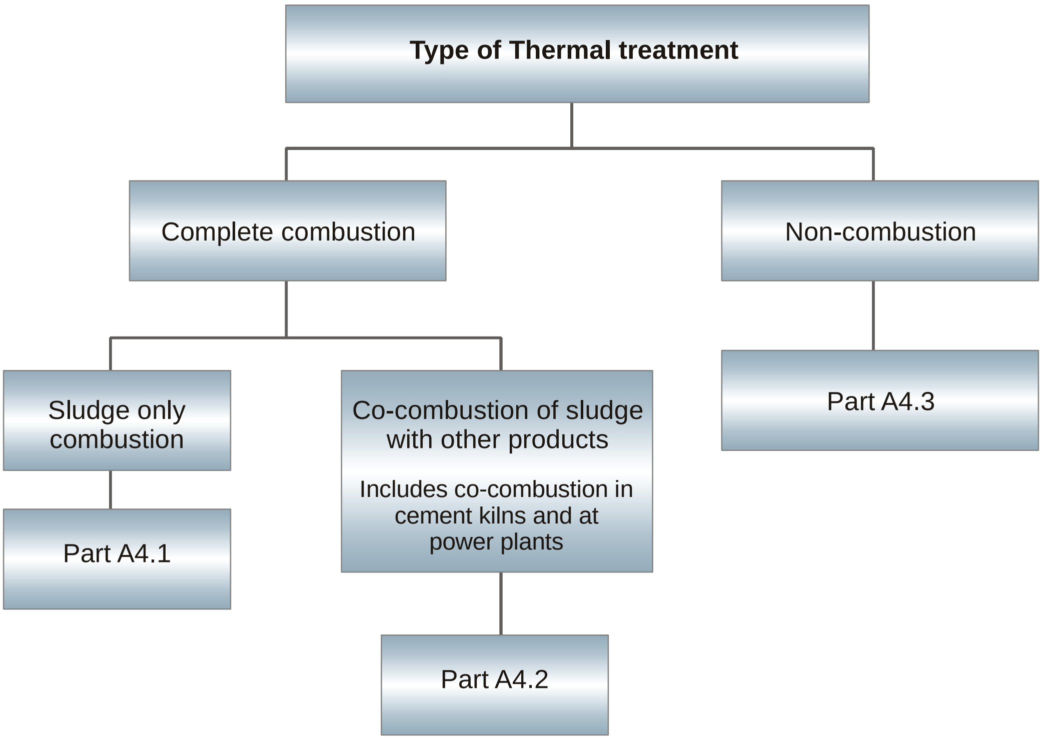


Figure 6: Flow chart to determine applicable air emission guidelines for respective thermal treatment options

Continuous monitoring and recording of the following must be done:

- Total hydrocarbon (THC) or carbon monoxide (CO) in the stack exit gas;
- Concentration of oxygen in the stack exit gas;
- Pressure;
- Temperature near the inner wall or at another representative point of the combustion chamber as authorised by the regulator; and
- Water vapour content of the exhaust gas. The continuous measurement of water vapour is not required if the sampled flue gas is dried before the emissions are analysed.

Frequency of Monitoring

The frequency of monitoring will depend on the type of thermal treatment technology applied and is discussed in Parts A4.1-A4.3.

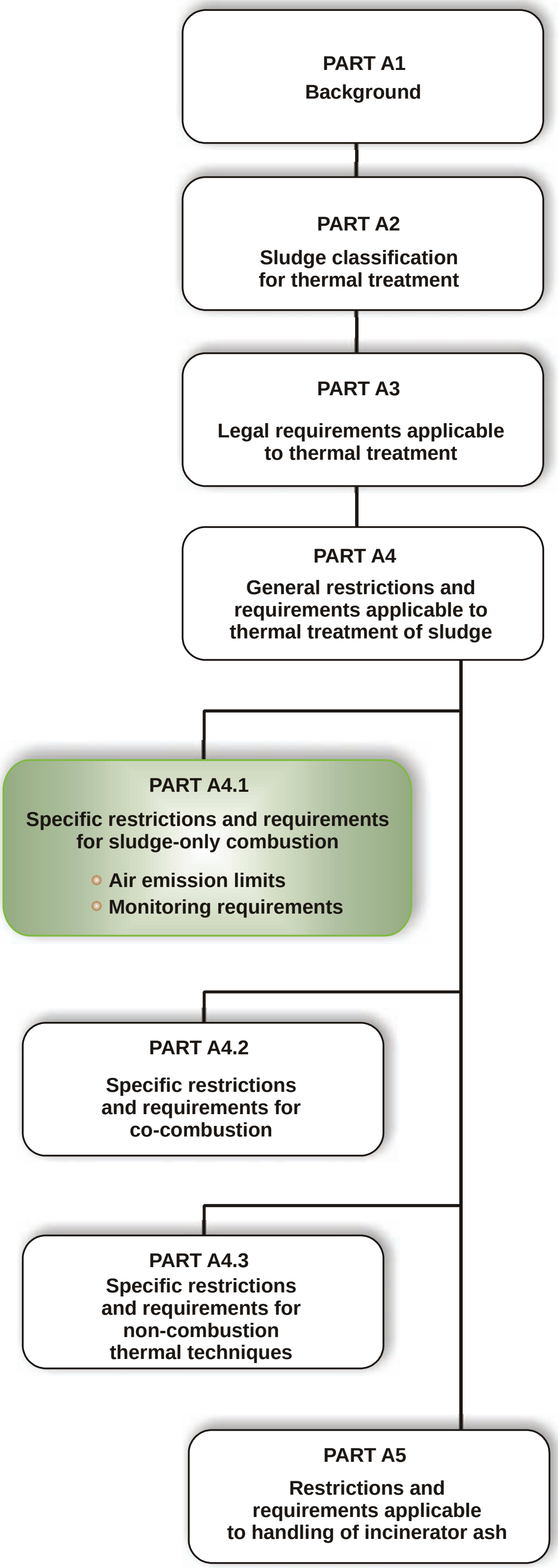
RECORD KEEPING REQUIREMENTS

The record keeping requirements for thermal sludge treatment is presented in Table 8.

TABLE 8: RECORD KEEPING REQUIREMENTS FOR THERMAL TREATMENT OF SLUDGE

	Description of records to be kept by the sludge user
1	Copies of the applicable permits and/or licences
2	The original or certified copy of the contract between the sludge producer and the sludge user (if applicable)
3	Information showing that emission requirements for beryllium (Be) and mercury (Hg) are being met, if applicable
4	Sludge feed rate
5	Stack height
6	Dispersion factor
7	Control efficiency for As, Cd, Cr, Pb and Ni (for each incinerator)
8	Risk specific concentrations (RSC) for chromium, if applicable
9	Total hydrocarbon (THC) or carbon monoxide (CO) monthly average concentrations in the stack exit gas
10	Oxygen concentration in the stack exit gas
11	Water vapour content of the exhaust gas
12	Combustion temperatures, including maximum daily combustion temperature, in the furnace
13	Measurements for required air pollution control device operating conditions

SECTION A: THERMAL TREATMENT ROADMAP



PART A4.1:

SPECIFIC RESTRICTIONS AND REQUIREMENTS FOR SLUDGE-ONLY COMBUSTION

International research identified As, Be, Cd, Cr, Pb, Hg and Ni as the most significant heavy metals to monitor when considering sludge incineration. It is therefore suggested that for all thermal treatment plants in which only sludge is treated, only these heavy metals need regular monitoring, either of the sludge content or of the flue gas emission monitoring (using emission limits). Regular dioxin and furan measurements are not a requirement for sludge only incinerators.

AIR POLLUTION EMISSION LIMITS

Monitoring of flue gas emissions can also be used to ensure that air quality will not be affected negatively by sludge incineration. The proposed Emission Limits are presented in Table 9. Additionally, the following requirements also apply:

- Total particulate emission should not exceed 180 mg/m^3 at 11% O_2, 0% moisture and 101.3 kPa;
- Opacity of the smoke should not exceed 20%;
- All emissions to air other than steam or water vapour should be odourless and free from mist, fume and droplets; and
- Any substance that the Authorities may consider necessary, e.g. polycyclic hydrocarbons, benzene, etc. should also be monitored.

TABLE 9: EMISSION LIMITS FOR SLUDGE ONLY INCINERATORS

Pollutant	Emission Limits (mg/m^3)
Total dust	10
Total organic carbon	10
HCl	10
HF	1
SO_2	50
NO and NO_2 expressed as NO_2 for existing incineration plants with a nominal capacity exceeding 6 t/h or new incineration plants	200
NO and NO_2 expressed as NO_2 for existing incineration plants with a nominal capacity of 6 t/h or less	400
Cd, Tl Hg (each)	0.05
Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V, Be, Ba, Ag, Sn (each)	0.5

MONITORING FREQUENCY

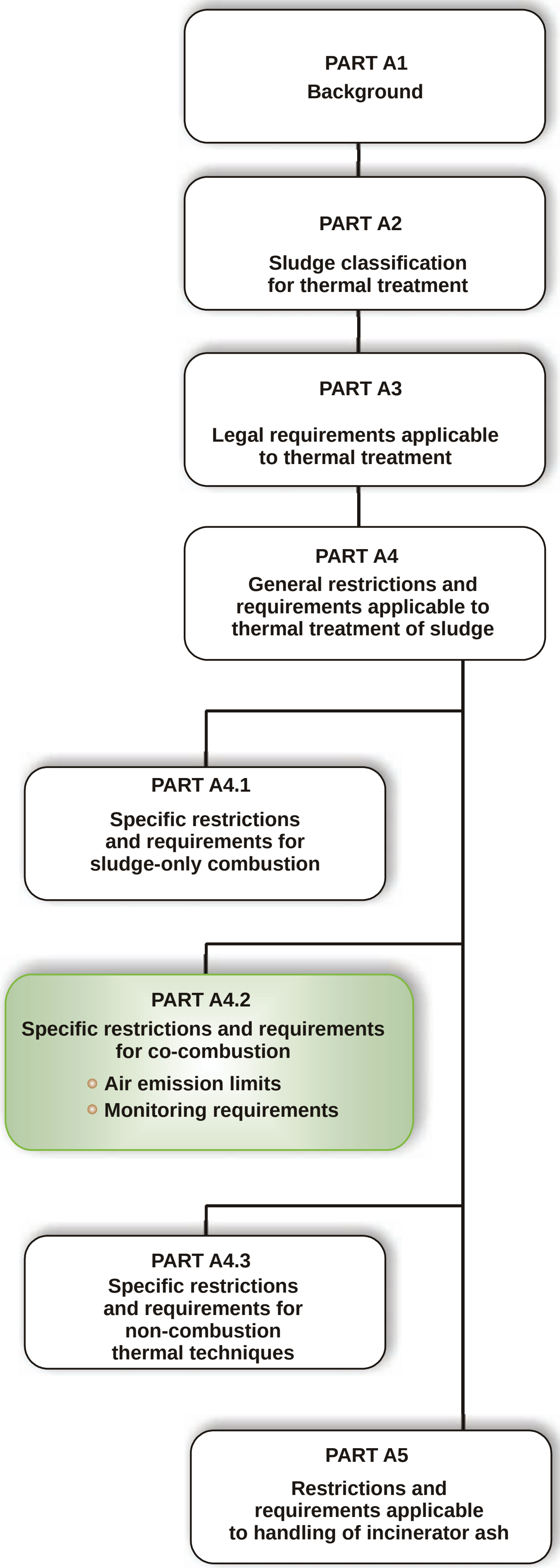
The minimum frequency of monitoring for management and operational aspects of sludge-only thermal treatment plants is given in Table 10.

PART A4.1: SPECIFIC RESTRICTIONS AND REQUIREMENTS: SLUDGE-ONLY COMBUSTION

TABLE 10: MONITORING FREQUENCY FOR SLUDGE-ONLY INCINERATORS

Sludge monitoring (pollutant concentration)	Amount of sewage sludge, fired (ton$_{dry}$/year)		Monitoring frequency
	Daily average	Yearly average	
As, Be, Cd, Cr, Pb, Hg and Ni concentrations	<5	<1 825	4 times per year
	5 - 45	1 826 - 16 500	6 times per year
	>45	>16 500	Monthly
Stack exit gas	**Monitoring Frequency**		
THC (or CO) concentration	Continuously, monthly averages reported, which is the arithmetic mean of hourly averages that include at least 2 readings per hour		
Oxygen concentration	Continuously		
Information needed to determine moisture content	Continuously		
Operational monitoring	**Monitoring Frequency**		
Combustion temperature in furnace	Continuously		
Air pollution control device conditions	As often as permitting authority requires		

SECTION A: THERMAL TREATMENT ROADMAP



PART A4.2:

SPECIFIC RESTRICTIONS AND REQUIREMENTS FOR CO- COMBUSTION

For thermal treatment options other than purely sludge combustion, which include co-combustion or conversion of combined wastes, stringent emission limits must be followed to protect the receiving environment.

AIR EMISSION LIMITS FOR CO-COMBUSTION THERMAL TREATMENT

Total air emission limits for pollutants of co-combustion treatment processes are presented in Table 11. Dioxins and furans form either in the incinerator through reactions of hydrocarbons and chlorine or in the waste heat boiler and controls through reactions of hydrocarbons, chlorine and particulate matter in the temperature range between 250-450^{o}C. Due to the potential presence of Cl in the co-combustion products, dioxins and furans may be formed during combustion and have to be monitored.

TABLE 11: TOTAL EMISSION LIMIT VALUES APPLICABLE TO CO-COMBUSTION OF SLUDGE WITH OTHER WASTE

Pollutant	Emission Limits (mg/m^3)
Total dust	30
HCl	10
HF	1
NO_x	500-800
SO_2	50
TOC	10
Sum of Cd, Hg, Tl	0.05
Sum of Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V	0.5

Measurement results to be standardised at: Temp 273K, pressure 101.3kPa, 10% oxygen, dry gas)

Dioxins and furans

Dioxins and furans*	0.1 ng/m^3 TEQ

* for determination of total concentrations of dioxins and furans the mass concentrations of individual elements should be multiplied by the toxic equivalence factors (TEQ) below before summation:

Dioxins	TEQ	Furans	TEQ
2,3,7,8 - Tetrachlorodibenzodioxin (TCDD)	1	2,3,7,8 - Tetrachlorodibenzofuran (TCDF)	0.1
1,2,3,7,8 - Pentachlorodibenzodioxin (PeCDD)	0.5	2,3,4,7,8 - Pentachlorodibenzofuran (PeCDF)	0.5
1,2,3,4,7,8 - Hexachlorodibenzodioxin (HxCDD)	0.1	1,2,3,7,8 - Pentachlorodibenzofuran (PeCDF)	0.05
1,2,3,6,7,8 - Hexachlorodibenzodioxin (HxCDD)	0.1	1,2,3,4,7,8 - Hexachlorodibenzofuran (HxCDF)	0.1
1,2,3,7,8,9 - Hexachlorodibenzodioxin (HxCDD)	0.1	1,2,3,6,7,8 - Hexachlorodibenzofuran (HxCDF)	0.1
1,2,3,4,6,7,8 - Heptachlorodibenzodioxin (HpCDD)	0.01	1,2,3,7,8,9 - Hexachlorodibenzofuran (HxCDF)	0.1
- Octachlorodibenzodioxin (OCDD)	0.001	2,3,4,6,7,8 - Hexachlorodibenzofuran (HxCDF)	0.1
		1,2,3,4,6,7,8 - Heptachlorodibenzofuran (HpCDF)	0.01
		1,2,3,4,7,8,9 - Heptachlorodibenzofuran (HpCDF)	0.01
		- Octachlorodibenzofuran (OCDF)	0.001

Note: The analyses of dioxins and furans are expensive and can only be determined by a limited number of laboratories in South Africa.

PART A4.2: SPECIFIC RESTRICTIONS AND REQUIREMENTS: CO-COMBUSTION

MONITORING REQUIREMENTS FOR CO-COMBUSTION

The following monitoring measurements of air pollutants are applicable to co-combustion plants:

- continuous measurements of NOx, CO, total dust, TOC, HCl, HF and SO_2;
- continuous measurements of the following process operation parameters:

  temperature near the inner wall or at another representative point of the combustion chamber,

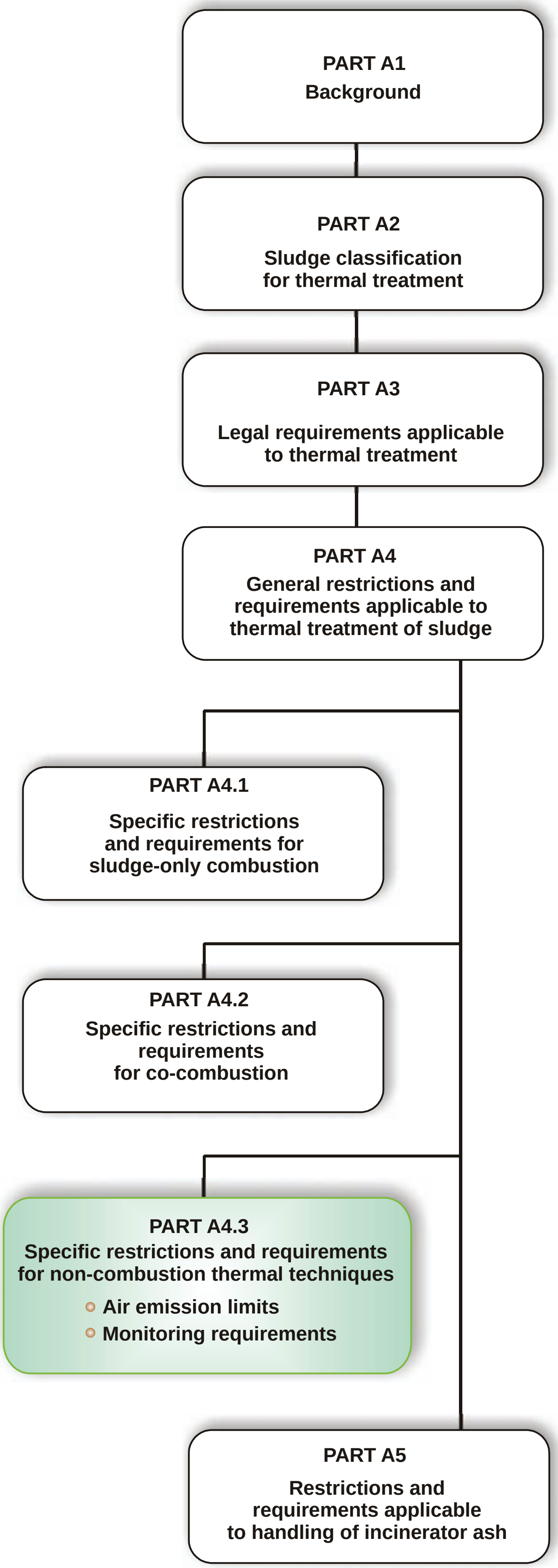
  concentration of oxygen,

  pressure,

  temperature and water vapour content of the exhaust gas;
- at least two measurements per year of heavy metals, dioxins and furans; one measurement at least every three months shall however be carried out for the first 12 months of operation.

Note: Monitoring frequency can be relaxed if the operator can prove that emissions of pollutants can under no circumstances exceed the prescribed emission limit values.

SECTION A: THERMAL TREATMENT ROADMAP



PART A4.3:

SPECIFIC RESTRICTIONS AND REQUIREMENTS FOR NON-COMBUSTION THERMAL TECHNIQUES

AIR EMISSION LIMITS FOR NON-COMBUSTION THERMAL TECHNIQUES

The average air emission limits for pollutants of non-combustion thermal treatment should be complied with (Table 12).

TABLE 12: AVERAGE EMISSION LIMITS FOR POLLUTANTS OF NON-COMBUSTION THERMAL TREATMENT TECHNIQUES

Pollutant	Emission Limits (mg/m^3)
Total dust	10
Total organic carbon	10
Sum of Cd and Hg	0.05
Sum of As, Cr, Pb, Mn, Ni, Be	0.5
Dioxins and Furans*	0.1 ng/m^3 TEQ
* to be calculated as explained in Section A4.2	

MONITORING REQUIREMENTS FOR NON-COMBUSTION

The following monitoring measurements of air pollutants are applicable to non-combustion thermal treatment plants:

- continuous measurements of NO_x, CO, total dust, TOC, HCl, HF and SO_2;
- continuous measurements of the following process operation parameters:

  temperature near the inner wall or at another representative point of the combustion chamber,

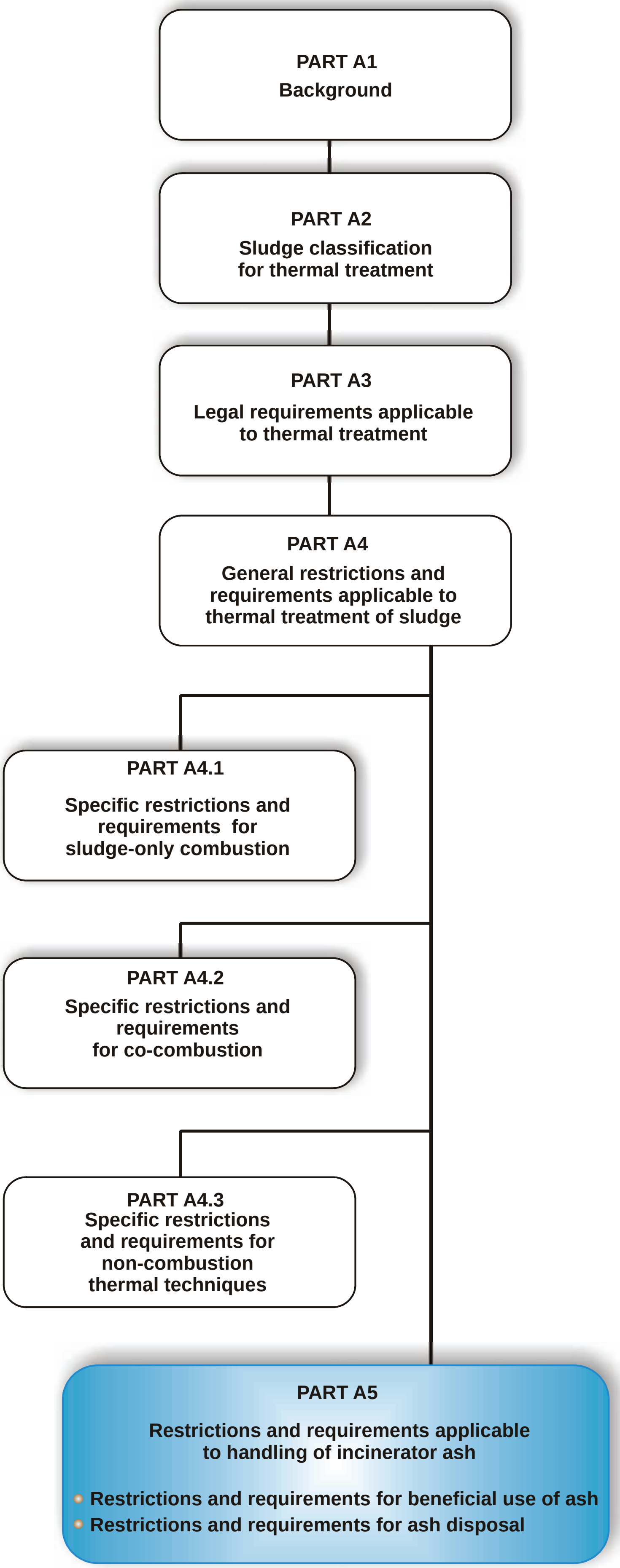
  concentration of oxygen,

  pressure,

  temperature and water vapour content of the exhaust gas;
- at least two measurements per year of heavy metals, dioxins and furans; one measurement at least every three months shall however be carried out for the first 12 months of operation.

Note: Monitoring frequency can be relaxed if the operator can prove that emissions of pollutants can under no circumstances exceed the prescribed emission limit values.

SECTION A: THERMAL TREATMENT ROADMAP



PART A5:

RESTRICTIONS AND REQUIREMENTS APPLICABLE TO HANDLING OF INCINERATOR ASH

Solid residues of sludge combustion are generally classified as *bottom ashes* or *fly ashes*.

- **Fly ash** is fine particulate ash sent up by the combustion of sludge. A small part of the ash is discharged as an airborne emission in the exit gas but the remainder is collected by the air pollution control (APC) device used at the treatment plant. These include electrostatic precipitators, fabric filters and scrubbers. Fly ash consists of inorganic, incombustible matter present in the sludge that has been fused during combustion into a glassy, amorphous structure. It may contain metals such as Pb, Cd, Cu and Zn as well as small amounts of dioxins and furans, depending on the type of combustion and the temperature of the operations. Since the particles solidify while suspended in the exhaust gases, fly ash particles are generally spherical in shape and range in size from 0.5 µm to 100 µm. They consist mostly of silicon dioxide (SiO_2), aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3). They are also pozzolanic in nature and react with calcium hydroxide and alkali to form cementatious compounds. Fly ash also contains certain heavy metals.

Figure 7: Fly ash recovered during sludge combustion

- **Bottom ash** is the non-airborne combustion residue of sludge combustion which falls to the bottom of the incinerator and is removed mechanically. It is a non-combustible, relatively coarse and generally toxic residue of incineration. Bottom ash can be utilised for the manufacture of bricks, as filling material in civil/road construction and as a component in cement production. Bottom ash mainly consists of insoluble silicates, phosphates, sulphates and refractory metal oxides, some of which may be soluble.

Figure 8: Bottom ash removed from the bottom of an incinerator (different particle sizes)

The collected fly and bottom ash can be sold for use in the cement/construction industry or disposed of on-site or on a suitable landfill.

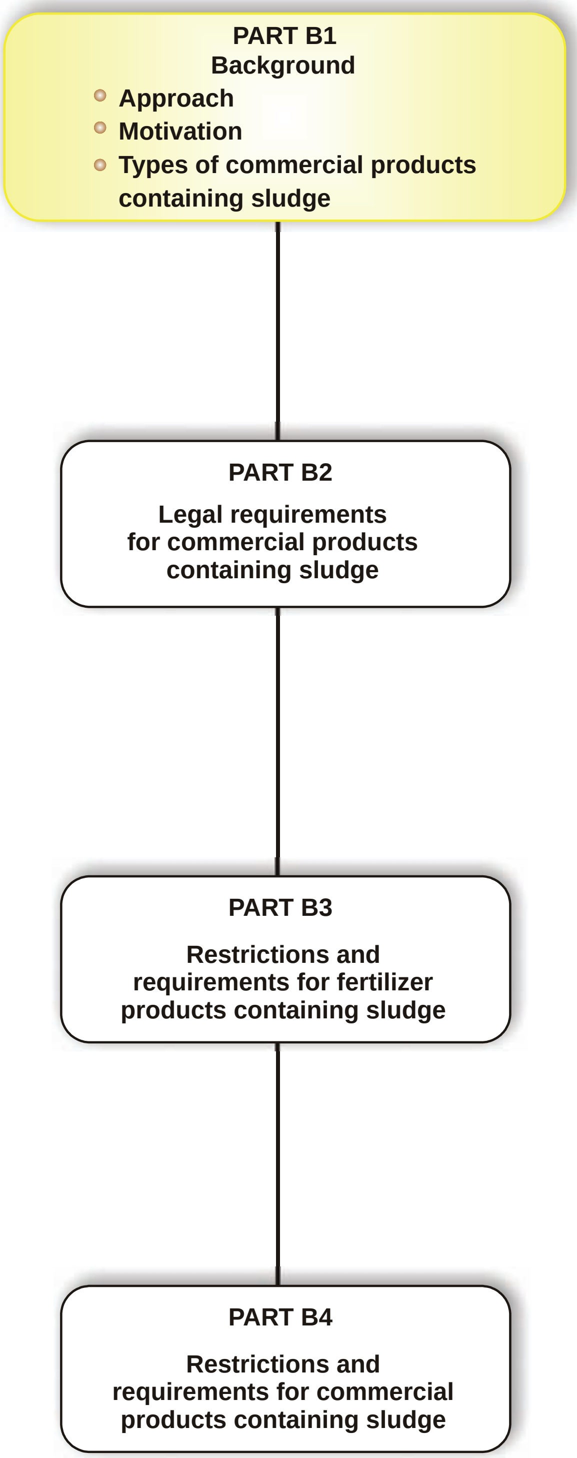
RESTRICTIONS AND REQUIREMENTS FOR BENEFICIAL USE OF ASH

If the ash is intended for beneficial use as a raw product in the production of commercial products, Section B of this document will apply.

RESTRICTIONS AND REQUIREMENTS FOR ASH DISPOSAL

When ash disposal is the management option chosen, the restrictions and requirements described in the Minimum Requirements (Latest edition) will apply. The ash will have to be analysed to determine its metal content which will in turn determine the applicable restrictions and requirements for disposal. These requirements may include delisting of the ash before it may be disposed on general landfill.

SECTION B: COMMERCIAL PRODUCTS ROADMAP



PART B1:

BACKGROUND

Section B of Volume 5 of the Guidelines was developed to promote the use of sludge in commercial products. It distinguishes between commercial products used as fertilizer (compost and pellets) and other commercial products primarily used in the construction business (cement, bricks, etc.). These guidelines deal specifically with technical and legislative aspects.

APPROACH FOLLOWED TO DEVELOP VOLUME 5 SECTION B

The Guidelines for incorporating sludge in commercial products is based on the following information:

- International research findings;
- Local legislative and guiding documents;
- International guidelines and legislative trends and;
- Minimum risk to the user.

The following constituents and properties of sludge have the potential to have negative effects on the use of sludge in commercial products:

- Pathogens – to protect the health of the general public, the final product should be a Microbiological class A;
- Odours – odours and vector attraction affect the public negatively (and could affect public health), therefore the stability of sludge is very important, especially when the final product is destined for use by the general public. The reduction of odours and vector attraction potential should be optimal and;
- Metals – to protect the receiving environment, the final product should be Pollutant class a in the case of commercial products used as fertilizer.

The conceptual thinking, development process and assumptions are presented in a document which is available from the WRC[1].

MOTIVATION FOR DEVELOPING GUIDELINES FOR USE OF SLUDGE IN COMMERCIAL PRODUCTS

The beneficial use of sludge is encouraged throughout the Sludge Guidelines to ensure sustainable sludge management and Volume 2 (Agricultural use), Volume 4 (Beneficial use) and Volume 5 (Commercial products) deal with these aspects. Sludge and fertilizer products containing sludge supply major plant nutrients as well as some essential micronutrients to plants. It can also improve soil physical properties such as water retention, soil water transmission and increased soil structure. However, certain substances present in sludge (metals and human pathogens) compromise beneficial use and should be restricted when sludge is destined for use by the general public. Therefore sludge quality and the quality of the final fertilizer product is the most important factor when sludge is intended for unrestricted use by the general public.

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[1] Herselman, J.E. and Snyman, H.G. 2008. Guidelines for the utilisation and disposal of wastewater sludge: Literature review and technical support document for Volumes 3-5. WRC Report 1622/1/09, 1622/2/09 and 1622/3/09.

The use of sludge or incinerator ash as raw material for manufacturing of commercial products other than fertilizer products will be less restrictive. Some form of thermal treatment forms part of the production process, destroying the pathogens that may be present in the sludge and stabilises the final product. The metals in the final product will also be bound in an insoluble form, eliminating the potential for environmental pollution.

TYPES OF COMMERCIAL PRODUCTS CONTAINING SLUDGE

Sludge and incinerator ash can be used as raw products to manufacture various types of commercial products. Although many of these products are very innovative, not all can be included in guidelines. Therefore, only the most commonly manufactured products are discussed in this Guideline, including fertilizer products and construction materials.

Fertilizer products

Fertilizer products manufactured from sludge include, but are not limited to, compost and pellets.

Compost

Composting is the process whereby sludge is decomposed and stabilised under aerobic conditions that promote the development of thermophilic temperatures through biological action. If proper procedures are followed, the product is humus-like, stable and free of pathogens and plant seeds and can beneficially and safely be applied to land.

Pellets

Different environmentally accepted methods exist to convert sludge into dry, pathogen free granules which can be used as a fertilizer, for land reclamation or as a fuel. These processes stabilize and pasteurize sludge while enriching it with the nutrients N and P.

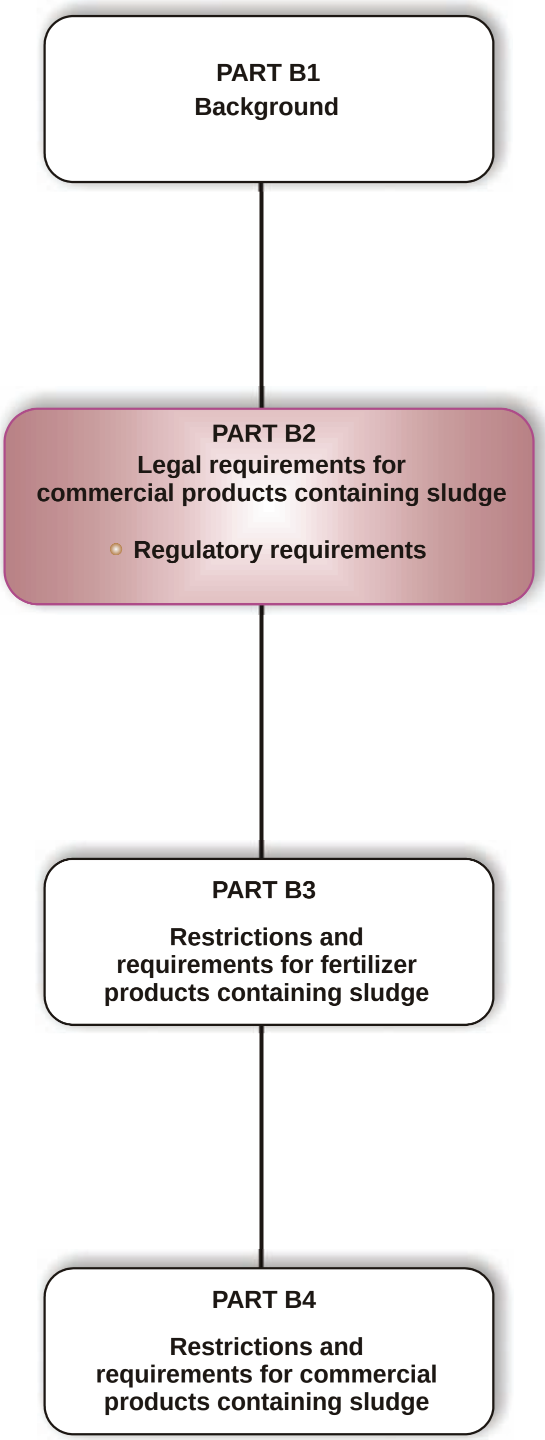
Construction materials

The majority of commercial products (other than fertilizer) produced with sludge and/or incinerator ash as raw material are used in the construction business. This includes, but is not limited to:

- bricks,
- cement,
- pumice and
- artificial aggregate.

Most of the manufacturing processes include a heating process where potential hazardous microbiological constituents and organic material present in the sludge are destroyed, leaving the product harmless and stable. In most instances the inorganic pollutants (metals) are also converted to an insoluble form.

SECTION B: COMMERCIAL PRODUCTS ROADMAP



PART B2:

LEGAL REQUIREMENTS FOR COMMERCIAL PRODUCTS CONTAINING SLUDGE

The environmental legislative framework is not well defined or prescriptive with respect to regulating the use of sludge/incinerator sludge ash in commercial products. Several pieces of legislation may therefore need to be considered, and more than one Government Department or sphere of government may have a regulatory role to play.

In relation to the use of sludge/incinerator ash, the key authorities that may have to be consulted are the Departments of Agriculture (DoA), Health (DoH), Environmental Affairs and Tourism (DEAT), and Water Affairs and Forestry (DWAF). It is thus the responsibility of the sludge user to ensure that the relevant authority(ies) are consulted prior to the use of the sludge/incinerator ash for the specific commercial product.

REGULATORY REQUIREMENTS

The legal requirements that may apply for commercial products containing sludge, from an environmental and health perspective, are listed in Table 13. Although no specific authorisation is required *per se*, it is important that the regulations relating to the various statutes are adhered to, where applicable. While not specified below, the DWAF and/or DEAT, need to be consulted in terms of any water use authorisation that may be required for a WWTP or a waste permit that may apply for an off-site management option, should the sludge be destined for use in a commercial product.

Other statutory requirements and product specifications may apply; for example those related to the building/construction industry (e.g. national building regulations). However those are beyond the scope of these guidelines.

TABLE 13: REGULATORY REQUIREMENTS APPLICABLE TO COMMERCIAL PRODUCTS CONTAINING SLUDGE

	Fertilizer products	Commercial products: Construction
Applicable Act Governing Practice	Fertilizer, Farm Feed, Agricultural Remedies and Stock Remedies Act (Act 36 of 1974) Hazardous Substances Act (Act No 15 of 1973) National Health Act (Act 61 of 2003)	Hazardous Substances Act (Act No 15 of 1973) National Health Act (Act 61 of 2003)
Authorisation Required	Registration as a fertilizer with Department of Agriculture	None specified
Lead Authority	Department of Agriculture	Department of Health
Regulatory Instrument	Certificate of registration Applicable health and pollution control regulations, provincial and local bylaws	Applicable health and pollution control regulations, provincial and local bylaws
Regulatory Guidelines	Sludge Guidelines (Volume 5) and/or Minimum Requirements (latest applicable versions)	

PART B2: LEGAL REQUIREMENTS FOR COMMERCIAL PRODUCTS CONTAINING SLUDGE

The Fertiliser, Farm Feed, Agricultural Remedies and Stock Remedies Act (Act 36 of 1947) provides for the appointment of a Registrar of Fertilizers, Farm Feeds and Agricultural Remedies; for the registration of fertilizers, farm feeds, agricultural remedies, stock remedies, sterilizing plants and pest control operators; to regulate or prohibit the importation, sale, acquisition, disposal or use of fertilizers, farm feeds, agricultural remedies and stock remedies; to provide for the designation of technical advisers and analysts; and to provide for matters incidental thereto.

Some important definitions from this Act in relation to Volume 5 include:

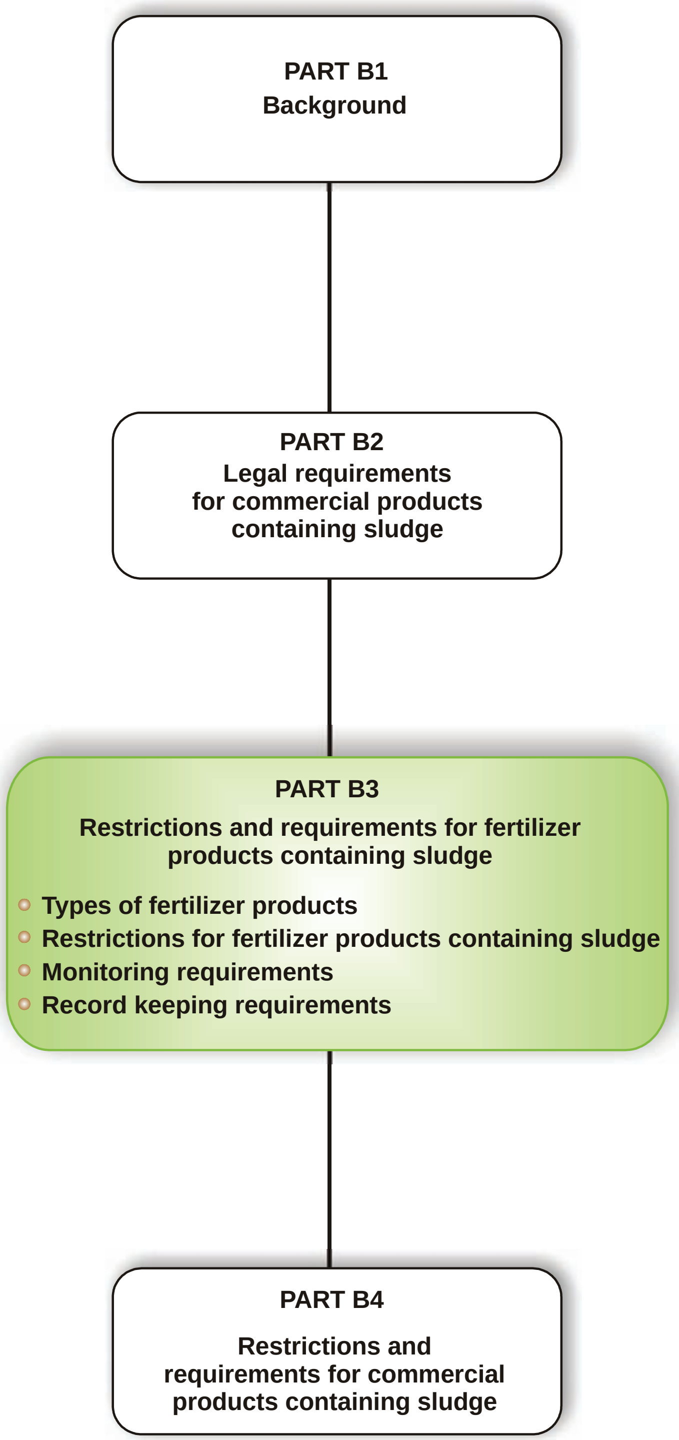
'agricultural remedy' means any chemical substance or biological remedy, or any mixture or combination of any substance or remedy intended or offered to be used-

(b) as plant growth regulator, defoliant, desiccant or legume inoculant, and anything else which the Minister has by notice in the Gazette declared an agricultural remedy for the purposes of this Act:

'sell'' includes agree to sell, or to offer, advertise, keep, expose, transmit, convey, deliver or manufacture for sale or to exchange or to dispose of to any person in any manner for any consideration whatever, or to transmit, convey or deliver in pursuance of a sale, exchange or disposal as aforesaid; and 'sale' has a corresponding meaning;

'advertisement' means any written, illustrated, visual or other descriptive material or oral statement, communication, representation or reference distributed to members of the public or brought to their notice in any other manner and which is intended to promote the sale of fertilizers, farm feeds, agricultural remedies or stock remedies or encourage the use thereof or draw attention to the nature, properties, advantages or uses thereof, and 'advertise' has a corresponding meaning;

SECTION B: COMMERCIAL PRODUCTS ROADMAP



PART B3:

RESTRICTIONS AND REQUIREMENTS FOR FERTILIZER PRODUCTS CONTAINING SLUDGE

This part of the Guidelines deal with fertilizer products, containing sludge, that are distributed to the general public for **unrestricted use**. The fertilizer products considered for the guidelines include compost and pellets.

TYPES OF FERTILIZER PRODUCTS

Sludge Compost

Composting is the process whereby organic material such as sludge is decomposed and stabilised under aerobic conditions that promote the development of thermophilic temperatures through biological action. The product is humus-like, stable, free of pathogens and plant seeds and can beneficially and safely be applied to land.

To achieve the correct conditions for successful composting, the following elements are essential:

1. Sludge must be mixed with a “bulking agent” that provides structural support and create voids in the composting matrix to enable air to pass freely through the pile;
2. Air must be introduced into the pile to promote the biological activity;
3. Sufficient organic energy must be present in the feed sludge to enable the biological activity in the pile to generate the required pasteurising temperatures (65-70°C); and
4. The nutrient mix of the sludge must be suitable to promote bacteriological growth. The optimal C:N ratio is approximately 20:1 and sludge tends to contain sufficient nitrogen to meet this requirement.

The quality of the compost is directly affected by the design and operation of the composting plant as well as the quality of the sludge. Due to the complexity of the process, operational guidelines for sludge composting are discussed in detail in Appendix 4 of this document.

Figure 9: Compost derived from wastewater sludge

PART B3: RESTRICTIONS AND REQUIREMENTS FOR FERTILIZER PRODUCTS CONTAINING SLUDGE

Pellets

Different methods can be used to make pellets from sludge. These processes provide an environmentally accepted method of converting sludge into dry, pathogen free granules which can be used as a fertilizer, for land reclamation or as a fuel. Two of these methods are briefly described below.

- Dewatered sludge, with a minimum solids content of 15-40% solids, goes into a drying drum where the temperature is between 450°C at the inlet and 130°C at the outlet. Rotation of the drum provides uniform drying and also serves to transport the granular sludge, through a cyclone and then a screw conveyor for cooling. Finally, a vibrating sieve separates the granules by size. Before storage, the temperature of the granules is lowered to 35°C by means of a cooling screw. The metal content of the sludge may be a restriction on the use of the pellets by the general public as fertilizer.

- Another process stabilizes and pasteurizes sludge while enriching it with the nutrients N and P. Dewatered sludge (stabilised or non-stabilised primary, secondary, tertiary sludge) of at least 15-20% dry solids is fed into the process. Ammonia (NH_3) is added to the sludge, which raises the temperature and pH of the sludge to about 60°C and 12 respectively. This step provides pasteurisation of the sludge through high pH, high temperature and ammonia toxicity. In addition, the NH_3 reacts with the organic matter in the sludge fixating part of the added NH_3.

  In the second stage of the process phosphoric acid (H_3PO_4) is added to neutralise the mixture to a pH of 7.0 while raising the temperature to about 70°C. The non-chemically bound NH_3 is evaporated and reused. Dry warm air is blown over a thin layer of final product to evaporate the moisture and dry the sludge.

Figure 10: Pellets produced from sludge

Other fertilizer products containing sludge

Other innovative products using sludge as raw product for its nutrient content, which are pasteurized to kill pathogens and stabilize the sludge, may also be used if the quality of the final product complies with this guideline.

PART B3: RESTRICTIONS AND REQUIREMENTS FOR FERTILIZER PRODUCTS CONTAINING SLUDGE

RESTRICTIONS FOR FERTILIZER PRODUCTS CONTAINING SLUDGE

The only restriction applicable to fertilizer products containing sludge is on the quality of the product as discussed in the sections that follow.

Product Quality

To protect the receiving environment and the general public from any adverse effects of any constituents that may be present in the product, the quality of the final product should be regulated. Therefore, all fertilizer products containing sludge to be used by the general public must be classified, even if a preliminary classification of the sludge was done before the production process as stipulated in Volume 1 of the Guidelines. The product must be sampled and analysed before distribution to the public and must comply with **Class A1a** according to its Microbiological class, Stability class and Pollutant class as discussed below.

Microbiological classification

Each batch of fertilizer product to be distributed must be monitored (at least 3 samples) and comply with **Microbiological class A** (Table 14) classification requirements. For analytical methods, see Volume 1 – Appendix 2 (Faecal coliforms) and Appendix 1 (this Volume) for the recommended new Helminth ova method for sludge and compost.

TABLE 14: CLASSIFICATION CRITERIA: MICROBIOLOGICAL CLASS

Microbiological class A	Target value	Maximum permissible value
Faecal coliform (CFU/g_{dry})	<1000	10 000
Helminth ova (Viable ova/g_{dry})	<0.25 (or 1 ova/4g_{dry})	1
Compliance requirements	90% compliance	The 10% samples that exceed the Target value may not exceed this value

Stability classification

The Stability class can be determined analytically and/or by complying with a vector attraction reduction requirement (Table 15). Every batch of fertilizer product to be distributed must comply with at least 1 vector attraction reduction option. The different applicable vector attraction reduction options are described in detail in Appendix 2.

TABLE 15: STABILITY CLASS AND VECTOR ATTRACTION REDUCTION OPTIONS

Stability class 1	
Product must **always** comply with one of the options below.	
Applicable Vector attraction reduction options	
Option 1	Reduce the mass of volatile solids by a minimum of 38 percent
Option 2	Demonstrate vector attraction reduction with additional anaerobic digestion in a bench-scale unit
Option 3	Demonstrate vector attraction reduction with additional aerobic digestion in a bench-scale unit
Option 4	Meet a specific oxygen uptake rate for aerobically treated sludge
Option 5	Use aerobic processes at a temperature greater than 40°C (average temperatures 45°C) for 14 days or longer (eg during sludge composting)
Option 6	Add alkaline material to raise the pH under specific conditions
Option 7	Reduce moisture content of sludge that do not contain unstabilised solids (from treatment processes other than primary treatment) to at least 75 percent solids

Pollutant classification

The Pollutant class of the final product can be determined by comparing results of the sample analyses to the limits in Table 16. Each batch of fertilizer product to be distributed must comply with Pollutant class **a** classification criteria.

TABLE 16: POLLUTANT CLASS FOR COMMERCIAL PRODUCTS

***Aqua regia* extractable metals (mg/kg)**	**Pollutant class**
	a
Arsenic (As)	<40
Cadmium (Cd)	<40
Chromium (Cr)	<1 200
Copper (Cu)	<1 500
Lead (Pb)	<300
Mercury (Hg)	<15
Nickel (Ni)	<420
Zinc (Zn)	<2 800

PART B3: RESTRICTIONS AND REQUIREMENTS FOR FERTILIZER PRODUCTS CONTAINING SLUDGE

Note: Table 16 requires the analyses of eight (8) potentially toxic metals and elements. These are typically the elements that might be of concern. However, the sludge used in the production process could be compromised by other elements. A full total elemental analysis including a number of other trace metals and elements is required for the preliminary sludge classification as detailed in Volume 1. The results of those analyses need to be consulted to determine if any other element of concern need to be monitored in the fertilizer product.

MONITORING REQUIREMENTS

Each batch of fertilizer product must be sampled and analysed before distribution to the public. At least three (3) statistically representative samples must be collected from each batch and send for analyses. All the samples must comply with the A1a classification as discussed in the previous sections. If the product does not comply it may not be distributed and must either be re-processed or disposed in an environmentally save manner (see Volume 3 for disposal options and its applicable restrictions and requirements).

RECORD KEEPING REQUIREMENTS

The following records should be kept by the producer of the fertilizer product containing sludge:

- Copies of the applicable permits and/or licences
- The original or certified copy of the contract/agreement between the sludge producer and the sludge user (if applicable)
- Monitoring data of each batch of product produced, pertaining to the:

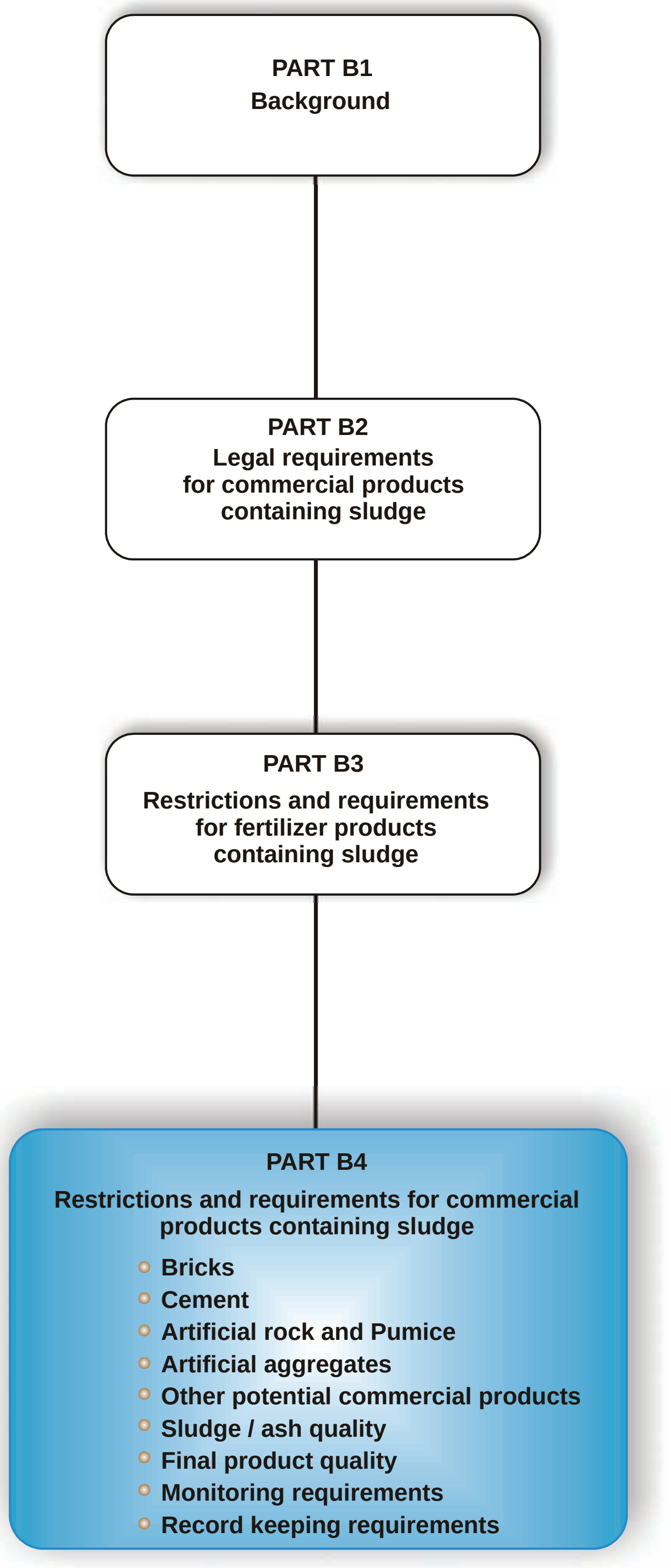
  Microbiological class

  Stability class

  Pollutant class

Note: Other monitoring and record keeping requirements in terms of fertilizer quality may apply, which is outside the scope of this Guideline.

SECTION B: COMMERCIAL PRODUCTS ROADMAP



PART B4:

REQUIREMENTS FOR COMMERCIAL PRODUCTS CONTAINING SLUDGE

The majority of commercial products (other than fertilizer) produced with sludge and/or incinerator ash as raw material are used in the construction business. This includes, but is not limited to, bricks, cement, pumice and artificial aggregate.

BRICKS

Incinerated sludge ash as well as dewatered sludge can be applied as raw material for brick manufacturing (Figure 11). The sludge brick is considered to be superior to traditional bricks in compression strength, water absorption rate, abrasion strength and bending strength. Potential benefits are that the firing process locks away any toxic heavy metals in the sludge and also destroys any hazardous microbes and organic material. However, public acceptance may remain a problem and such bricks might need to meet additional standards to guarantee they don't pose health hazards.

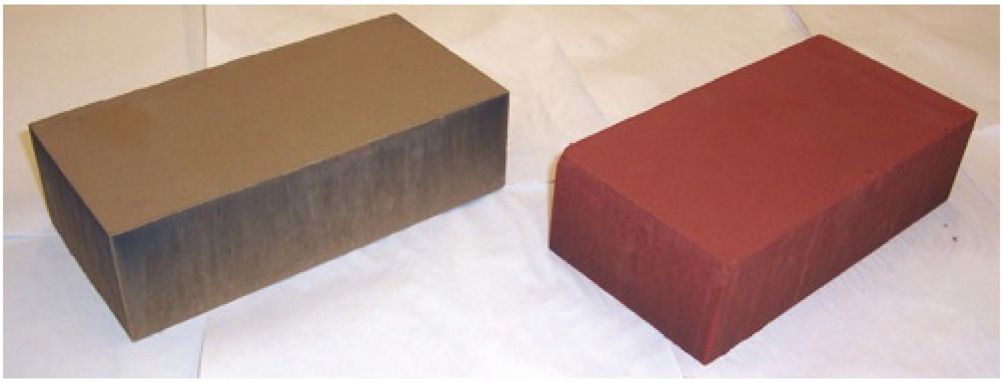


Figure 11: Bricks produced from sludge

Bricks manufactured from incinerator ash

The composition of the ash is a key factor in the quality of the brick. Some important factors are:

- The average particle size of the ash should be under 30 µm, otherwise the end product will be subject to hairline cracks. Thus, ash from a fluidized bed incinerator is better than ash from a multiple hearth incinerator because it yields finer ash.
- Organic substances and moisture present in the ash will cause cracking of the brick during firing. Therefore, the ignition loss of the ash and the moisture content of the ash should be below 1%.
- As the CaO content of the ash increases more hairline cracks will appear on the surface of the end product. Therefore, lime should not be used for conditioning of sludge during dewatering or thickening and the concentration of CaO in the ash should be less than 15%.

Bricks manufactured from dewatered sludge

The optimum conditions for manufacturing good quality bricks from dewatered sludge are:

- The raw material should include 10-20% sludge;

- Moisture content of sludge should be 24%;
- Firing temperature should be 880-1000^{o}C.

CEMENT

In principle, cement works can use suitable types of waste as an alternative fuel or raw material. However, this must not increase the emission of air pollutants from kilns or reduce the quality of the cement produced.

Blended cements are produced by intimately and uniformly mixing or blending two or more types of fine materials. Cement and fly ash look very similar and are handled in virtually the same way (Figure 12). Cement manufacturers can use incinerated ash, dried sludge or dewatered sludge cake as a raw material for their product, depending on the manufacturers' operations. The major ingredients of cement are CaO, SiO_2 and F_2O_3, traditionally supplied in the form of natural limestone and clay. However, sludge can substitute for a portion of these ingredients. This application for sludge holds significant potential for easing the final disposal of sludge and promoting environmental conservation.

Figure 12: Cement (on the left) and fly ash (on the right) look very similar

Blended cements are used in all aspects of concrete construction in the same manner as portland cements (Figure 13). Blended cements can be used as the only cementatious material in concrete or they can be used in combination with other material added at the concrete plant. Blended cements are often designed to be used in combination with fly ash and slag cement.

Figure 13: Blended cement produced from fly ash

ARTIFICIAL ROCK AND PUMICE

Dewatered sludge as well as incinerator ash can be used to manufacture artificial rock. When the ash content in the sludge and incinerator ash is heated to 1300^{o}C, a molten slag is formed. The slag is kept at a constant temperature of approximately 1000-1100°C to precipitate the anorthite crystals that comprise the majority of granite, to produce artificial rock (Figure 14).

In nature, pumice rocks are igneous rocks which were formed when lava cooled quickly above ground. It is actually a kind of glass and not a mixture of minerals. Artificial pumice is made using the same approach as bricks, with the addition of crushing and sieving processes. The kiln temperature can be changed to adjust the properties of the pumice to meet specific final use requirements. The final product can be used for the under layer of athletic fields because it rapidly drains excess water but holds sufficient moisture, thus maintaining the condition of the athletic field. Because it is light weight, it can be used as a decorative landscape stone (Figure 14).

Figure 14: Artificial rock (left) and pumice (right) produced from sludge

ARTIFICIAL AGGREGATES (SLAG)

Slag can be used as a substitute for natural coarse aggregate, including concrete aggregate and back-filling material, ready-mixed concrete aggregate, roadbed materials, permeable pavement, interlocking tiles and other secondary concrete products (Figure 15).

When dewatered sludge cake is heated and its moisture evaporates, the combustible organic matter is destroyed. The inorganic matter starts to melt into a molten slag. When it is cooled, a slag is formed. By using this melting process, the volume of the sludge is reduced, with increasing stability making it possible to use sludge as a recyclable resource. The metals present in the slag are immobile and the slag is safe to be used as aggregate material.

This process can begin with either dewatered sludge cake (cake slag) or incinerator ash (ash slag). Processing cake slag is fuel efficient, and the calorific value of the organic content of the sludge cake contributes to heat the furnace. In some cases, self-combustion is possible. However, the process requires an effective drying unit and skilful operation.

In the ash/slag process, fluctuations of the properties of the dewatered sludge cake are absorbed during incineration, thus simplifying the design and operation of the melting furnace. The incinerator and the melting furnace can be operated independently to maximise the performance of each.

The final aggregate product is a spherical shaped pellet that could be used as fillers, planter soil, additives in flower vases, thermal insulator panels, rapid sand filters and water-infiltrating pavements.

Figure 15: Artificial aggregates produced from sludge and incinerator ash

OTHER POTENTIAL COMMERCIAL PRODUCTS

When slag is reheated at very high temperatures (>1500°C) and then gradually air-cooled, it crystallizes. The end product then becomes a marble-like material with a semi-crystallised structure, like a manmade marble. The material is characterized by tough strength and high acid resistance and has been used for making jewellery and tombstones (Figure 16).

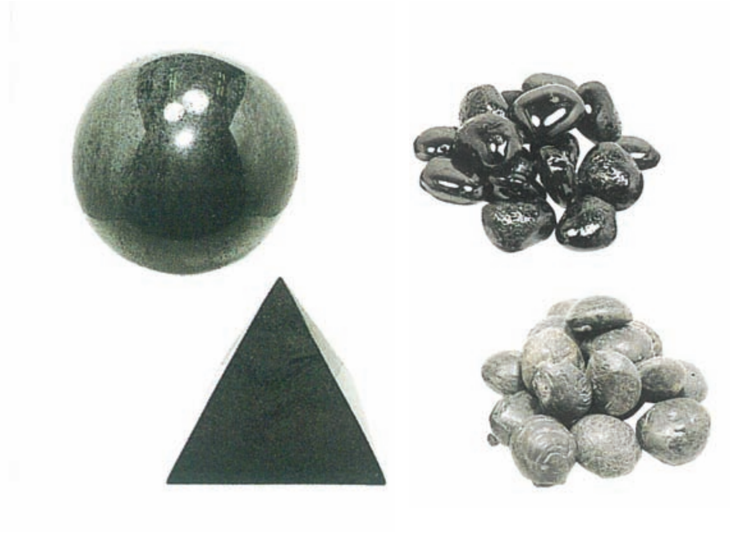


Figure 16: Marble-like material manufactured from sludge

Another potential product is oil production from sludge. The sludge is dried and heated to 450°C in the absence of oxygen, to cause vaporisation. The mixing of the vaporised sludge with char residue produces a fuel oil as a result of thermal and catalytic reactions. This process can produce 150-300 litres of oil per ton of sludge produced.

The products discussed here are only examples of commercial products that can be manufactured from sludge and/or incinerator ash. Many other innovative processes and products may exist which can also be used, provided that the product will not be hazardous to the user and the environment due to its chemical composition.

PART B4: REQUIREMENTS FOR COMMERCIAL PRODUCTS CONTAINING SLUDGE

SLUDGE / ASH QUALITY

Most of the manufacturing processes for the commercial products discussed in this document include a heating process where potential hazardous microbiological constituents and organic material present in the sludge are destroyed, leaving the product harmless and stable. In most instances the inorganic pollutants (metals) are also converted to an insoluble form. Therefore, the quality of the sludge in terms of its Microbiological class, Stability class and Pollutant class is not a limiting factor in these processes. There might be some preference for dewatered sludge rather than wet sludge, depending on the requirements of the user.

FINAL PRODUCT QUALITY

South African National Standards (SANS)

The standard and quality of construction and building material is regulated by the South African Bureau of Standards (SABS). These standards are published documents which list specifications and procedures established to ensure that a material or product is fit for its purpose and perform in the manner it was intended for. It defines quality, establishes safety criteria and provides the basis for consumer protection, health and safety. Standards for building and construction material are included in the South African National Standards (SANS): Materials and Mechanical Standards. Where an applicable SANS for a specific product exists, the final product must conform to this standard before it can be used.

Material Safety Data Sheet (MSDS)

A Material Safety Data Sheet (MSDS) is designed to provide both workers and emergency personnel with the proper procedures for handling or working with a particular substance. It reflects the hazards of working with the material in an occupational fashion. For example, an MSDS for paint is not highly pertinent to someone who uses a can of paint once a year, but is extremely important to someone who does this in a confined space 40 hours a week. MSDS's include information such as physical data (melting point, boiling point, etc.), toxicity, health effects, first aid, reactivity, storage, disposal, protective equipment, and spill/leak procedures.

Although a MSDS is not intended for consumers, contractors that will use the products containing sludge on continuous bases will need a MSDS of the final product where applicable. These MSDS's should include, as a minimum, the following information:

- Product components – a list of the components used to manufacture the final product as well as the hazards associated with these components;
- Hazardous decomposition products – information on the decomposition products associated with the final product;
- Personal Protection Information – information on adequate Personal Protective equipment (eye protection, skin protection, etc.), ventilation and respiratory protection against dust;
- Health hazard information – this must include information on risks of overexposure;
- Hazard classification – information on whether this product is classified as hazardous; and

- Disposal – disposal options will depend on the hazard classification.

MONITORING REQUIREMENTS

Extensive tests should already have been done on the products to compile the MSDS and to register the product. Therefore, it is unlikely that further monitoring will be required for these products, unless specifically requested by the Regulatory Authority.

RECORD KEEPING REQUIREMENTS

The following records should be kept by the sludge producer / user:

- The original or certified copy of the contract/agreement between the sludge producer and the sludge user (if applicable); and
- Monthly sludge/ash volumes supplied / processed.

Note: Other record keeping requirements might apply in terms of commercial or industrial specifications, which is beyond the scope of this guideline.

CONCLUSION

Volume 5 of the Sludge Guidelines informs the reader regarding thermal treatment of sludge as well as the production of commercial products containing sludge and/or incinerator ash. During thermal treatment of sludge the fossil fuel energy of the material is utilized but air quality might be compromised by the presence of organic pollutants, metals and other constituents in the exhaust gas. The incinerator ash may also contain elevated concentrations of metals and should be used/disposed of appropriately. The legal requirements for sludge incineration and air emission limits for different types of thermal treatment processes are discussed. These air emissions should be monitored on a continuous basis to ensure compliance with the necessary permits.

Commercial products containing sludge and/or incinerator ash can be two-fold, i.e. fertilizer products and products used mainly in the construction business. The fertilizer products are used by the general public without restrictions and, to protect the environment and public health, the quality of the final product should be restricted to Class A1a. Operational guidelines for sludge composting to achieve this quality product are also supplied.

Commercial products containing sludge used in the construction business use dewatered sludge and/or incinerator ash as raw materials. In most instances additional thermal treatment forms part of the production process, ensuring that all organic pollutants and pathogens are destroyed, that the final product is stable and that the metals are left in an insoluble form.

It is recognized that new information is constantly generated and is recommended that the Sludge Guidelines be revised every 5 to 10 years. This will allow the South African wastewater industry sufficient time to implement these guidelines and highlight shortcomings, constraints and operational difficulties.

APPENDIX 1: RECOMMENDED NEW PROCEDURE TO DETERMINE HELMINTH OVA IN WASTEWATER SLUDGE

Note: This is a new method which was developed after Volume 1 of the New Sludge Guidelines have been published and differs from the method published in Volume 1.

Appendix 1.1: Method for analyses of sludge

Note: It is always preferable to work with small sub-samples as eggs may not be as easily released from a large sample to float out of the sludge when doing the $ZnSO_4$ flotation technique. Rather increase the number of sub-samples than overload each test-tube in order to keep the number of tubes down.

The number of sub-samples will also be dependent on the helminth ova load expected. This will require knowledge of the epidemiology of helminths in the particular area in South Africa. Consequently, more sub-samples must be done in an area of low endemicity and less in a highly endemic area.

1. Mix the sludge sample well by swirling and stirring with a plastic rod. From the total sample take 4 x 15 mℓ sub-samples and place them into 4 x 50 mℓ test tubes. (If the solid content is high this should be sufficient sample. If it is low, take more 15 mℓ sub-samples).

2. Add either a few millilitres of 0.1% Tween80 or AmBic solution to the samples, vortex and add more wash solution. Repeat this procedure until the tubes are filled to approximately a centimetre from the top.

3. Place the 150 µm sieve in a funnel in a retort stand with a plastic beaker underneath to catch the filtrate. Filter the well-mixed contents of the tubes one at a time, rinsing out each tube and washing this water through the sieve as well.

4. Pour the filtrate into test tubes and centrifuge at 1389 g (±3000 rpm) for 3 minutes. Suction off the supernatant fluids and discard. Combine the deposits into a suitable number of tubes so that there is not more than 1 mℓ in a 15 mℓ tube or 5 mℓ in a 50 mℓ tube

5. Re-suspend each of these deposits in a few millilitres of $ZnSO_4$ and vortex well to mix. Keep adding more $ZnSO_4$ and mixing until the tube is almost full.

6. Centrifuge the tubes at 617 g (±2000 rpm) for 3 minutes. Remove from the centrifuge and pour the supernatant fluids through the 20 µm filter, washing well with water.

7. Collect the matter retained on the sieve and wash it into test tubes.

8. Centrifuge the tubes at 964 g (±2500 rpm) for 3 minutes; remove & discard the supernatant fluid. Combine the deposits into one test tube, using water to recover all the eggs from the other tubes. Then centrifuge again at 964 g for 3 minutes to get one deposit.

9. Once there is one final deposit, remove all of it using a plastic Pasteur pipette and place it onto one or more microscope slides. Place a coverslip over each deposit and examine

microscopically using the 10x objective and the 40x objective to confirm any unsure diagnoses.

10. Each species of helminth ova is enumerated separately and reported as eggs per gram of sludge.

Note: Samples may be examined slightly differently from that described in step No. 10 above by doing the following:

The deposits are filtered through a 12 µm ISOPORE membrane, which is then rinsed with distilled water. The membrane is air-dried, cut in half and placed on a microscope slide. Immersion oil is used to clear the membrane before examining under the microscope.

<u>To test for viability:</u>

Perform steps 1 to 8 of the procedure above and continue as follows:

9. Once there is a final deposit in the test tube, re-suspend it in 4 mℓ of 0.1 H_2SO_4. Before incubating mark the test tube with the level of liquid and incubate at a temperature of 26°C for three to four weeks. Check the level of liquid in each one of the test tubes and add the reagent every time that is necessary, compensating for any evaporation that may occur.

10. Once the incubation time is over, homogenize the deposit and proceed to quantify the eggs. Remove all of the deposit using a plastic Pasteur pipette and place it onto one or more microscope slides. Place a coverslip over each deposit and examine microscopically using the 10x objective and the 40x objective to confirm any unsure diagnoses. Only those ova where the larva is observed are considered viable.

<u>Equipment required and related information</u>

1. A centrifuge with a swing-out rotor and buckets that can take 15 mℓ and/or 50 mℓ plastic conical test tubes.
2. Vortex mixer.
3. Retort Stand with at least 2 clamps on it.
4. Large plastic funnels to support the filters (±220 mm diameter).
5. Filters / Sieves : 1x 150 µm; 1x 100 µm; 1x 20 µm.
6. Approximately 6 Plastic beakers (500 mℓ) & 3 Plastic wash bottles.
7. At least 4 glass “Schott” bottles (1 ℓ, 2 ℓ & 5 ℓ sizes) for make-up and storage of the chemical solutions and de-ionized water.
8. Magnetic stirrer and stirring magnets.
9. 15 mℓ and 50 mℓ plastic conical test tubes.
10. 3 x Small glass beakers (100 mℓ).
11. Plastic Pasteur Pipettes & Plastic Stirring Rods.
12. Glass microscope slides (76 x 26 x 1,2 mm).

13. Square & Rectangular Cover-slips (22 x 22 mm & 22 x 40 mm).

14. A binocular compound microscope with 10x eyepieces, a 10x objective and a 40x objective.

Working out the g-force of your centrifuge

G-force (or g) = $(1{,}118 \times 10^{-5})\ r\ s^2 = 0{,}00001118 \times r \times s^2$

where : s = revolutions per minute (i.e. the speed you spin at)

r = the radius (the distance in centimetres from the centre of the rotor to the bottom of the bucket holding the tubes, when the bucket is in the swing-out position)

Reagents

Zinc Sulphate

- ZnSO4 (heptahydrate) is made up by dissolving 500 g of the chemical in 880 mℓ de-ionised or distilled water.
- A hydrometer must be used to adjust the specific gravity (SG) to 1.3, using more chemical if the SG is too low or more water if it is >1,3.

This high specific gravity facilitates the floating of heavier ova such as *Taenia* sp. (SG = 1.27). It is not critical if the SG of the $ZnSO_4$ solution is just over 1.3 but it should **never** be below this value!

Ammonium Bicarbonate

The AMBIC solution is essentially a saturated ammonium bicarbonate solution. Ammonium bicarbonate can be obtained from Merck Chemicals and is made up by dissolving 119 g of the chemical in 1000 mℓ of de-ionised water.

0,1% Tween80

1 mℓ of Tween80 is measured out using a pipette and placed in 1000 mℓ of de-ionized or distilled water to give a 0,1% wash solution.

Note: Tween80 is extremely viscous and it is necessary to wash **all** of it out into the water in which it is made up, by alternately sucking up water and blowing it out using the same pipette.

References:

WRC Report number: TT 321/08. Standard methods for the recovery and enumeration of Helminth ova in wastewater, sludge, compost and urine diversion waste in South Africa.

Posters: Standard methods and photographs of Helminth ova.

Appendix 1.2: Helminth ova procedure for compost

1. Weigh out 2 or more 1 g samples into 15 mℓ test tubes. 50 mℓ test tubes may be used if a centrifuge that can take these large tubes is available. If using 50 mℓ tubes, weigh out 3 g maximum per tube.

2. Add a few millilitres of AmBic or 0.1% Tween80 and vortex well. Add more solution to about 6 mℓ (in a 15 mℓ tube) or 20 mℓ (in a 50 mℓ tube) and vortex on and off, repeating the addition of solution and vortexing until the tubes are filled to 10 mℓ/40 mℓ and have been vortexed over a period of about 30 minutes in total.

3. Centrifuge the tubes at 1389 g (±3000 rpm) for 3 min and discard the supernatant . Re-suspend in de-ionized water and vortex to wash off the AmBic or Tween80, and centrifuge again at 1389 g for 3 minutes. Discard the supernatant.

4. Re-suspend each deposit in a few millilitres of $ZnSO_4$ and vortex well to mix. Keep adding more $ZnSO_4$ and mixing until the tube is almost full.

5. Centrifuge the tubes at 617 g (±2000 rpm) for 3 minutes. Carefully remove the tubes from the centrifuge and, using a plastic Pasteur pipette, transfer the supernatant to 3 or 4 test tubes. Fill these tubes with distilled water to reduce the SG of the $ZnSO_4$ so as not to damage the eggs and also to allow them to deposit upon centrifugation.

6. Centrifuge at 964 g (±2500 rpm) for 3 minutes. Remove tubes and discard the supernatant fluid. Combine the deposits into one test tube, using water to recover all the eggs from the other tubes. Centrifuge again at 964 g for 3 minutes to get one deposit.

Note: At this point if the sample contains a lot of large particles of light debris that floated with the eggs, e.g. grass, filter the deposit through a 100 µm filter, collect the filtrate in test tubes and centrifuge again to get a deposit for microscopy.

7. Once there is one final deposit, remove all of it using a plastic Pasteur pipette and place it onto one or more microscope slides. Place a coverslip over each deposit and examine microscopically using the 10x objective and the 40x objective to confirm any unsure diagnoses.

8. Each species of helminth ova is enumerated separately and reported as eggs per gram of compost.

APPENDIX 2: VECTOR ATTRACTION REDUCTION OPTIONS

The following options are available to reduce the vector attraction potential. These options have been adopted from the US EPA Part 503 Rule.

Option 1: Reduction in Volatile Solids Content

Vector attraction is reduced if the fraction of volatile solids in the primary sludge is reduced by at least 38 percent during the treatment of the sludge. This percentage is the amount of volatile solids reduction that is attained by anaerobic or aerobic digestion plus any additional volatile solids reduction that occurs before the sludge leaves the treatment works, such as through processing in drying beds or lagoons, or by composting.

Digestion process efficiency can be measured by the reduction in the volatile solids content of the feed sludge to the digester and the sludge withdrawn from the digester. Anaerobic digestion of primary sludge generally results in a reduction of between 40 and 60% of the volatile solids.

O'Shaunessy's formula can be used to calculate the volatile solids (VS) reduction in a digester:

VS reduction (%) = $\{(V_i – V_o)/ V_i – (V_i \times V_o)\}x100$

Where V_i = volatile fraction in feed sludge

V_o = volatile fraction in digested sludge

Example of calculation of VS reduction

Assume volatile solids in feed sludge	=	84%		
Therefore volatile fraction of feed sludge	=	0.84	=	V_i
Assume volatile solids of digested sludge	=	68%		
Therefore volatile fraction of digested sludge	=	0.68	=	V_o

VS reduction (%) = {(0.84 – 0.68) / 0.84 – (0.84 x 0.68)} x 100

= 59%

Option 2: Additional Digestion of Anaerobically Digested Sludge

Frequently, primary sludge is recycled to generate fatty acids or the sludge is recycled through the biological wastewater treatment section of a treatment works or has resided for long periods of time in the wastewater collection system. During this time, the sludge undergoes substantial biological degradation. If the sludge is subsequently treated by anaerobic digestion for a period of time, it adequately reduces vector attraction. Because the sludge will have entered the digester already partially stabilized, the volatile solids reduction after treatment is frequently less than 38 percent.

Under these circumstances, the 38 percent reduction required by Option 1 may not be achievable. Option 2 allows the operator to demonstrate vector attraction reduction by testing a portion of the previously digested sludge in a **bench-scale unit** in the laboratory. Vector attraction reduction is demonstrated if, after anaerobic digestion of the sludge for an additional 40 days at a temperature between 30°C and 37°C, the volatile solids in the sludge are reduced by less than 17 percent from the beginning to the end of the bench test.

Option 3: Additional Digestion of Aerobically Digested Sludge

This option is appropriate for aerobically digested sludge that cannot meet the 38 percent volatile solids reduction required by Option 1. This includes activated sludge from extended aeration plants, where the minimum residence time of sludge leaving the wastewater treatment processes section generally exceeds 20 days. In these cases, the sludge will already have been substantially degraded biologically prior to aerobic digestion.

Under this option, aerobically digested sludge with 2 percent or less solids is considered to have achieved vector attraction reduction, if in the laboratory after 30 days of aerobic digestion in a batch test at 20°C, volatile solids are reduced by less than 15 percent. This test is only applicable to liquid aerobically digested sludge.

Option 4: Specific Oxygen Uptake Rate (SOUR) for Aerobically Digested Sludge

Frequently, aerobically digested sludge is circulated through the aerobic biological wastewater treatment process for as long as 30 days. In these cases, the sludge entering the aerobic digester is already partially digested, which makes it difficult to demonstrate the 38 percent reduction required by Option 1.

The specific oxygen uptake rate (SOUR) is the mass of oxygen consumed per unit time per unit mass of total solids (dry-weight basis) in the sludge. Reduction in vector attraction can be demonstrated if the SOUR of the sludge that is used or disposed, determined at 20°C, is equal to or less than 2 milligrams of oxygen per hour per gram of total sludge (dry-weight basis). This test is based on the fact that if the sludge consumes very little oxygen, its value as a food source for micro-organisms is very low and therefore micro-organisms are unlikely to be attracted to it. Other temperatures can be used for this test, provided the results are corrected to a 20°C basis. This test is only applicable to liquid aerobic sludge withdrawn from an aerobic treatment process.

Option 5: Aerobic Processes at Greater than 40°C

This option applies primarily to composted sludge that also contains partially decomposed organic bulking agents. The sludge must be aerobically treated for 14 days or longer, during which time the temperature must always be over 40°C and the average temperature must be higher than 45°C.

This option can be applied to other aerobic processes, such as aerobic digestion, but Options 3 and 4 are likely to be easier to meet than the other aerobic processes.

Option 6: Addition of Alkaline Material

Sludge is considered to be adequately reduced in vector attraction if sufficient alkaline material is added to achieve the following:

- Raise the pH to at least 12, measured at 25°C, and without the addition of more alkaline material, maintain a pH of 12 for at least 2 hours.
- Maintain a pH of at least 11.5 without addition of more alkaline material for an additional 22 hours.

The conditions required under this option are designed to ensure that the sludge can be stored for at least several days at the treatment works, transported, and then used or disposed without the pH falling to the point where putrefaction occurs and vectors are attracted.

Option 7: Moisture Reduction of Sludge Containing no Un-stabilised Solids

Under this option, vector attraction is considered to be reduced if the sludge does not contain unstabilised solids generated during primary treatment and if the solids content of the sludge is at least 75 percent before the sludge is mixed with other materials. Thus, the reduction must be achieved by removing water, not by adding inert materials.

It is important that the sludge does not contain un-stabilised solids because the partially degraded food scraps likely to be present in such sludge would attract birds, some mammals, and possibly insects, even if the solids content of the sludge exceeds 75 percent. In other words, simply dewatering primary sludge to a 75% solid is not adequate to comply with this option. Activated sludge, humus sludge and anaerobically digested sludge can, however be dewatered to 75% solids and comply with option 7.

APPENDIX 3: ESSENTIAL CONDITIONS TO BE INCLUDED IN A CONTRACTUAL AGREEMENT BETWEEN A SLUDGE PRODUCER AND SLUDGE USER

Producer

1. Name and address
2. Name and contact details of responsible person (signatory)
3. Classification of sludge
4. Volume and type (liquid or dewatered) of sludge to be supplied
5. Notification of local authorities involved where applicable

User

1. Name and address
2. Name and contact details of responsible person (signatory)
3. Name of transporter of sludge (where applicable)
4. Name and location of site where sludge will be used (where applicable)
5. Classification of final product (where applicable)

Agreement

1. Specification of commercial product to be produced subject to Volume 5 (where applicable)
2. Inspection of user's activities by any appropriate authority
3. Breach of contract – termination of sludge supply and punitive measures

APPENDIX 4: OPERATIONAL GUIDELINES FOR SLUDGE COMPOSTING

BACKGROUND

Composting is the process whereby organic material such as sludge is decomposed and stabilised under aerobic conditions that promote the development of thermophilic temperatures through biological action. The product is humus-like, stable, free of pathogens and plant seeds and can beneficially and safely be applied to land.

To achieve the correct conditions for successful composting, the following elements are essential:

1. Sludge must be mixed with a "bulking agent" that provides structural support and create voids in the composting matrix to enable air to pass freely through the pile;

2. Air must be introduced into the pile to promote the biological activity;

3. Sufficient organic energy must be present in the feed sludge to enable the biological activity in the pile to generate the required pasteurising temperatures (65-70°C); and

4. The nutrient mix of the sludge must be suitable to promote bacteriological growth. The optimal C:N ratio is approximately 20:1 and sludge tends to contain sufficient nitrogen to meet this requirement.

As a Class A1a product is required, the composting plant will have to be designed and operated at very high standards. The major design and operational aspects of such a composting plant are outlined below.

DIFFERENT COMPOSTING CONFIGURATIONS

There are two basic types of composting systems, loosely referred to as "open" and "reactor" systems. Reactor configurations are those in which the sludge/bulking agent mix is placed in an enclosed reactor where it is aerated and normally agitated in some way. Most of these are systems marketed by process contractors and tend to be capital intensive and, due to their complexity and high maintenance nature, they are unlikely to be viable under Southern African conditions and are not addressed further in this Guideline.

Open systems are batch composting systems that make use of piles of material laid out on concrete slabs. Two main configurations based on this principle are widely used and are described below:

Windrow Configuration

This system comprises of long piles, or "windrows" of sludge mixed with bulking agent. Oxygen is introduced into the piles primarily as a result of natural ventilation which is induced by the temperature gradients that develop within the pile. As the pile heats up due to biological action, the air rises, drawing fresh air into the pile. In order to provide the porosity needed for effective natural ventilation a high proportion of bulking agent is required in the composting mixture. These piles are also agitated at regular intervals by breaking them up and reforming them using either front-end loaders or specialised equipment. This results in the redistribution of the material within the pile to ensure that all the material is subjected to the high temperature stabilisation and pasteurisation process within the pile and also ensures that the pile remains porous to air movement.

Although this is a relatively simple and inexpensive composting system it is not considered reliable enough to produce a high quality compost product complying with the requirements of an A1a classification.

Static Pile Configuration

In this configuration the compost is also laid out in long piles. However the piles are not broken up and reformed, and the oxygen is supplied into the pile by means of forced aeration. The aeration system comprises of a blower connected to an air distribution system under the pile that introduces air into the pile, either by a blowing or sucking action. Because the pile is not broken up and reformed on a regular basis the material is not mixed and therefore much more care has to be exercised to ensure that the aeration is properly distributed throughout the pile so that it is all subjected to the necessary stabilising process and pasteurising temperatures.

Note: The static pile configuration is considered **ideal for producing Class A1a compost** under Southern African conditions because it is relatively easy to control and monitor.

DESIGN AND OPERATIONAL CONSIDERATIONS

In order to produce a Class A1a product the following aspects of a composting plant have to be considered and optimised:

Quality of sludge feedstock

Firstly, for a composted sludge to be classified as A1a quality it must comply with the organic and inorganic pollutant limits laid out in Part B2 this document. The decomposed bulking agent adds relatively little to the mass of the compost and so the pollutant concentration of the final product remains essentially the same as that of the feedstock sludge. Therefore if the sludge to be composted does not comply with the Pollutant class **a** limits, it is unlikely that the final product will comply and it should be deduced that the sludge in question is not suitable for composting to A1a quality.

Moisture content of sludge feedstock

The sludge feedstock to be composted must contain sufficient organic energy to drive the biological process and generate the required pasteurising temperatures. The energy levels (or degree of stability) of the sludge is closely linked to the moisture content. The wetter the sludge cake the more energy is required in order to evaporate the excess water.

- Stabilised sludge from anaerobic digesters and activated sludge plants will only contain sufficient energy to drive the composting process if they are dewatered to approximately 30-35% solids; while
- Primary sludge only needs to be dewatered to between 20-25% solids.

Type of sludge

- Well stabilised sludge (anaerobic digesters or extended aeration activated sludge plants) **are not suitable** for composting due to insufficient organic energy to enable the biological activity to generate the required pasteurising temperatures of 65-70^{o}C.
- It is recommended that waste activated sludge be blended with primary sludge at no less than a 50:50 dry weight ratio before use as compost feed stock.

Bulking agent

Sludge cake, even when dewatered to solids contents of 20% will have very little structural strength to stand-up permanently in a pile and will have very little pore spaces to allow air to pass through it. It therefore has to be mixed with a bulking agent comprising of large angular solid pieces which will form a three dimensional matrix. This will provide the sludge cake/bulking agent mixture with structural support and form voids large enough to be partially filled with wet substrate and to provide porosity to the pile for air flow through it.

Different types of bulking agent include:

- Organic material like wood chips or garden waste, which is most widely used, as well as straw, rice hulls and peanut shells. These are all biodegradable and over time are integrated into the final compost product and therefore have to be replaced on an on-going basis.

- Inorganic substances such as shredded motor vehicle tyres and plastic pieces can also be used. These have the advantage of being virtually non-biodegradable and can therefore be readily removed from the compost and recycled and very little make-up is required. However they generally require a high initial capital outlay and can result in the final product being contaminated with such items as stainless steel wire from the tyres. As a result they are not widely used.

Depending on the size and nature of the bulking agent used and the solids concentration of the sludge cake, bulking agents are normally added to the sludge in proportion of between 1.5:1 (ideally shaped wood chips) to 3:1 (garden waste) by volume.

Aeration

The aeration of the compost forms an integral and essential part of the composting process. Its major contribution to the process is three-fold namely:

- It must satisfy the oxygen demand of the bacterial breakdown of organic waste within the sludge, which drives the stabilisation and pasteurisation function of the process;

- It contributes to the drying of the sludge. Moisture evaporates in the heated pile and the air flow carries away the vapour formed;

- The airflow can be used to control the temperature of the pile. If the aeration rate is too low the bacterial action will be retarded and the temperature will drop. If the rate is high enough to provide optimal bacterial action it may result in a build-up of the heat generated to a point that the pile becomes too hot for bacterial activity and in this event the airflow may have to be increased in order to carry away excessive heat generated.

Air can be introduced into the pile using the following methods:

- Fresh, ambient air can be blown into the bottom of the pile using positive pressure from a blower or

- It can be drawn into the pile by the negative pressure created by the forced extraction of the hot process air from the bottom of the pile also using a blower.

Both systems are widely used and each has their advantages and disadvantages.

- Blowing air into the pile has the advantage of better flow distribution, better moisture removal, a lower bulking agent requirement, lower head losses and the fact that consequently larger piles can be used. However it has the major disadvantage of creating potential odour problems and fly breeding. The exhaust gases from the pile are discharged to the atmosphere in an uncontrolled, diffused manner and if they contain malodorous substances they can create a problem. Also the gaseous by-products of biothermal decomposition are forced to the outer layers of the pile where they condense and are very attractive to flies. This can result in major fly breeding problem developing.

- Sucking out the exhaust gases has the advantage that the discharge of the gases occurs at a single point and can be controlled, and if necessary can be treated to remove malodorous substances. It also does not create an ideal fly breeding environment in the outer layers of the pile. However it does have the disadvantage of less efficient flow distribution and higher head losses.

Quantity of Air Required

The quantity of oxygen, and hence air required for the system, is largely dependent on the organic and moisture content of the feed sludge. An average air flow of between 50 and 100 $m^3/hr/ton_{dry\ solids}$ composted is required. Allowance should however be made for peak flow rates of up to 400 $m^3/hr/ton$ due to intermittent use of the blowers and the fact that the oxygen demand will be higher at the beginning of the composting cycle than at the end.

Air Distribution System

The air distribution system essentially comprises of perforated pipes laid at the base of the pile and connected to centrifugal blowers which either blow air into the pile or draw fresh air into it by sucking the exhaust gases from the pile.

Inexpensive, disposable, relatively small diameter (150-200 mm) perforated plastic piping are used on small systems to form the air distribution. The pipes are normally imbedded in a layer of bulking agent before the sludge cake/bulking agent pile is build above it. If care is exercised in removing the pile after treatment the pipes can be recovered and reused several times.

On larger, more sophisticated plants permanent distribution pipe systems are used, connected to permanently mounted centrifugal blowers. These can either comprise of pipe networks laid above ground or set in concrete slabs. The above ground networks are less expensive and easier to keep clean and unblock, but great care has to be exercised not to damage them when removing the treated compost with mechanical equipment.

Controlling the Aeration Rate

The control of the aeration rate can vary in sophistication from manual throttling of valves or on/off sequencing by timers to feedback control based on temperature or oxygen concentrations in the compost pile or exhaust gas stream.

In the former, less sophisticated mode the operator would establish by experience what throttling valve setting or timing sequence would produce adequate temperatures in the pile and a stable, pasteurised product and would control the aeration accordingly.

In the latter mode either thermocouples or oxygen probes would be inserted into the pile or exhaust gas streams and used to modulate the air flow rate through a PLC to maintain a set point. This more sophisticated mode is recommended when operating a facility to produce a Class A1a product because it removes a large element of potential operator error. Temperature control is normally used for wetter substrates because the air flow requirement is dominated by the moisture removal function and the oxygen concentration is always high under these conditions. For drier substrates the air flow is dominated by the biological oxygen demand in the pile and so the oxygen concentration varies significantly in response to the air supply rate.

Duration of composting process

Compost will be pasteurised and stabilised to a large degree after **21 days** of high rate composting using forced aeration.

Curing

To achieve product quality commensurate with Class A1a classification, further stabilisation will be required in curing piles where the more slowly biodegradable products in the feed as well as the products of the biological degradation during the high rate composting phase are broken down. The normally accepted duration of the curing process is **30 days**.

There are 2 curing options:

- The compost can be screened after the primary treatment stage and placed in curing piles that are subjected to forced aeration. The advantage of this strategy is that the area required for the curing process is greatly reduced and the bulking agent can be re-used directly in the next composting batch. The disadvantage is that aeration of the pile is necessary.
- The alternative is to place the compost in curing windrows before screening and to rely on natural ventilation through the bulking agent matrix caused by temperature gradients within the pile to provide the oxygen required. This will require more space, but will significantly reduce cost and operational complexity. A further advantage of this option is that the compost will be much drier after the curing process and hence the screening operation will be much more efficient.

Screening

In composting systems the provision of bulking agent constitutes a significant cost component of the system and so it has to be separated from the final product so that it can be reused as often as possible. Removing the bulking agent also ensures that the final product comprises only fine, friable compost particles.

The effectiveness of the screening process is highly dependent on the moisture content of the product. At high moisture contents the wet sludge tends to adhere to the bulking agent and is screened out with it. The expected screening efficiency will be as follows:

- 30% at a moisture content of 60%;
- 70% at a moisture content of 50%; and
- 90% at a moisture content of 40%.

Depending on the size of the bulking agent and the moisture of the compost being screened, the screen opening size used is normally between 12 mm and 18 mm.

Recycling of Compost

As stated earlier, the sludge cake produced at South African WWTPs tend to have relatively low solids content of below 20% by weight and this is generally too wet for effective composting. One way of overcoming this is to recycle treated compost that has normally been dried to approximate 60% solids during the composting process.

Two options are available for recycling the compost, namely:

- The compost can be recycled prior to screening so that product and bulking agent are recycled together. This has the major advantage that the recycled product does not have to be screened which takes a significant load off the screening process.
- Only screened product is recycled which means that the recycled product has to pass through the screens, thereby greatly increasing the load on the screening equipment.

Considering that the bulking agent is already recycled after screening, it makes sense that recycling occurs ahead of screening. Recycling of compost also reduces the required mix ratio for bulking agent relative to feed cake from 2:1 to between 1.5:1 and 1:1 and therefore it is well worth considering.

Bulk materials handling

A major feature of operating a composting plant is the handling of the bulk materials. The following bulk handling functions are required:

- The dewatered sludge cake has to be transported from the dewatering facility to the composting facility and stockpiled;
- The bulking agent has to be transported to the composting facility and stockpiled;
- The sludge cake and bulking agent have to be transported to the mixing facility, where it has to be fed into the mixer;
- The sludge cake/bulking agent mixture has to be transported from the mixer to the composting area and formed into piles;
- The compost product has to be transported to the curing area and formed into piles;
- The recycled compost has to be transported to the mixing facility and mixed with the sludge cake/bulking agent stream;
- The final cured compost has to be transported to the screening facility and fed to the screens.
- The final screened compost product has to be transported from the screening facility to the final stockpile;
- The screened bulking agent has to be transported from the screening facility to the bulking agent stockpile.

Odour Control

By its nature the composting process carries a high risk of odour nuisance from the production of such substances such as volatile fatty acids, amines, aromatics, hydrogen sulphide and ammonia. There are four main methods for removing these substances from the exhaust gases from the composting process:

- **Absorption** – This is the process where the odour creating substances are dissolved in a scrubbing liquid. These systems tend to be expensive and are complex to operate and have, to a large extent been replaced by adsorption and biological oxidation systems.

- **Adsorption** – Adsorption is the process whereby specialised solid compounds such as activated carbon or specially treated alumina based media remove the malodorous compounds from the gas flows passed through them by adsorption onto their surface. These specialised media are packed into towers and the air to be treated is drawn through using blowers.

These systems are very effective in removing odours, but they suffer from the drawback that adsorption does not destroy the odour causing compound, but merely captures and stores it. They therefore have a finite capacity and have to be either regenerated or replaced once they have become saturated or odour break-through starts to occur.

- **Oxidation in Activated Sludge Plants** – Most malodorous compounds are broken down by biologically mitigated oxidation and therefore an activated sludge reactor is an ideal environment for this to occur. On plants where use is made of fine bubble diffused air aeration systems the exhaust gas can be blended in with the aeration air ahead of the blowers. However, consideration has to be given to possible corrosion potential created by the presence of sulphur products in the gas. Cognisance must also be given to the fact that the exhaust gases from the compost pile will be low in oxygen and will therefore reduce the efficiency of the aeration system. To overcome this use can be made of dedicated systems aimed at only disposing of the malodorous air, but this tends to be expensive as the air has to be compressed to at least 0.5 bar to overcome the hydrostatic water pressure in the tank.

- **Biofiltration** – Biofiltration is a system used for scrubbing malodorous compounds from air using a biologically active, solid media bed. The compounds are absorbed/adsorbed from the stream and subsequently oxidised by the bacteria in the bed.

  These systems are widely used on composting plants because the filter bed can be made up from the compost produced at the plant.

MONITORING OF PRODUCT QUALITY

Each batch of the final compost product to be distributed to the public must comply with the A1a classification. It must be assured that the sample being tested is statistically representative of the batch of compost it is taken from.

Microbiological class

It is recommended that a compost sample should be collected and analysed for its Microbiological content before it enters the curing stage because by this time all the helminths ova should have been deactivated by the high temperatures generated in the composting piles. If viable helminths ova are found in this compost then the composting period should be extended to ensure compliance because the temperatures in the curing piles will be lower than in the composting piles.

Stability class

Sludge composted in a properly designed and operated plant should readily comply with at least Options 2 and 5 described in Appendix 2 of this document.

Pollutant class

If the batch being tested does not comply with the Pollutant class limits, it must either be classified at whatever level it does comply with and be disposed of accordingly or be stockpiled and subsequently blended with a batch that does comply.

DEFINITIONS AND DESCRIPTION OF KEY TERMS

Acceptable exposure:	The concentration of a substance that will have minimal effect on the environment or human health.
Agricultural land:	Land on which a food crop, a feed crop, or a fibre crop is grown. This includes grazing land and forestry.
Agronomic rate:	The sludge application rate (dry-weight basis) designed (i) to provide the amount of nitrogen needed by the food crop, feed crop, fibre crop, cover crop, or vegetation grown on the land and (ii) to minimise the amount of nitrogen in the sewage sludge that passes below the root zone of the crop or vegetation grown on the land to the groundwater.
Agricultural use:	The use of sludge to produce agricultural products. It excludes the use of sludge for aquaculture and as an animal feed.
Air pollution control (APC) device	Mechanism or equipment that cleans emissions generated by an incinerator by removing pollutants that would otherwise be released to the atmosphere.
Annual pollutant loading rate:	The maximum amount of a pollutant that can be applied to an area of land during a 365-day period.
Assimilative capacity:	This represents the ability of the receiving environment to accept a substance without risk.
Available metal content (Soil):	Specific to Volume 2. Metal fraction extracted with ammonium nitrate in soil samples.
Beneficial uses:	Use of sludge with a defined benefit, such as a soil amendment.
Bioavailability:	Availability of a substance for uptake by a biological system.
Biosolids:	Stabilised Sludge. Organic solids derived from biological wastewater treatment processes that are in a state that they can be managed to sustainably utilise the nutrient, soil conditioning, energy, or other value.
Bottom ash:	Residue remaining in the incinerator after waste is burned
Bund wall:	A properly engineered and constructed run-off interception device around a waste disposal site or down slope of a waste disposal site.
Chronic Risk Specific concentration (CRSC):	The allowable increase in the annual average ground-level ambient air concentration for pollutants at or beyond the property line of a thermal treatment plant.
Co-disposal (liquid with dry waste):	The mixing of high moisture content or liquid waste with dry waste. This affects the water balance and is an acceptable practice on a site equipped with leachate management measures.
Co-disposal (dewatered sludge with dry waste):	The mixing of dewatered sludge with dry waste in a general landfill site or hazardous landfill site without affecting the water balance of the site.

Composting: The biological decomposition of the organic constituents of sludge and other organic products under controlled conditions.

Contaminate: The addition of foreign matter to a natural system. This does not necessarily result in pollution, unless the attenuation capacity of the natural system is exceeded.

Controlled access: Where public or livestock access to sludge application areas is restricted or controlled, such as via fences or signage, for a period of time stipulated by this guideline.

Cradle-to-grave: A policy of controlling a Hazardous Waste from its inception to its ultimate disposal.

Cumulative pollutant loading rate: The maximum amount of a pollutant that can be applied to a unit area of land.

Cut-off trench: A properly engineered and constructed trench to intercept and collect run-off.

Dedicated land disposal: Sites that receive repeated applications of sludge for the sole purpose of final disposal.

Delisting: If the estimated environmental concentration (EEC) is less than the Acceptable Exposure (AE) which is 10% of the LC_{50}, the waste can be delisted, i.e. be moved to a lower Hazard Rating or even disposed of at a General Waste landfill with a leachate collection system.

Dewatering: Dewatering processes reduce the water content of sludge to minimise the volumes for transport and improve handling characteristics. Typically, dewatered sludge can be handled as a solid rather than as liquid matter.

Disinfection: A process that destroys, inactivates or reduces pathogenic microorganisms.

Disposal: The discharge, deposit, injection, dumping, spilling, leaking, or placing of any solid waste or hazardous waste into the environment (land, surface water, ground water, and air).

Disposal site: A site used for the accumulation of waste with the purpose of disposing or treatment of such waste. See also Waste Disposal Site.

Domestic sewage: Waste and wastewater from humans or household operations that is discharged to, or otherwise enters a treatment works.

Dose: In terms of monitoring exposure levels, the amount of a toxic substance taken into the body over a given period of time. See also LD_{50}.

Domestic waste: Waste emanating, typically, from homes and offices. Although classified as a General Waste, this waste contains organic substances and small volumes of hazardous substances.

Dose-response: How an organism's response to a toxic substance changes as its overall exposure to the substance changes. For example, a small dose of carbon monoxide may cause drowsiness; a large dose can be fatal.

Drying: A process to reduce the water content further than a dewatering process. The solids content after a drying process is typically > 75%.

Dry-weight (DW) basis: The method of measuring weight where, prior to being weighed, the material is dried at 105°C until reaching a constant mass (i.e. essentially 100% solids content).

Dump: A land site where wastes are discarded in a disorderly or haphazard fashion without regard to protecting the environment. Uncontrolled dumping is an indiscriminate and illegal form of waste disposal. Problems associated with dumps include multiplication of disease-carrying organisms and pests, fires, air and water pollution, unsightliness, loss of habitat, and personal injury.

E. coli: A group of bacteria normally found in the intestines of humans and animals. Most types of *E. coli* are harmless, but some active strains produce harmful toxins and can cause severe illness. In sanitary bacteriology, *Escherichia coli* is considered the primary indicator of recent faecal pollution.

Ecotoxicity: Ecotoxicity is the potential to harm animals, plants, ecosystems or environmental processes.

Electrostatic precipitator (ESP) An electrostatic precipitator (ESP), or electrostatic air cleaner is a particulate collection device that removes particles from a flowing gas (such as air) using the force of an induced electrostatic charge.

Emission: The release or discharge of a substance into the environment. Generally refers to the release of gases or particulates into the air.

Emission Standards: Government standards that establish limits on discharges of pollutants into the environment (usually in reference to air).

Environment: Associated cultural, social, soil, biotic, atmospheric, surface and groundwater aspects associated with the disposal site that could potentially be, impacted upon by the disposal.

Environmental Impact Assessment (EIA): An investigation to determine the potential detrimental or beneficial impact on the surrounding communities, fauna, flora, water, soil and air arising from the development or presence of a waste disposal site.

Estimated Environmental Concentration (EEC): The Estimated Environmental Concentration represents the concentration of a substance in the aquatic environment when introduced under worst case scenario conditions, i.e. directly into a body of water. It is used to indicate possible risk, by comparison with the minimum concentration estimated to adversely affect aquatic organisms or to produce unacceptable concentrations in biota, water or sediment.

Faecal coliform: *Faecal coliforms* are the most commonly used bacterial indicator of faecal pollution. *Faecal coliforms* are bacteria that inhabit the digestive system of all warm-blooded animals, including humans.

Flue gas: The exhaust gases from a combustion / oxidation processes in the stack that discharges them to the atmosphere.

Fly ash: Tiny solid particles of ash that escape the incinerator; removed by pollution-control equipment.

Hazard Rating: A system for classifying and ranking Hazardous waste according to the degree of hazard they present.

Hazardous waste: Waste that may, by circumstances of use, quantity, concentration or inherent physical, chemical or infectious characteristics, cause ill health or increase mortality in humans, fauna and flora, or adversely affect the environment when improperly treated, stored, transported and disposed of.

Helminth ova: The eggs of parasitic intestinal worms.

Hydrogen chloride (HCl): Hydrogen chloride is a colourless gas with a pungent odour; its aqueous solution is known as hydrochloric acid. Hydrogen chloride is produced by burning hydrogen and chlorine together.

Incineration: Incineration is both a form of treatment and a form of disposal. It is simply the controlled combustion of waste materials to a non-combustible residue or ash and exhaust gases, such as carbon dioxide and water.

Integrated Environmental Management (IEM): A code of practice ensuring that environmental considerations are fully integrated into the management of all activities in order to achieve a desirable balance between conservation and development.

Land application: The spraying or spreading of wastewater sludge onto the land surface; the injection of wastewater sludge below the land surface; or the incorporation of wastewater sludge into the soil so that the wastewater sludge can either condition the soil or fertilise crops or vegetation grown in the soil.

Land disposal: Application of sludge where beneficial use is not an objective. Disposal will normally result in application rates that exceed agronomic nutrient requirements or cause significant contaminant accumulation in the soil.

Landfill: To dispose of waste on land, whether by use of waste to fill in excavation or by creation of a landform above ground, where the term “fill” is used in the engineering sense.

LC_{50}: The median lethal dose is a statistical estimate of the amount of chemical, which will kill 50% of a given population of aquatic organisms under standard control conditions. The LC_{50} is expressed in mg/l.

LD_{50}: The median lethal dose is a statistical estimate of the amount of chemical, which will kill 50% of a given population of animals (e.g. rats) under standard control conditions.

Leachate: An aqueous solution with a high pollution potential, arising when water is permitted to percolate through decomposing waste.

Liner: A layer of low permeability placed beneath a landfill and designed to direct leachate to a collection drain or sump, or to contain leachate. It may comprise natural materials, synthetic materials, or a combination thereof.

Maximum available threshold (MAT): The maximum available (NH_4NO_3 extractable) metal concentration allowed for soils receiving sludge.

Maximum permissible level: The maximum total metal concentration allowed in soils at sludge disposal sites. Soil remediation would not be necessary except if this level is exceeded.

Minimum Requirement: A standard by means of which environmentally acceptable waste disposal practices can be distinguished from environmentally unacceptable waste disposal practices.

Monthly average: The arithmetic mean of all measurements taken during a given month.

Most probable number (MPN): A unit that expresses the amount of bacteria per gram of total dry solids in wastewater sludge.

Nitrogen oxides (NOx): A generic term for mono-nitrogen oxides. These oxides are produced during combustion, and are of interest in air pollution.

Off-site: Sludge disposal site outside the boundaries of the wastewater treatment plant (WWTP).

On-site: Sludge disposal site within the boundaries of the wastewater treatment plant (WWTP).

Pathogenic organisms: Disease-causing organisms. This includes, but is not limited to, certain bacteria, protozoa, viruses, and viable helminth ova.

pH: The logarithm of the reciprocal of the hydrogen ion concentration. The pH measures acidity/alkalinity and ranges from 0 to 14. A pH of 7 indicates the material is neutral. Moving a pH of 7 to 0, the pH indicates progressively more acid conditions. Moving from a pH of 7 to 14, the pH indicates progressively more alkaline conditions.

Polycyclic aromatic hydrocarbons (PAH): Chemical compounds that consist of fused aromatic rings. Many of them are known or suspected carcinogens. They are formed by incomplete combustion of carbon-containing fuels.

Pollution: The direct or indirect alteration of the physical, chemical or biological properties of a (water) resource so as to make it less fit for any beneficial purpose for which it may reasonably be expected to be used; or harmful or potentially harmful to the welfare, health or safety of human beings; to any aquatic or non-aquatic organisms; to the resource quality; or to property.

Pozzolanic properties The characteristic of a material to form compounds possessing cementatious properties when reacting with calcium hydroxide in the presence of water at room temperature.

Primary treatment: Treatment of wastewater prior to other forms of treatment and involving settling and removal of suspended solids.

Qualified person: A person is suitably qualified for a job as a result of one, or any combination of that person's formal qualifications, prior learning, relevant experience; or capacity to acquire, within a reasonable time, the ability to do the job.

Receptor: Sensitive component of the ecosystem that reacts to or is influenced by environmental stressors.

Recycle: The use, re-use, or reclamation of a material so that it re-enters the industrial process rather than becoming a waste.

Rehabilitation: Restoring a waste site for a new industrial function, recreational use, or to a natural state.

Remediation: The improvement of a contaminated site to prevent, minimize or mitigate damage to human health or the environment. Remediation involves the development and application of a planned approach that removes, destroys, contains or otherwise reduces the availability of contaminants to receptors of concern.

Residue: A substance that is left over after a waste has been treated or destroyed.

Responsible person: A person(s), who takes professional responsibility for ensuring that all or some of the facets of the handling and disposal of Hazardous Waste are properly directed, guided and executed, in a professionally justifiable manner.

Restricted agricultural use: Use of sludge in agriculture is permitted but restrictions apply (crop restrictions, access restrictions, etc.).

Risk: The scientific judgement of probability of harm. This basic and important concept has two dimensions: the consequences of an event or set of circumstances and the likelihood of particular consequences being realised. Both dimensions apply to environmental risk management with it generally being taken that only adverse consequences are relevant.

Risk assessment: The evaluation of the results of risk analysis against criteria or objectives to determine acceptability or tolerability of residual risk levels, or to determine risk management priorities (or the effectiveness or cost-effectiveness of alternative risk management options and strategies).

Risk management: The systematic application of policies, procedures and practices to identify hazards, analysing the consequences and the likelihood associated with those hazards, estimating risk levels, assessing those risk levels against relevant criteria and objectives, and making decisions and acting to reduce risk levels to acceptable environmental and legal standards.

Secondary Treatment: Treatment of wastewater that typically follows primary treatment and involves biological processes and settling tanks to remove organic material.

Sludge-amended soil: Soil to which sludge has been added.

Sludge: Solid, semi-solid, or liquid residue generated during the treatment of domestic sewage in a treatment works. Wastewater sludge includes, but is not limited to, domestic septage; scum or solids removed in primary, secondary, or advanced wastewater treatment processes; and material derived from wastewater sludge in a wastewater sludge incinerator. It does not include the grit and screenings generated during preliminary treatment of domestic wastewater in a treatment works.

Soil organisms: A broad range of organisms, including microorganisms and various invertebrates living in or on the soil.

Specific oxygen uptake rate (SOUR): The mass of oxygen consumed per unit time per unit mass of total solids (dry-weight basis).

Stabilisation: The processing of sludge to reduce volatile organic matter, vector attraction, and the potential for putrefaction and offensive odours.

Stabilised sludge: Organic solids derived from biological wastewater treatment processes that are in a state that they can be managed to utilise the nutrient, soil conditioning, energy, or other value.

Sterilise: Make free from microorganisms.

Sulphur dioxide (SO_2): Inorganic compound, heavy, colourless, poisonous gas. It has a pungent, irritating odour (the smell of a just-struck match). Sulfur dioxide is formed when sulfur-containing fuels are burned; in the atmosphere it can combine with water vapour to form sulfuric acid, a major component of acid rain.

Supplier: A person or organisation that produces and supplies sludge for use. This includes a water business producing and treating sludge and processors involved in further treatment.

Surface water interception mechanism: A mechanism placed between the disposal site and the surface water body to intercept possible run-off from the disposal site before it can reach the water body.

Sustainability: Being able to meet the needs of present and future generations by the responsible use of resources.

Sustainable use: The use of nutrients in sludge at or below the agronomic loading rate and/or use of the soil conditioning properties of sludge. Sustainable use involves protection of human health, the environment and soil functionality.

Thermal treatment The treatment of waste in a device which uses elevated temperatures as the primary means to change the chemical, physical, or biological character or composition of the waste.

Total investigative level (TIL): The total metal concentration in agricultural soils where further investigation is necessary before sludge application can commence.

Total load capacity: The capacity of a landfill site to accept a certain substance or the amount of a substance, which can be safely disposed of at a certain site. The total load capacity is influenced by the concentration levels and mobility of the waste, and by the landfill practice and design.

Total maximum threshold (TMT): The maximum total metal concentration allowed in agricultural soils receiving sludge.

Total metal content: Metal fraction extracted using an *aqua regia* solution (HCL/HNO_3 solution).

Total trigger value: The total metal concentration in soils at disposal sites indicating that additional management options should be implemented to reduce the impact on the soil.

Toxic: Poisonous.

Toxicity: An intrinsic property of a substance which can cause harm or a particular adverse effect to humans, animals or plants at some dose.

Toxicity Characteristic Leaching Procedure (TCLP): A test developed by the USA Environmental Protection Agency to measure the ability of a substance to leach from the waste into the environment. It thus measures the risk posed by a substance to groundwater.

Toxic equivalence: The international method of relating the toxicity of various dioxin/furan congeners to the toxicity of 2,3,7,8-tetrachlorodibenzo-p-dioxin.

Transporters:	A person, organisation, industry or enterprise engaged in or offering to engage in the transportation of waste.
Treatment:	Treatment is used to remove, separate, concentrate or recover a hazardous or toxic component of a waste or to destroy or, at least, to reduce its toxicity in order to minimise its impact on the environment.
Unrestricted agricultural use:	Sludge is of such good quality that it can be used in agricultural practices without any restrictions.
VAR:	Vector Attraction Reduction.
Vector attraction:	The characteristic of wastewater sludge that attracts rodents, flies, mosquitoes, or other organisms capable of transporting infectious agents.
Vectors:	Any living organisms that are capable of transmitting pathogens from one organism to another, either: (i) mechanically by transporting the pathogen or (ii) biologically by playing a role in the lifecycle of the pathogen. Vectors include flies, mosquitoes or other insects, birds, rats and other vermin.
Waste:	An undesirable or superfluous by-product, emission, or residue of any process or activity, which has been discarded, accumulated or stored for the purpose of discarding or processing. It may be gaseous, liquid or solid or any combination thereof and may originate from a residential, commercial or industrial area.
Waste disposal site:	Any place at which more than 100kg of a Hazardous Waste is stored for more than 90 days or a place at which a dedicated incinerator is located.
Wastewater Sludge:	The material recovered from predominantly domestic wastewater treatment plants. (Also see Sludge).
Wastewater Treatment Plant (WWTP):	Any device or system used to treat (including recycling and reclamation) either domestic wastewater or a combination of domestic wastewater and industrial waste of a liquid nature.
Wet weight:	Weight measured of material that has not been dried (see Dry-weight basis).