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Sludge Treatment and Disposal

Management Approaches and Experiences

By ISWA's Working Group on Sewage & Waterworks Sludge
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Foreword

Wastewater treatment plants are becoming more advanced and more common world wide. In recent years, significant progress has been made in several countries to curb water pollution from municipal wastewater. Almost the entire population of Denmark is now served by wastewater treatment facilities and more than 90% of the population in Sweden, the Netherlands and Luxembourg is served by treatment plants. A problem that needs to be considered carefully is the efficient and environmentally sound management of the sludge generated by these plants. When processing sludge it is critical not to fall into the trap of simply redirecting the pollution that originally affected water, to other media, such as soil and air. This can happen through the use of inappropriate technologies or by applying disposal approaches unsuitable for the local conditions.

This report describes various methods of sludge treatment and disposal: it is intended for those charged with the task of determining the fate of sludge, providing them with the information necessary to select among action alternatives. The report has been developed thanks to co-operation between the European Environment Agency (EEA) and the International Solid Waste Association (the Working Group on Sewage and Waterworks Sludge.) This collaboration has allowed not only the analysis, condensation and assessment of the quality of this information in an efficient and comprehensive manner but also the organisation of this document in the structured presentation found here.

One of programmes of the EEA is to develop documents to address environmental issues that may support more efficient implementation of environmental policies. This responds to two main objectives: the pooling of existing information on different techniques without promoting or supporting specific ones; and the dissemination of relevant facts and figures to promote the wise management of natural resources. We believe that this publication – which aims to give a balance between technical and practical information – is a significant step towards meeting these objectives. The EEA is aware of the controversy raised by incineration, which has to be considered very carefully, but to respect the original idea of the programme we had to assure that the full range of techniques used today were covered. The final choice is left to the users of this information.

The reader will find a discussion on sludge characterisation by physical, chemical and biological parameters, described by Ludivico Spinosa, who also developed the work on transportation and storage. Agricultural use of sludge was prepared by Alice Saabye, which is followed by a section on composting of sludge by Isabelle Coulomb. Drying techniques are illustrated in Chapter Seven by Ådne Ø. Utvik. A chapter on incineration including vitrification and co-incineration was prepared by Isabelle Coulomb. A section on accumulation and landfilling of sludge was prepared by Bela Deak. The report ends with a look at new technologies and environmental impact assessments, also presenting a tree for sludge disposal. Legislation related to sludge treatment and disposal is given in the Appendix.

We would like to thank all contributors and reviewers of this document who have co-operated to produce this important report.

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1. Introduction

This booklet gives a general perspective of the alternative methods for handling and disposing sewage waste water sludge. It provides an overview of the different methods for processing and disposing sludge generated by waste water treatment plants.

The booklet is intended to be a helping hand to both technical experts as well as politicians, public officials, decision makers and others who need to see things in a broader perspective when faced with the choice between alternative methods of handling and disposal of sludge.

This booklet has been written by members of the ISWA Working Group on Sewage & Waterworks Sludge.

2. Background

The percentage of the population served by sewage waste water treatment facilities varies considerably among the countries of the EU. The differences among thirteen member countries of the Organisation for Economic Co-operation and Development (OECD) are illustrated in figure 2.1.

For some countries an improvement in the number, size and efficiency of the treatment plants would have significant positive impacts on the quality and health of aquatic environments.

Dry weight per capita production of sewage sludge resulting from primary and secondary treatment is about 90 grams per day per person, which is more or less the same in all EU countries where municipal communities are served by two stage physical, mechanical and biological processing plants. After the implementation of the Urban Waste Water Treatment Directive (UWWTD) (91/271/EEC), the vast majority of the EU 15 population will be served by sewage treatment facilities by the year 2005. This is expected to result in the generation of about 10.7 million tons (dry weight) of sewage sludge every year or about a 38% increase from the 7.7 million tons produced today. This cumulative percentage is distributed among the member states as shown in figure 2.2.

Information on the methods and approaches used by different member states for the final disposal of sewage sludge is still uncertain. In some European countries the main practice is landfilling (50 to 75%), while the rest is disposed in agricultural fields as soil conditioner/fertiliser (25 to 35%) or other recycling outlets (e.g. parks, land restoration and landscaping).

Agricultural use of raw sludge or other composting practices is encouraged by national authorities as the best way for recycling, while incineration is considered the worst. Directive 86/278/EEC on Sewage Sludge in Agriculture requires, however, that no-one may permit the use of sewage sludge on agricultural land unless specific requirements are fulfilled. The Directive aims at avoiding the accumulation of toxic substances, especially heavy metals, that might reach excessive levels in the soil after a number of applications.

Figure 2.1.

Percentage of the population served by Waste Water Treatment Facilities in 1990
Source: The World Resource Institute „World Resources, 1994-95" Oxford University Press, Oxford, 1994, p. 331

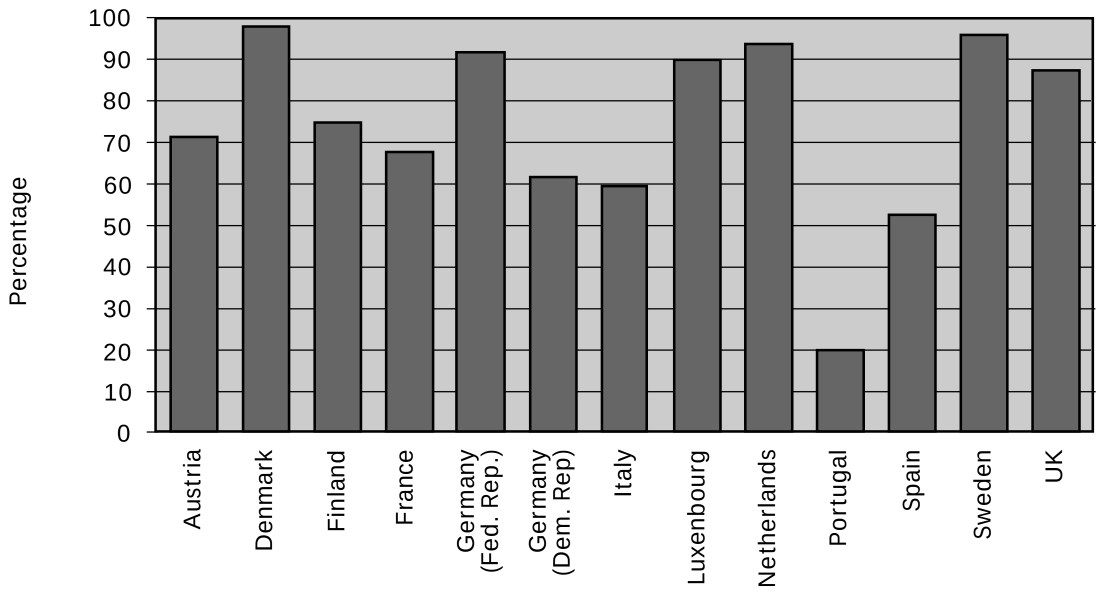
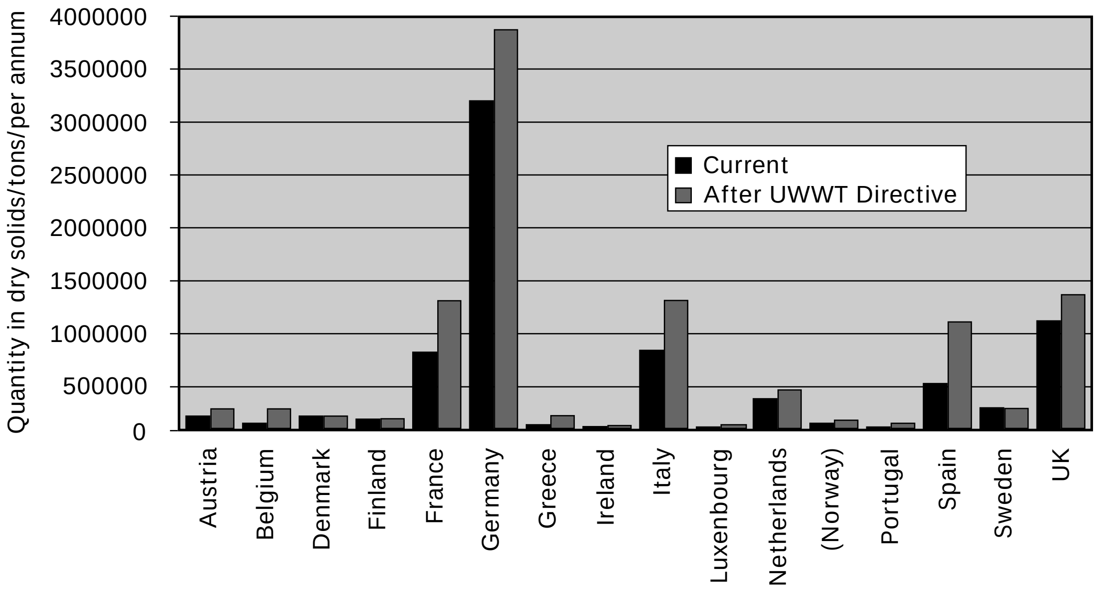


Figure 2.2.

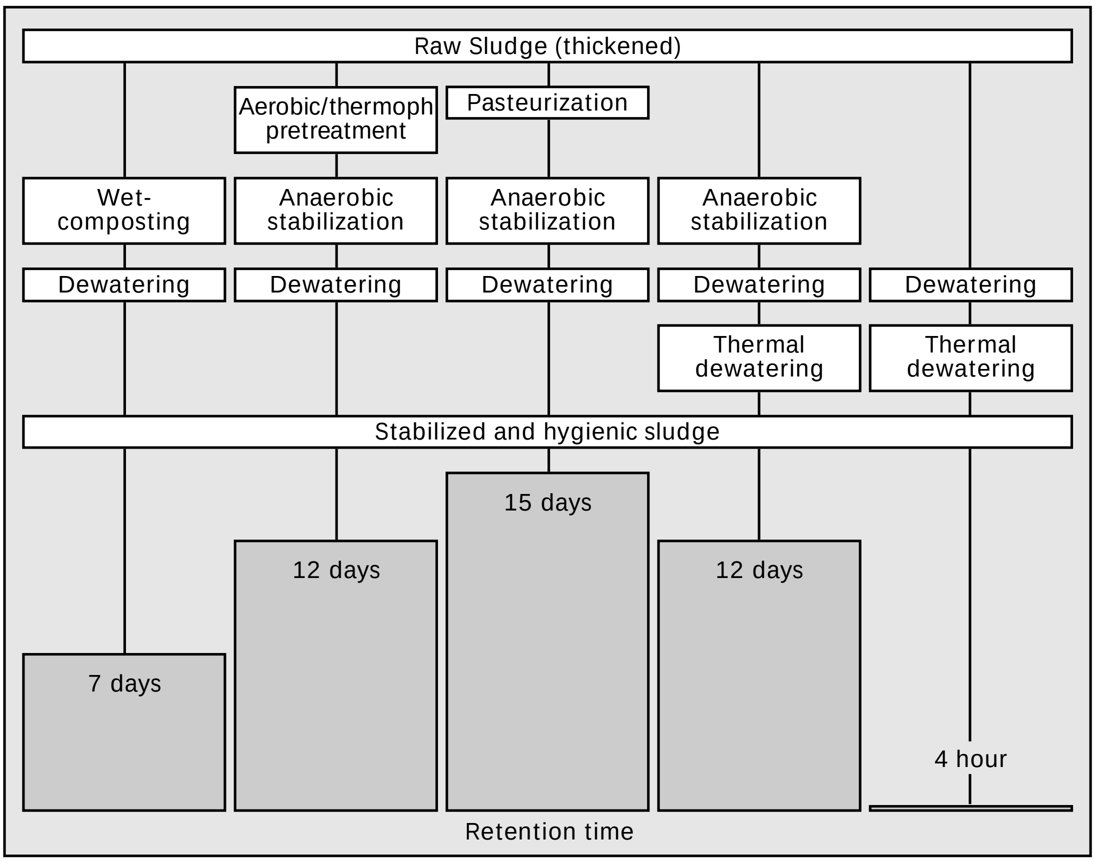


Sludge Generation in member states before and after the Urban Waste Water Treatment Directive *Source: European Waste Water Group, „EU Waste Water Strategy": Observation From the European Waste Water Group", direct communication to ISWA, London, October 10, 1997*

Sea dumping is now prohibited, and landfilling will also be regulated if the new Landfill Directive is passed and the removal of the organic content is made mandatory. The final disposal of sewage sludge remains therefore an unsolved problem; both because the amount generated will increase and also because agriculture can absorb only a limited number of field applications.

The problem could be particularly difficult for the 10 accession countries (Bulgaria,

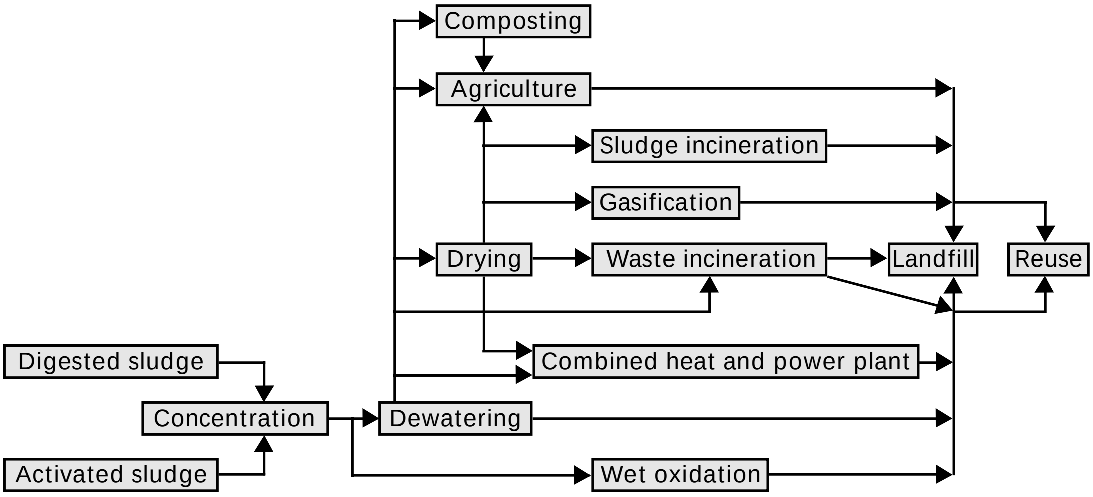
Figure 2.3.



Different methods of pretreatment of sludge

Figure 2.4.

Treatment and disposal routes for sludge



Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia and Slovenia) which will have to transpose the UWWTD and phase in plant treatment and disposal of about 4 million tons of sewage sludge generated every year.

Plant treatment of sludge generated by anaerobic or aerobic digestion, mechanical de-watering and incineration, usually accounts for up to 50% of the total investment in the complete facility. Plant treatment can dramatically reduce the size of the final and more complex disposal problem. Therefore it is important to consider the full range of alternatives for sludge handling and disposal when planning sewage management strategies.

An overview of the pre-treatment methods adopted for transforming and concentrating raw and wet sludge is presented in figure 2.3.

In some countries, thin sludge is still utilised directly as fertiliser in agriculture. However, an increasing part of thin sludge is now processed. The methods used most frequently for treatment and disposal are shown in Figure 2.4.

3. Sludge Characterisation

By Ludovico Spinosa[1]

3.1. Introduction

Sewage sludges exhibit wide variations in their properties depending on origin and previous treatment, but their characterisation based on history only gives qualitative information. Many parameters have therefore been introduced and tests developed to measure specific properties of sludge in relation to particular methods of treatment.

Some of them have been adopted as national standard methods, others as international ones, but essential differences between them remain. For this reason, a vast standardisation activity aiming at defining European standard methods is currently in progress in Europe, under the action called CEN/TC308/WG1.

Conventional characterisation parameters can be grouped in physical, chemical and biological parameters:

- physical parameters give general information on sludge processability and handlability;
- chemical parameters are relevant to the presence of nutrients and toxic/dangerous compounds, so they become necessary in the case of utilisation in agriculture;
- biological parameters give information on microbial activity and organic matter/pathogens presence, thus allowing the safety of use to be evaluated.

A list of parameters which can be used, and their relevance to treatment and disposal steps, is presented in table 3.1.

3.2. Characterisation Parameters

The sludge characteristics which are impor-

Table 3.1.

Disposal and use operations parameters

Method of Treatment and Disposal													
		Stabilisation											
Parameter	Sedimentation	aerobic	anaerobic	chemical	thermal	Thickening	Dewatering	Drying	Transportation	Landfilling	Composting	Agriculture	Incineration
Temperature		x	x				x	x			x		x
Density						x		x	x				
Rheological prop.							x	x	x	x		x	x
Settleability	x					x	x						
Solids concentr.	x	x	x	x	x	x	x	x	x	x	x	x	x
Volatile solids		x	x	x	x				x	x	x	x	x
Digestability			x										
pH		x	x	x			x				x	x	
Volatile acids			x										
Fats and oils		x	x									x	
Heavy metals			x							x	x	x	x
Nutrients		x	x								x	x	
Particle size	x					x	x						
CST						x	x						
Spec. resistance						x	x						
Compressibility							x						
Centrifugability							x						
Calorific value													x
Leachability										x			
Microbiol. prop.		x	x								x	x	

[1] *C.N.R. Water Research Institute, Via F. De Blasio 5, 70123 Bari, Italy*

tant to know, strictly depend on the handling and disposal methods adopted. Below, the most important parameters in relation to the disposal / use operations listed in table 3.1 are briefly discussed.

3.2.1. Agricultural Use

Dry Matter
Dry matter plays a role in the transport, application and spreading operations. Methods and systems of application to land also depend to a great extent on rheological properties.

Volatile Solids (Organic Matter)
The reduction of volatile solids through stabilisation is very important, mainly to avoid odour problems. Organic matter also exerts beneficial effects on land, but changes in the content of organic matter do not significantly modify sludge applicability.

Table 3.1 Disposal and use operations parameters

Nutrients, Heavy Metals, Organic Micropollutants, Pathogens, pH
Application rates are affected by the content of nutrients, heavy metals and organic micropollutants in sludge and soil, while hygienic risks are associated with the pathogens presence. All of the above factors are influenced by pH.

3.2.2. Composting

Temperature, Dry Matter, Volatile Solids
The process performance strictly depends on temperature, dry matter and volatile solids in terms of both biological evolution and hygienization (pathogens reduction). In particular, a concentration of solids of 40-60% and a temperature around 60°C are generally required.

Nutrients
The C / N ratio is very important to ensure a proper process evolution and a good end product. Values of 25-30 should be maintained.

Heavy Metals, Organic Micropollutants
Heavy metals and organic micropollutants can either prove to be toxic to the process or reduce application rates of compost.

3.2.3. Incineration

Temperature, Dry Matter, Volatile Solids, Calorific Value
The economics of incineration depend to a great extent on auxiliary fuel requirements and, therefore, the above parameters are all important to ensure an autogeneous combustion.

Rheological Properties
Rheological properties are important as far as the feeding system is concerned.

Heavy Metals, Organic Micropollutants
The toxicity of emissions (gaseous, liquid, solid) depend on the presence of heavy metals and organic micropollutants at origin and / or when improper operating conditions occur.

3.2.4. Landfilling

Dry Matter
It is important to know whether the sludge is consistent enough to be landfilled. Additionally, rheological properties are essential in relation to the sludge bearing capacity.

Volatile Solids
The amount of volatile solids has an impact on the development of malodours and process evolution, including biogas production.

Heavy Metals
Heavy metals can negatively affect the evolution of the biological process and the quality of the leachate.

From the above it follows that dry matter and volatile solids are the most important parameters in sludge characterisation involved in all the application / disposal methods. They can be modified through stabilisation and solid-liquid separation processes, which are operations almost always present in a waste water treatment system.

3.3. Stabilisation

Stability can be defined as the quality of being stable over the course of time; generally, it is mainly related to biological and chemical aspects, and not physical (structural) ones.

Many parameters are potentially available [2], but the concept of stability is usually associated with that of odour, which depends on particular compounds difficult to analytically detect and also to correlate with a certain degree of stability.

Quantitative odour measurement is possible by asking each person of a panel of selected people to sniff progressively diluted odoriferous gases until the odour is no longer detected. These tests are cumbersome, expensive and cannot be conducted in the field.

The volatile / total solids ratio and / or the percentage of volatile solids destroyed can be used as stability index. Ratios below 0.60 and percentages above 40% are, generally, an indication of achieved stabilisation. Oxygen uptake rates less than 2 mg / g-volatile-solids / h at 18 °C are indicative of a stable sludge.

The measurement of stability can also involve the evaluation of the organic substrate concentration, such as volatile suspended solids, COD, BOD_5 and organic carbon, ATP and enzymatic activity [3].

3.4. Solid-Liquid Separation

Solid-liquid separation processes include thickening and dewatering.

Thickening is defined as the capacity of a sludge to increase its concentration of solids (normally by 2-3 times) by filtration and gravitational / centrifugal acceleration. Ability to thicken is commonly evaluated by allowing sludge to settle in a graduate cylinder. This measure is subjected to several errors (wall effects, bridging, liquid depth) which can be overcome by using proper column diameter (100 mm) and height (500-1000 mm) and incorporating a slowly rotating stirrer [1]. Another technique is based on the use of a low-speed stroboscopic centrifuge: the test is fast and requires only a small amount of sludge [5].

Dewatering is the further increase of concentration of solids; it can be accomplished by filtration or centrifugation, usually preceded by conditioning. Dewaterability can be evaluated by general parameters and specific tests, the latter referred to as a specific technique.

The classical parameter used to evaluate filterability is the Specific Resistance to Filtration, which represents the resistance offered to filtration by a cake deposited on the filter medium having a unit dry solids weight. Values of the order of 10^{-12} m / kg or less are indicative of good industrial filterability (raw sludges generally exceed 10^{-14} m / kg); specific resistance can be reduced by conditioning, most commonly performed by chemicals (organic or inorganic). By measuring resistance at different pressure, the Compressibility coefficient is obtained, which provides information on the most suitable operating pressure level.

The CST (Capillary Suction Time) is a simple, useful and rapid way to evaluate filterability, but only for comparative evaluations; the multi-probe CST apparatus enables a direct, but less precise, estimate of the specific resistance.

Specific tests to evaluate vacuum-filter and beltpress performance are also available. The filter-leaf test reproduces the vacuum-filter cycle [9], while tests including draining and filtration under vacuum or pressure allow a prediction of beltpress performance [4], [6].

Centrifugability is defined as the aptitude of a sludge to be dewatered under the action of centrifugal force; moreover, sludge consistency must be such that it can be easily conveyed by the screw. However, it is not possible to reproduce on a laboratory scale all the conditions actually occurring in a full scale machine, so centrifugability parameters (settleability, scrollability, floc strength) must be separately measured. The method proposed by Vesilind [8], allows both settling and scrolling properties to be evaluated. Vesilind and Zhang [10], showed that sludge can be characterised by correlating the final solids concentration to the number of gravities and the time of centrifugation. Another method is based on the calculation of a Specific Resistance to Centrifugation index based on the sludge floc strength, consisting of the measurement of CST after different periods of standard stirring [7].

3.5. Concluding Remarks

Many physical, chemical and biological parameters and tests are available for the characterisation of sewage sludge, thus allowing its behaviour when processed and impact on the environment when disposed / used to be evaluated.

A problem relating to the tests discussed above is that the methodologies adopted are generally conducted in individual laboratories under different conditions, thus producing rarely comparable results. In order to overcome this problem, the European Committee for Standardization (CEN) has set up a Technical Committee (TC308) for the standardisation of methods applied to characterise sludges.

Furthermore, conventional parameters are often specific to the method of treatment and disposal / use adopted, so parameters and tests able to give more basic information on the sludge in question would be needed. For this reason, many recent research activities in the field of characterisation address the development of methods able to evaluate fundamental properties of sludge. These are briefly outlined in Appendix 14.3.

4. Transportation and Storage

By Ludovico Spinosa[2]

4.1. Introduction

The effective optimisation of a sewage sludge treatment and disposal system requires correct planning of the operations linking the treatment steps to those of disposal / use, i.e. storage and transportation.

Storage systems integrated into the processing sequence allow the speed and capacity of the various waste water and sludge handling aggregates to be adapted, while transportation is a consequence of the fact that the disposal sites are almost invariably far from those of production.

4.2. Storage

4.2.1. Operation Description

The main function to be ensured by storage is the equalisation between a continuously entering sludge flow (production) and a discontinuously exiting one (disposal) [8].

A more uniform composition for mixtures of different batches and the possibility of isolating different batches could also be achieved, thus guaranteeing a more constant quality and facilitating analytical controls.

The elimination of differences between input and output is particularly important in the case of agricultural use as this practice is subjected to a great variability in time depending on cultivation type and weather conditions. Consequently, sufficient sludge storage capacity must be provided when unfavourable conditions occur.

Although certain short-term storage possibilities are available within the waste water treatment system (clarifiers, aeration tanks, etc.) and the sludge treatment system (thickeners, digesters, etc.), sludge storage is generally accomplished by separate facilities: they can be internal to the waste water treatment plant itself or external when a centralised sludge treatment platform serving several plants is planned.

The selection of the most suitable method of storage basically depends on whether the sludge is in the liquid or dewatered state, i.e. it depends on its dry matter content. In addition, knowledge of the sludge's physical consistency, through its rheological characterisation, is of great help when defining what kind of installation to choose.

Moreover, during storage several phenomena can occur, including:

- development of malodours, due to anaerobic conditions, which can be reduced through stabilisation;
- variation in the fertilising value, including mineralization of organic matter with loss of ammonia;
- hygienization, as a consequence of pathogens reduction.

It follows that factors of primary importance to be considered when designing sludge storage facilities are:

- solids concentration (which can be increased through solid-liquid separation processes such as mechanical dewatering),
- rheological properties,
- stability (increased through stabilisation processes, also able to perform some hygienization),
- nutrient and organic matter contents,
- pathogens content (reduced through disinfection processes).

4.2.2. Equipment

For liquid sludge, the most suitable ways of storing are in [8]:

- tanks / vessels having a square, rectangular or circular cross section with vertical walls;
- excavated lagoons / ponds, normally lined at the bottom, with inclined walls.

Since open tanks can be the source of unpleasant odours, they should be covered and / or placed at a convenient distance from urbanised areas. Often, installation of aeration and mixing equipment is useful to

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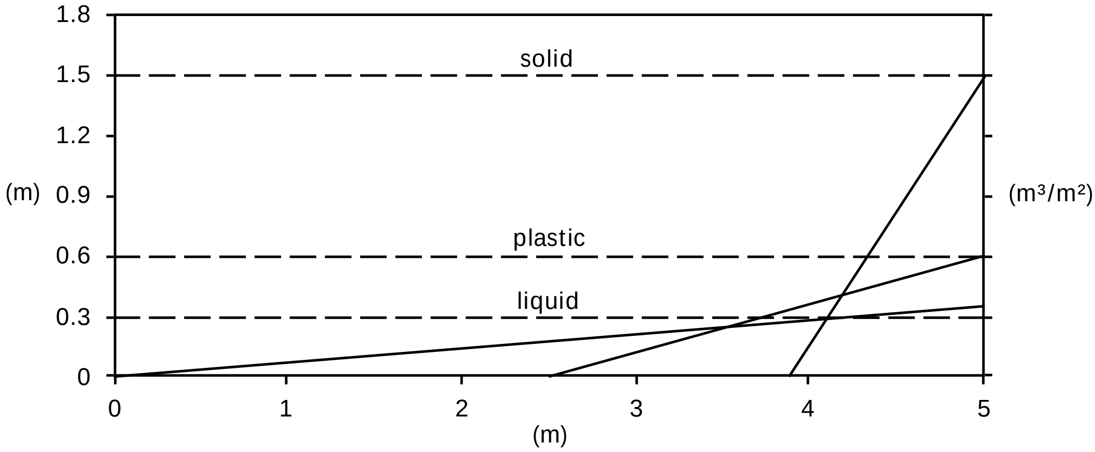
Figure 4.1.

Volume to area ratio for storing same volumes of different sludges (solid > 0.80; plastic < 0.60; liquid < 0.30)



perform additional stabilisation and homogenisation. Closed tanks should also be fitted with special equipment to counteract the risk of dangerous gases escaping from the tanks. A lagoon normally occupies an area at least double that of a classic vessel. Pumps are normally used for filling / emptying operations.

The most widely used systems of storage for dewatered sludge are dumps, basins and containers, depending on the obtainable sludge volume ratio in terms of m^3-storage / m^2-occupied-area (Figure 4.1): it ranges from 1.50 to 0.80 for sludges behaving similarly to solids, 0.80 to 0.40 for those showing a certain degree of plasticity and below 0.40 for more liquid sludges. The storage of dewatered sludge generally requires a drainage control for water and gases and, in areas with heavy rainfall, covering and sealing systems. Filling / emptying operations can be performed by a wide range of equipment, including belt-, screw-, pneumatic- and positive displacement type-conveyors, chutes and inclined planes, bucket elevators, grapple buckets, etc. The equipment sometimes has to be fitted with a special apparatus to prevent it from blocking during operation.

4.3. Transportation

4.3.1. Operation Description

Sludge must almost invariably be transported from the point of production to the disposal / use site, possibly via a centralised processing platform.

Generally, the transport step is a large share of costs for works serving large municipalities, as they must transport great amounts of sludge over a great distance to reach a suitable disposal site. However, higher costs as a consequence of great distances could be counterbalanced by savings due to large transported volumes. The cost problem is generally less important for small communities, and they can reduce investments in dewatering equipment and plan centralised solutions.

Sludges can be transported by pipeline, barge, rail or truck.

Transport by pipeline is a practice suitable for moving large quantities of sludge having a quite low solids concentration, generally below 10%. The main disadvantages lie in high installation costs, relatively long construction time and, above all, in the fact that the pipeline has to be shut down during maintenance and repair works. The design of the pipeline can be carried out simply by multiplying figures for clean water by empirical coefficients, but the application of such simple criteria could be misleading, so more reliable procedures are suggested [6], [3].

Transport by rail and barge is more convenient for moving large quantities of sludge over long distances. In this case the availability of suitable waterways and railway connections is a further essential condition.

For the above reasons, transport by truck is the most widespread method used. The most significant advantages are relatively low investment costs and a high degree of flexibility. Rerouting and alteration of collection points are also easily arranged. Drawbacks are possible leakage and odour / dust emission.

4.3.2. Equipment

In pumping, sludges with solids concentration of less than 2-4% behave like water, while above 10% it is necessary to use volumetric pumps (single- or double-acting piston or helicoidal rotor) or rotodynamic ones with radial, axial or mixed flow. Highly concentrated sludges (with a concentration above 20%) can be transported by eccentric helicoidal rotor pumps provided with a hopper and fed by a screw-drive [9]. Selection criteria for pumps were defined by Frost [2], [4], while criteria enabling the most economical pipe diameter and the pumping system to be designed and optimised, for whatever fluid may be pumped, are reported in Castorani et al. [1].

All other transport systems require the most suitable container / tanker to be chosen according to the physical state of the sludge. For vehicles equipped with loading / unloading systems, the knowledge of sludge fluidodynamic and consistency characteristics, i.e. rheological properties, are of great importance as well.

Tanker trucks for transportation of liquid sludge are usually of uniform design. Larger tankers are best suited to distances exceeding 20 km and annual transport volumes of 4000 m^3 at least. These vehicles are normally designed with a vacuum suction system for collecting waste water and sludge, which is afterwards discharged by gravity.

Trucks for transportation of dewatered sludge are equipped with unusually large watertight hatches for the loading / unloading operations. In order to make optimal use of various types of loading equipment, such tankers are fitted with large loading hatches and a seal to prevent odours from escaping. The interior of the tank is fitted with baffle plates to counteract movement of the sludge during acceleration and braking. Rapid unloading is ensured by tipping the tank to a maximum of about 30° so that the sludge falls through the rear trap door, which can be swung open. When closed, this door is rendered impermeable by seals and rotary locks. In tankers designed for transporting dewatered sludge with a solids concentration exceeding 30%, the interior baffle plates can be extended and retracted in order to adapt to the sludge viscosity. Sliding doors on top of the vehicle can facilitate the loading operation (Spinosa and Sportelli, 1986). All equipment and fittings of trucks must be designed to exclude any possibility of sludge leakage during the various handling procedures.

A very important factor in a sludge transport system is the loading and unloading equipment: it must be of simple and reliable design and permit rapid operations, especially for short distances (to be covered in less than 1 h).

In any case, the rheological characterisation of sludge is very useful in the selection of the best equipment to be used and optimal procedure adopted.

4.4. Concluding Remarks

Storage and transportation of sludge must not be regarded as isolated problems, but be considered as part of an integral system of treatment and disposal: this will ensure that the overall system is used to its full capacity and, consequently, that overall costs are reduced.

In particular, storage allows the production capacity of sludge to be adapted to that of disposal / use, while proper transport systems involve consistent reduction of costs and avoid possible environmental problems, due to sludge leakage and malodour diffusion.

Several systems for sludge storage and transportation are available. The selection mainly depends on the dry matter content and the consistency of sludge, so, in addition to the conventional evaluation of solids concentration, the rheological characterisation appears to be a very useful tool in the prediction and estimate of the sludge behaviour when submitted to the above-mentioned operations and, therefore, in the equipment selection.

A generally valid financial estimate for storage and transport systems is not possible because it is strongly affected by oil and labour costs, which vary widely depending on local conditions and economics. In some cases, national tariffs exist.

5. Agricultural Use

By Alice Saabye[3]

5.1. Conditions for Agricultural Use

The purpose of using sludge in agriculture is partly to utilise nutrients such as phosphorus and nitrogen and partly to utilise organic substances for soil improvement.

5.1.1. Sludge Types and Sludge Quality

In principle, all types of sludge can be spread on farmland if they fulfil the quality requirements (heavy metals, pathogens, pre-treatment) laid down by the legislation of the relevant country (see Appendix 14.1).

Most often, the amounts of sludge allowed to be spread are limited by the amount of nutrients required by the plants and the total amount of dry solids (see Appendix 14.2).

5.1.2. Legislation

All Western European countries and the USA have acts or bills on the use of sludge on farmland, but their legislation differs a great deal. In Denmark, Sweden, Holland, Switzerland and the USA, the amount of nutrients is restricted by law. In Norway, Finland, Germany, Ireland, Italy and Spain, the amount of dry solids is subject to restrictions, whereas in France and Great Britain, the amount of heavy metals places restrictions on sludge spreading [1]. In some countries the regulations are so strict that only a minor part of the sludge can fulfil the conditions.

The following requirements are common to these regulations:

- Pre-treatment (reduction of the water-content in sludge, reduction of organic substances, reduction of pathogens)
- Restriction on the amount of heavy metals contained in sludge
- Restriction on the amount of dry solids and heavy metals spread per unit of land and time
- Restriction on the content of heavy metals in the soil on which sludge is spread, and requirements for the pH of the soil
- Restriction on the amount of nutrients added to the soil (nitrogen and phosphorus)
- Restriction on the choice of crops
- Restricted access conditions to farmland on which sludge is spread
- Legislative compliance control

5.2. Description of Agricultural Use

In general, the sludge is stored in the treatment plant or it is taken to the farmer for immediate storage.

Large amounts of sludge and limited storage capacity often make it necessary to dewater the sludge to reduce its volume.

The sludge is normally spread on farmland once or twice a year in connection with ploughing and seeding. Hence, the maximum uptake of nutrients by the plants is obtained and thus a reduced washout of the nutrients to the ground and surface water.

In general, the farmers' own equipment for spreading liquid and livestock manure is also used for spreading sludge. As the equipment is not ideal for this purpose, it is often difficult to comply with the legislative requirements in relation to the amounts of dry solids and nutrients allowed to be added.

Consequently, it is important that the amount of dry solids required in the sludge matches the equipment available. If not, it is necessary to invest in special spreading equipment.

After spreading, the sludge is ploughed into the soil. Legislation often requires that this must be done very shortly after the spreading to reduce odour nuisances.

Liquid sludge can be injected directly into the soil.

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5.3. Advantages/Disadvantages of Agricultural Use

Spreading of sludge on farmland offers the following advantages:

- Utilisation of nutrients contained in the sludge, i.e. phosphorus and nitrogen
- Utilisation of organic substances contained in the sludge for improvement of the humus layer of the soil (i.e. soil improvement)
- Known regulation on its application
- Often the cheapest disposal route

Sludge spread on farmland may have the following disadvantages:

- Major investments in storage facilities as sludge can only be spread on farmland a few times a year
- Dependency on the individual farmers and considerable administration of agreements
- Lack of knowledge as to the content of organic micro-pollutants and pathogenic organisms in sludge and their impact on the food chains
- Thorough legislative compliance control

5.4. Financial Estimate

When making a financial estimate of sludge spread on farmland, the following costs must be taken into consideration:

- Transport costs from treatment plant to storage
- Storage investments and operating costs
- Transport costs from storage to farmer
- Investments in spreading equipment (can often be omitted as the farmer uses his own equipment)
- Expenses for spreading and ploughing (can often be omitted as the farmer uses his own equipment)
- Expenses for analysis of sludge quality
- Expenses for analysis of soil quality
- Administrative expenses for e.g. declara tion of sludge, conclusion of agreements with farmers and control of application.

The price for agricultural use of sludge is in the order of DEM 150-400/tonne of sludge with 20% dry solids. It should be noted, however, that the price depends on local conditions and may differ considerably from the above.

6. Composting

By Isabelle Coulomb[4]

Sludge composting aims at biologically stabilising sludges while controlling pollution risks in order to develop agriculture or other end use outlets exploiting the nutrient or organic value of sludges. It can be applied either to non-digested sludge (e.g. Italy, France) or to digested sludge (e.g. the Netherlands). Composting involves aerobic degradation of organic matter, as well as a potential decrease of the sludge water content, the efficiency of which depends on the composting process.

Since organic substances and nutrients, such as phosphorus and nitrogen, are in demand by farmers, compost, rich in organic nutrients, is considered a valuable soil improver. Sludges composted for agricultural end use are therefore of value to secondary markets. In the case of sludges treated by incineration, waste sludges can be composted as a pre-treatment to decrease the water content, thus increasing the efficiency of the incineration process.

Nevertheless, it may be too expensive to first compost and then incinerate the sludge. Besides, some of the organic matter will decompose, thus limiting the increase of the calorific value linked to sludge drying.

6.1. The Influence of Variable Conditions in Defining the Composting Process

Sludges can be composted if they have sufficient organic matter as well as a relevant water content. In order to effectively compost materials, certain nutrients are required, including nitrogen and phosphorus, as well as proper moisture and aeration levels that facilitate and enable, after mixing with a co-product, the sustainability of micro-organisms.

Since liquid sludges have a high water content, they alone are not sustainable mediums for micro-organism growth. However, they can be composted when used in relevant quantities in a mixture with other highly fermentable organic wastes possessing a lower or a deficient water content.

Sludges with a water content greater than 15% are easily co-compostable, particularly when mixed with bark or other structuring materials making the compostable mixture porous.

As a general reference, the water content of a compostable mixture of organic wastes should be around 55% while the organic matter content should be greater than 70%, facilitating effective bio-degradation. A high moisture content above 60%, reduces the temperature, porosity and thus the oxygen concentration while a low moisture content, below 50%, could limit the rate of composting. At values of 10-15% the bacterial metabolism generally ceases to function. Bacterial activity is also influenced by pH, with the optimal values being between 5.5 and 8.

A balance of the nitrogen and carbon content is necessary for the proper growth of micro-organisms. The carbon to nitrogen ratio (C/N) of the mixture is therefore commonly used to define the optimum functional conditions. Although values ranging between 25 and 30 are recommended, the types of molecules concerned must be evaluated when establishing the ideal ratio.

Structuring composting conditions and mixture ratios naturally depend on the types of wastes to be treated as well as the quality specifications set for the resulting compost.

For example, the processing of organic materials would be different if the goal was to incinerate the end product, thus demanding that the water content of sludges should be reduced, than if the goal of the composting process was to produce a soil improver, as defined by a particular agricultural outlet, which would therefore require that specific nutritional and structural properties should be present in the end product.

Different ratios of wastes and different processing policies would have to be implemented under the constraints of each programme. Therefore the types of sludges to be treated, the quantitative/qualitative constraints for incorporating them into a composting process, and the efficiency of the composting biodegradation process itself, depend on the end product specifications as defined in any given project.

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If, for instance, a compost end product targeted for an agricultural outlet is considered, many market and regulatory constraints will have an impact on the definition of the composting process itself. For example, although organic pollutants such as the pesticides, PCB, HAP, PCDD, PCDF do not have regulatory limits at European level because the concentration of these contaminants has proven to be low, the contrary is true for the heavy metal content in composts.

The heavy metal content of the final compost product is critical. The end product standards must meet the specifications defined by local and national legislation. Obviously, since the materials are composted at a temperature level sufficient to kill pathogens, the risk of pathogenic problems is minimised, an advantage supporting the processing of organic materials by composting over other treatment methods. In addition, microbial competition during composting also favours pathogen reduction.

Market conditions also have an impact on the process design of a compost system. In addition to their inclusion in some national regulations, aesthetic contaminants such as plastic, glass, metals or stones are undesirable because they may limit the marketing potential of the final product.

In the case of agriculture end use composts, it must not only support local vegetation growth, it must also meet both the qualitative and quantitative demands of the local market; the compost end product must be nutritionally balanced to the local soil demand and produced in quantities which do not exceed the outlet application potential.

For example, to utilise the final compost for a soil substrate application, the nutrient and salt content must be low while the water retention capacity must be sufficiently high, thus meeting the necessary water/aeration requirements of specific types of vegetation.

The pH of substrate also becomes an important criteria in designating the type of vegetation to be sustained and must be accounted for in compost end quality specifications. Whether designated as a soil improver or a substrate application, decomposition of organic material must be sufficiently high. In addition, the process of producing a quality end-product must ensure germination and sustainability of plant growth and ensure that no germination of foreign seeds occurs as a result of the compost.

The example of composting sludges as a pretreatment method for incineration is technically appealing because composting results in both mass reduction and decreased water content, thus providing a more efficient waste stream for incinerators. A financial and market analysis must, however, be completed to validate the viability of this option: is composting in itself viable, and is the level of bio-degradation necessary to justify the incineration of pre-treated, composted sludges over the incineration of raw untreated sludges?

6.2. General Description of the Process of Composting and Plant Conception Factors

The process of composting is based on aerobic degradation of organic matter, under variable conditions as described above. In essence, the activity of microorganisms causes both an increase in temperature, hence the pathogen destruction, and a release of energy, CO2, H2O, NH3 and other gases, while consuming oxygen.

The rate of the bio-degradation process can thus be controlled by regulating aeration, moisture content and mechanical processing of the material. For instance, the composting process could be controlled and accelerated by:

- Forced aeration, which provides sufficient oxygen to meet demand, while providing an odour control mechanism;
- Mechanical turning of compost, which contributes to the mixing and the increased aeration of the material.

A particular market demand may also be accommodated by mechanical screening to a defined particle size.

In developing an actual plant to process organic wastes and sludges into compost, the following system development and costs must be taken into account:

- Waste reception and storage areas;
- Mechanical mixing system to be applied;

Figure 6.1.

Sludge composting plant of Tortona (Italy): example of a turned pile composting system with forced aeration in corridor silos

- Storage area for the compostable mixture, before aeration: Note, this step is not compulsory but can be interesting for the flexibility of the operation;

- Fermentation / bio-reactor area. Note: reactors, containers, lockers, tunnels, channels as well as their process retention times, ranging from 10 days to five weeks, are defined in relation to the objectives of the programme;

- Storage area for compost maturation and final stabilisation of the product;

- Mechanical screening systems: the size of the screen depends on the local utilisation of the compost; the fine fraction can be stored, commercialised or eliminated whereas the raw fraction can be recycled as a structuring material for composting;

- Control of variable local facility demands such as: sewage water, odours, dust control and control of other nuisances such as noise, flies, and the potential of foraging animals.

A wide range of composting systems exist world-wide, however they tend to be classified into several general categories:

- Open composting systems (see Figure 6.1)
  - static pile :
    - natural ventilation
    - forced aeration with suction or blowing in windrows or in silos
  - turned pile :
    - natural ventilation
    - forced aeration in corridor silos, in windrows or in tabular piles

- Closed composting systems functioning continuously or periodically with forced aeration (see Figure 6.2)
  - rotating horizontal reactors (tube)
  - static vertical reactor (tower)
  - in-vessel systems (boxes)

The choice between the different systems depends on the technical and economic parameters. In general, when composting sludge, process control, reduction of labour, and sensitivity to weather generally necessitate forced aeration technologies.

6.3. Advantages/Disadvantages of Composting Sludges

Advantages

Composting offers several advantages in comparison with other sludge treatment methods. In comparison with the direct application of non-composted sludges in agriculture for example, composting allows:

- A reduction in the volume of materials to be transported for distribution in agricultural fields;
- A facilitation, with respect to sludge, of storage and use in places and at times far from those of production;
- A facilitation of the spreading process due to the lower water content of the product;
- Control of compost material specifications, which results in a well-defined, stable end product composition with the potential of improving the soil humus layer and nutrient levels;
- Control of nutrient content as defined by application and vegetation standards;
- Product hygiene control before agricultural application;

Disadvantages

- The treatment cost is higher than simple direct raw sludge application;
- Aeration consumes energy;
- There is a need for an outlet market for the compost end product; competitive soil improvers exist;

The need for mixing sludge with other materials in order to obtain an optimal C/N ratio, can be considered either as an advantage when bulking agent is another waste to be treated (complementarity of treatment) or as a disadvantage when this bulking agent has to be bought.

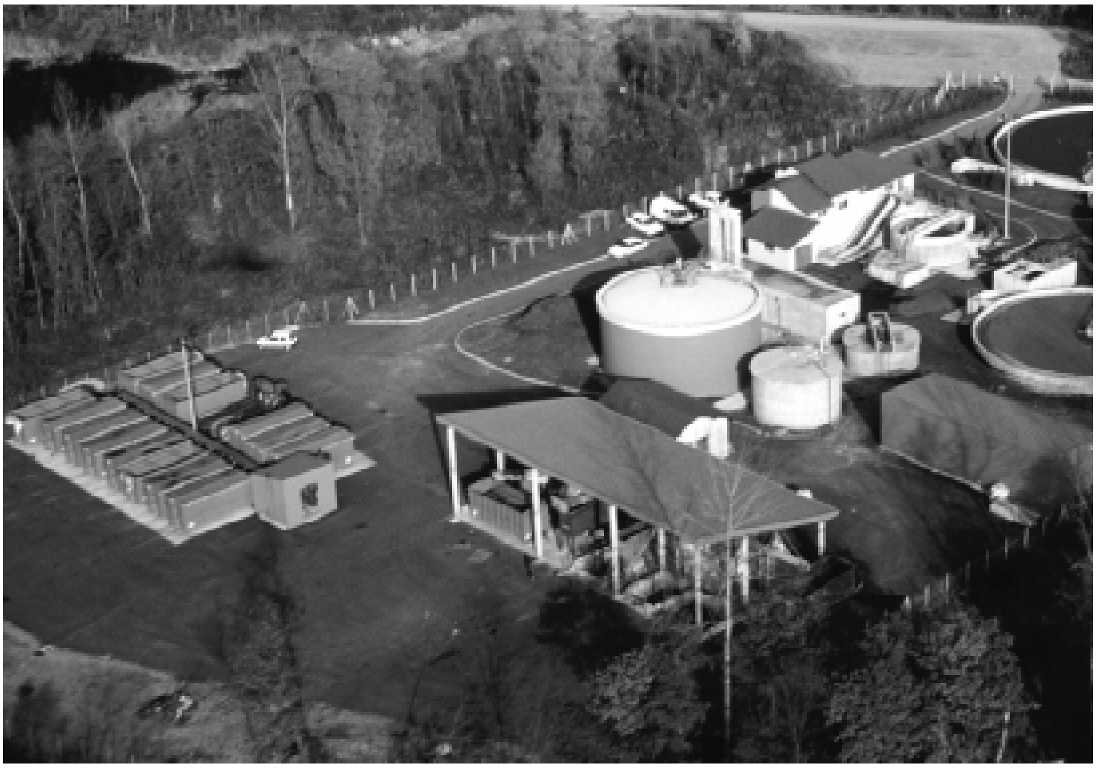
Conclusion

Although costs are elevated when sludge is composted in contrast to, for example, direct application of sludges in agricultural crops, the market and health aspects such as pathogen risk, odour, and nutrient control in response to vegetation demand, often emphasise and necessitate the demand for alternative solutions, justifying composting as a viable and environmentally sound option.

6.4. Financial Estimates

Evaluating the costs of different treatment options for sludges is necessary. For example, the following costs must be taken into account when a sewage water treatment plant decides to compost its sludges:

Figure 6.2.



Sludge composting plant of La Roche sur Foron (France): example of an in-vessel composting system.

- The cost of transporting the sludge to the composting plant;

- Capital investment and engineering costs for the composting system itself and the plant infrastructure (buildings, aeration, odour and air cleaning equipment, machinery for turning and mixing the compost, sieves, conveyers if necessary, front loaders, ...);

- Plant operating costs: personnel, energy (electricity, fuel), bulking agents (including the cost of transporting bulking agent to the composting plant if necessary), maintenance, overhead expenses, taxes,...;

- Quality control expenses: characterisation of wastes and the compost end product as well as process evaluation;

- Marketing costs, including market studies and marketing materials;

- Cost of transporting the compost from the composting plant (when necessary).

An indication of price range for composting is between DEM 275 - 525 / tonne in France. See Table 12.1.

6.5. Concluding Remarks

Although there are a lot of processes and patents in the composting profession, many systems are not viable under end product demand and market demand constraints; they are either too simple and not adaptable to either waste and / or market demands or, they are too capital investment heavy and / or labour intensive and the return on the investment is not justified. In developing an approach for the treatment of waste sludges by composting, all the intricate waste, end product, and market constraints must be evaluated in defining the process itself and structuring a facility.

Consequently, the prescriptions mentioned above concerning system and market plant analysis and planning factors as well as adequate conditions for composting are the key to success of a quality compost production. However, this quality improvement has to be financially assessed.

7. Drying

By Ådne Ø. Utvik[5] with contributions by Albrecht R.ببresters[6] and Martin Würdemann[7]

7.1. Introduction

The purpose of this chapter is to describe different processing methods for drying of sludge.

7.2. Conditions for Drying of Sludge - Amounts and Drying Rates

Basically, there are no specific pre-conditions to be fulfilled in order to apply drying. This means that all known sludges from municipal waste water treatment plants may be processed in a properly designed and operated drying plant. However, as in all industrial processes, the total cost per tonne increases when throughput decreases.

Presently, a small plant for municipal sludge removes less than 0.5 tonne of water / h, whereas a large plant evaporates nearly 30 tonnes of water / h.

The main reasons for this great variation in capacity are:

1) Size of one or more WWTPs (inlet flow, m_ / h)

2) Pollution, kg dry solid / m_ of effluent water

3) Treatment process - chemical / biological etc.

4) Undigested or digested sludge

5) Dry solid content in dried sludge

Ad 4) When the sludge is digested, the dry solid content (DS) will be reduced by approximately 20%, due to transformation of organics into biogas.

Ad 5) The DS is normally raised to 40-50% as preparation for immediate subsequent incineration. To make a storable product for multi purpose utilisation, for instance as fertiliser, soil conditioner, fuel etc., the DS is raised to 90-95% and granulated.

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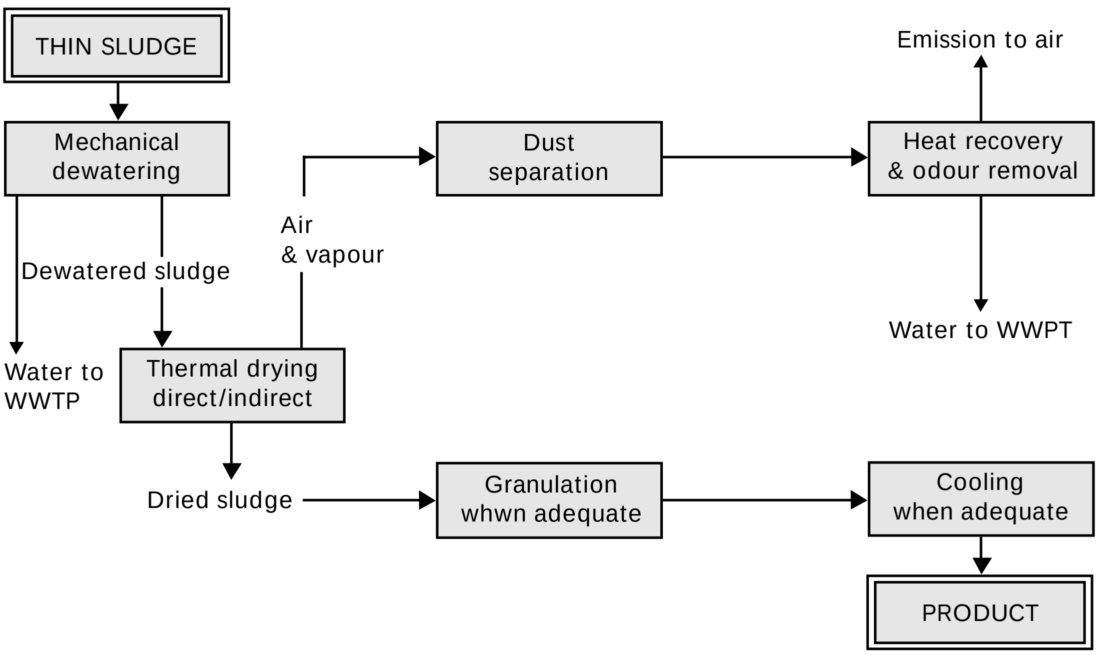
Figure 7.1.

Generel flow sheet for a drying process



7.2.1. Quality

The quality as fertiliser / soil conditioner and / or as fuel mainly depends upon:

1) Content of organic solids

2) Content of plant available fertilising components, mainly phosphorous, potassium and nitrogen

3) Ability to absorb and retain water

4) Content of heavy metals

5) Content of pathogenic bacteria and fungi viruses, helminth ova and toxins

6) Repopulation rate of pathogenic micro-organisms.

Whereas 2) and 4) depend upon the content in the effluent water and the treatment, 1) and 3) are influenced by digestion, which degrades organic material.

The possible presence of pathogens is a major concern and must be taken seriously. Proper drying, where the most relevant factors are retention time / retention time distribution and temperature, particle size and heat conductivity, is regarded the safest method in this respect. Under certain drying conditions some N-NH_3 may be lost. If this is predominant and damaging, the loss may be counteracted by additives.

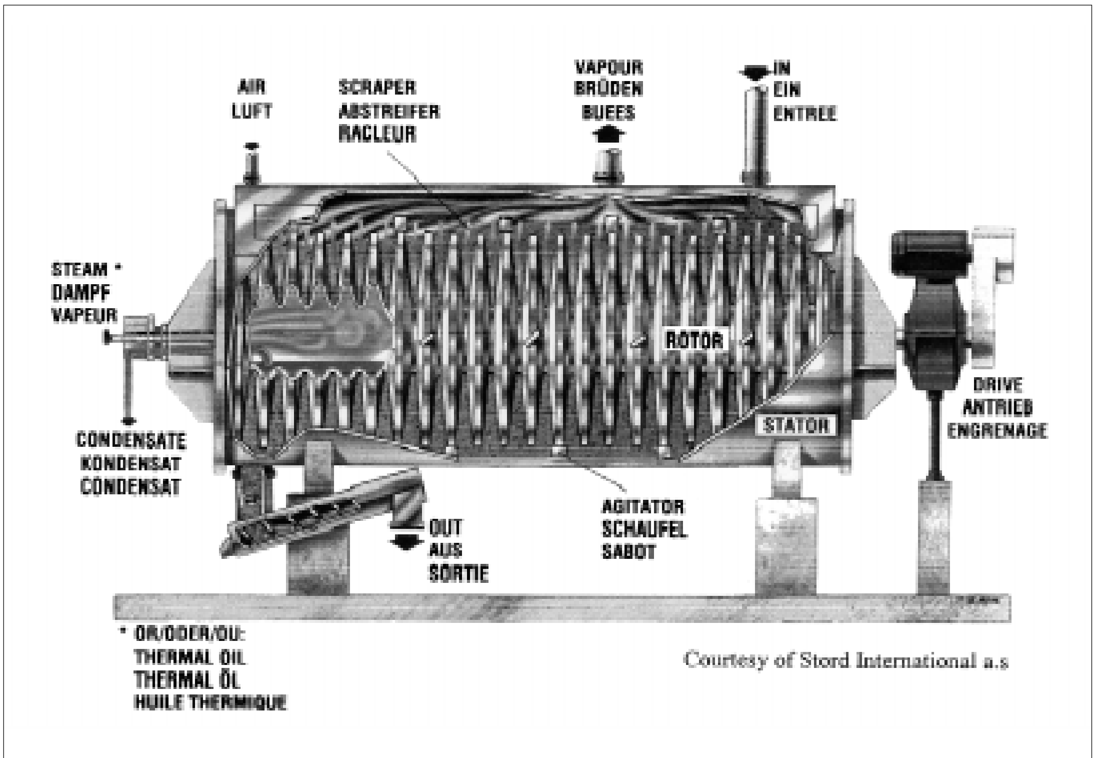
The actual flow sheet depends upon a number of factors, of which type of dryer used (indirect / direct) and dry solids in end product (approx. 70% or 90%) are the most decisive ones. Heat recovery may be more efficient with indirect dryers, whereas some direct dryers may not require separate granulation.

7.3. Drying and Dryers

There are approx. 20 suppliers of drying equipment (please refer to ISWA literature and documentation, for instance the ISWA Yearbook). The two distinctly different drying methods are indirect and direct drying. In direct dryers there is a direct contact between the material to be dried - the sludge - and the heated gas supplying the required heat for evaporation and simultaneously carrying the water vapour formed out of the system.

Figure 7.2.

Example of a disc dryer



7.3.1. Indirect Dryers

In the other type, the indirect dryer, heat is transferred to the material to be dried indirectly by heat conduction through a heat transfer surface. Thus, the heating medium, for instance steam or thermal oil, is not in contact with the sludge. A small stream of air may be used for transport of the water vapour formed, although an indirect dryer may well be operated without any air, thereby keeping the odour removal cost at a minimum and heat recovery at a maximum.

Among the indirect dryers the disc dryer is widely used. An example of a disc dryer is shown in figure 7.2.

A disc dryer is a slow, rotating machine. The concept is simple, and the dryer is easy to operate.

The stator consists of a nearly cylindrical, horizontal drum, enclosing the material to be dried. Scraper bars, acting as mixers, are attached to the drum. On the top of the stator there is an open space serving both as dust separator and as a collector and duct for the escaping vapours. The dryer is normally operated with a slight underpressure.

The rotor consists of parallel hollow discs welded to a horizontal shaft, and the steam - or other heating medium such as thermal oil or hot pressurised water - flows inside the discs. Agitators are welded on the top of the discs. A small flow of air is advantageous from an operational point of view, however, the drier may well be run without any air. Little or no air keeps dust separation and odour abatement costs at a minimum.

To ensure a permanently high heat transfer rate, it is crucial to maintain the heat transfer surface - the discs - clean. The stickiness of sludge is a challenge in this respect.

The ability of the disc dryer to handle sticky and ‘easy-to-coat’ materials is generally due to:

- The self cleaning ability of all of the heat transfer surface (the discs) due to gentle friction forces created when the discs turn in the material to be dried.

- The action of the agitators and the scrapers causing adequate mixing and turbulence and maintaining a high heat transfer rate simultaneously with causing the sludge to move through the dryer.

7.3.2. Direct Dryers

With direct dryers, the heat for drying is transferred from the hot gases to the sludge. This requires an intensive contact between gas and sludge material. The most important types of dryers are the revolving drum dryer and the fluidised bed dryer.

With revolving drum dryers the sludge is fed into one side of the dryer. Through the rotation of the drum and the internals in the drum, the sludge is transported to the other end and simultaneously comes into a very intensive contact with the hot gases. The result is a granulated sludge with a dry solid content of more than 90 %. In order to prevent clogging within the drum, the feed material should have a dry solid content of more than 65%. Therefore, back-mixing of dried sludge with dewatered sludge is normally required before the material can be fed into the dryer.

With fluidised bed dryers, the intensive contact is realised by an upward flow of hot gases, carrying the sludge particles until they are dried, resulting in a very turbulent gas flow. Depending on the sludge type, the dried sludge has a dry solid content of more than 90% in the form of dust-free granules. The dust in the flue gas is transported by the gas stream, removed by cyclones and fed back into the dryer after mixing with dewatered sludge. Additionally, a heat exchanger can be included in the fluidised bed, resulting in an intermediate drying system between direct and indirect drying.

As a result of the intensive contact between gas and sludge and the good heat transfer, the specific performance of the direct dryers can be higher than that of the indirect dryers. Additionally, the mechanical design can be simpler.

On the other hand, direct dryers have the following disadvantages:

- The used gases contain a large amount of pollution, especially strong odorous components. This requires very substantial gas treatment.

- This type of dryer is less suitable for use with low temperature heat. This is especially the case for the revolving drum dryer.

- Explosions possible

It is, however, possible to recirculate part or all of the used gases and vapours, but this leads to more complicated drying systems, through which the advantages of direct systems decrease substantially. The selection of a direct or indirect drying system therefore depends on sludge characteristics and other specific and local conditions. Both systems are subject to much practical experience.

7.4. Advantages/Disadvantages of Drying

In terms of energy, water removal by evaporation / drying is generally more expensive than mechanical methods such as pressing and centrifugation / decanterisation. Prior to drying, proper mechanical dewatering must therefore be installed.

A drying plant, which in most cases includes granulation, is more expensive to install than most other methods. On the other hand, drying results in a great volume reduction and a storable free flowing and hygienic product. Due to the great volume reduction, dried sludge implies reduced costs for transportation, handling and storage.

The greatest advantage in having sludge in a dry form as compared with various other methods is the possibility of 'marketing' the product for a number of applications and at the most suitable time:

- Fertiliser / soil conditioner in agriculture and forestry
- Fuel in cement kilns, power plants and incinerators
- Top soil, landscaping, landfilling and disposal

For most applications it is of great importance - and cost saving - that thermally dried sludge has been subject to safe hygienisation and considerable volume reduction.

7.5. Financial Estimate

As mentioned above, the disadvantage is the high investment cost relative to other methods. No reliable and generally valid estimates are known since local factors influence heavily.

A few questions may clarify this point:

- It may for instance be questioned whether making biogas is favourable or not. What is the price per kW / h as compared with the market price for electric power?
- How much will digestion of sludge reduce the organic content and its value as fuel and fertilising / soil conditioning?
- The heat supplied to the dryer, for instance through steam, is still present, but at a lower temperature. Is there a need for this low temperature heat, and how should it be priced?
- Does the sludge owner have only one 'customer', except for deposit? How will this one and only customer pay him in the future, and what changes in the deposit cost are expected?

An example

A plant - without digestion - handling 2,400 tonnes of DS / year in the form of 12,000 tonnes of dewatered sludge (20% DS) a year, may have a cost of approx. NOK 1,300 / t of DS (approx. DEM 295, FFR 1,000, GBP 130) including capital (investment NOK 5-6 mill.) and operating cost (lime, polymer, transport, etc.).

If the cost of the building, storage, required heat and disposal of the dry material is included as well, the cost may typically be in the order of DEM 600 to 700 per tonne of DS.

8. Incineration (Vitrification, Co-incineration)

By Isabelle Coulomb[8] and A. Myrope[9]

Today considered the last method used in the treatment of waste sludges, either alone or in combination with other wastes, treatment by incineration represents 15% of the total mass of sludges treated in Europe.

The agricultural use of sludges, by direct application, as well as landfilling of sludges are subject to more and more regulatory control. For this reason, incineration of sludges is expected to increase, even though it can be a capital intensive investment and it is also subject to strict regulation pertaining to combustion criteria, management of the off-gas treatment residues and treatment of fly and bottom ashes.

Incineration of sludges can be performed in designated incinerators or in municipal solid waste incinerators under the particular constraints for each type, where the process results in combustion of the organic matter of the sludges.

After pre-drying, sludges can also be incinerated in cement kilns because they have a high calorific value. Pollutants are stabilised in the clinker which is an interesting way of treating polluted sludges.

From an economic point of view these methods of treatment are mainly justified for sludges not allowed to be used in agriculture or incinerated in municipal solid waste incinerators.

Another method of stabilisation is vitrification of the product. Japan has some experience in this method, but the process remains too expensive. Therefore, these methods of treatment will not be further detailed in the following paragraphs.

8.1. Designated Sludge Incinerators - a General Description

Specific sludge incineration facilities have been operating for many years. Rotary kiln furnaces and the multiple hearth furnace of the classic or pyrolytic type are today more and more frequently being replaced by

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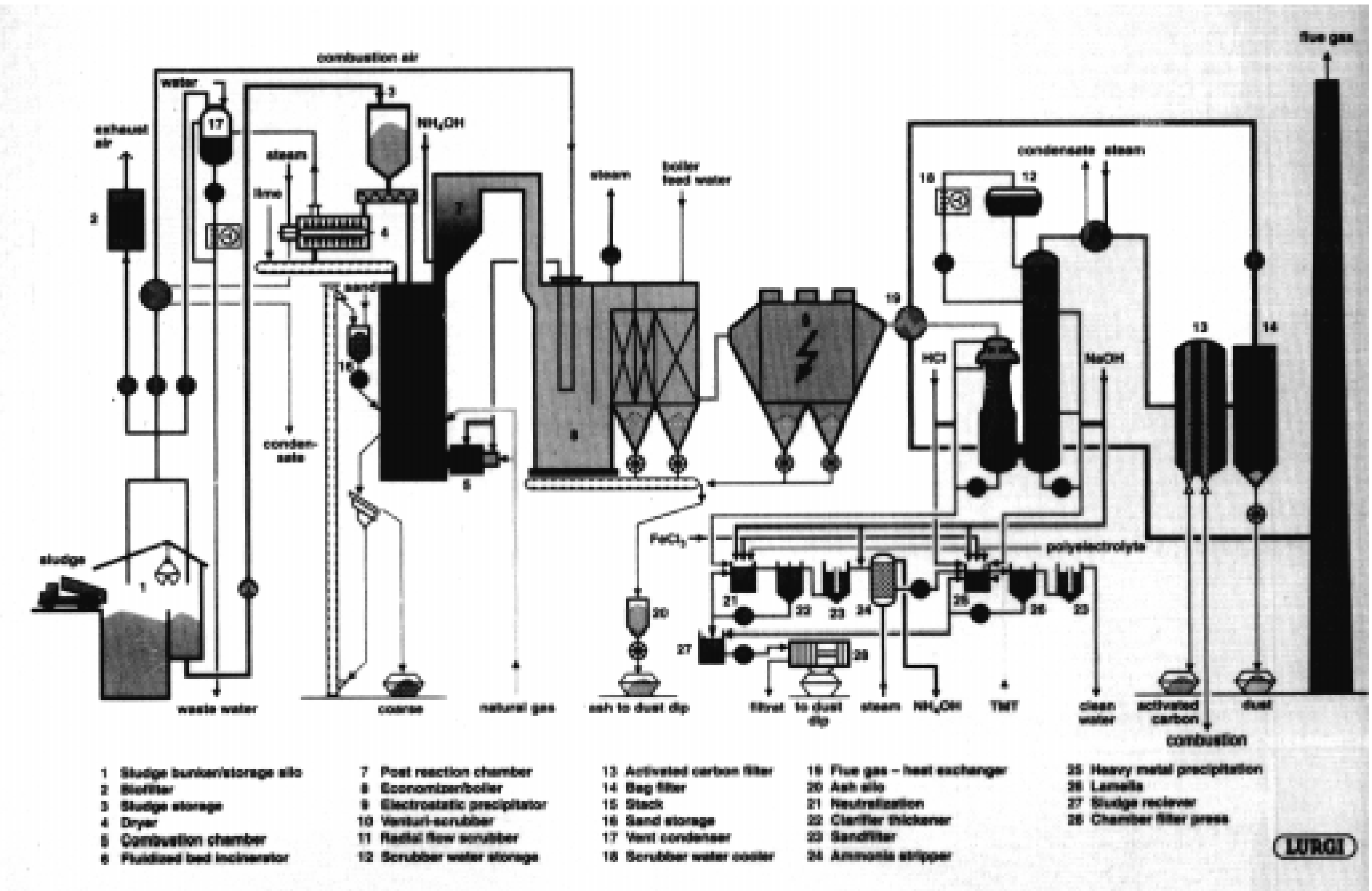
Figure 8.1.

Sludge incineration plant of Dordrecht (Netherlands)

Figure 8.2.



Process scheme of the sludge incineration plant of Dordrecht (the Netherlands)
Courtesy: Lurgi

fluidised bed systems, which tend to be easier to operate (see Figure 8.1).

The fluidized bed system consists of a vertical combustion chamber lined with a refractory material at the base of which a bed of sand is brought to high temperature and held in suspension due to a grate equipped with injectors forcing a flow of hot air. The sludges are introduced inside or above the bed of sand.

The gas must be heated to 850°C to ensure complete burn-out of the flue gas. Therefore, except in the case of fresh primary sludges, the incineration of sludges coming from mechanical dehydration machines is not able to be completed unless combustible energy is provided.

In order to limit the consumption of extra combustibles, a heat recovery system is installed for the hot gas leaving the combustion chamber. Three techniques are used to recover and reuse this heat: one heating the combustion air in a smoke / air exchanger, another one pre-drying the sludge above the furnace as a result of steam produced by a recovery boiler, and the last one pre-drying the sludge in separate rotary disk dryers prior to incineration, the heat required for this drying process being recovered by steam boilers behind the furnaces.

The second process is thermally more productive than the first one as it enables an achievement of autocombustibility of sludges with a dry matter content of 20-25% and with a rate of volatile material / dry material of 60-70% before pre-drying. Extra recovery of the evaporation steam from the dryer, and on the condensates before they go back to the boiler tank, can also improve this result.

It should be noted, however, that this type of heavy equipment and investment can usually only be justified in the case of large installations (capacity higher than 2.5 tonnes of evaporated water per hour). The third process is applied in some modern plants in Germany, the Netherlands and the UK, which are autotherm with sludges at a dry solid content of approximately 23% (see Figure 8.2).

8.2. Co-incineration - a General Description

The use of municipal solid waste incinerators to treat the sludges of urban stations is attractive, particularly if the incinerator is quite close to the water purification station that generates waste sludges, assuming that the capacity of the incinerator is not already saturated by local municipal solid wastes.

Mixing municipal solid waste with wet sludge must be carefully designed because a potential decrease of the energy content of the production is not unlikely. However, a way must be found to introduce the pre-dried or untreated sludges into the incinerator.

One method of doing this consists of drying the sludges to a dry material content of 65%, which results in a calorific value similar to municipal solid waste (2000 th / t= 2000 kcal / kg). The sludges can then be injected into the oven (hopper) taking into account that the quantity of municipal solid waste treated must be decreased proportionally to compensate for the weight of sludge.

This can be a drawback if the incinerator capacity is already close to saturation, but more so an advantage for periods of the year when many medium size units have a lack of waste. The granulated material obtained from sludges represents an important source of energy and can be easily stored without presenting much of an odour problem.

Another solution consists of adopting processes conceived to enable direct injection of pasty sludges by means of a high pressure pump. The sludge is forced through injectors which gauge and distribute the material above the grate (see Figure 8.3)

The sludge is injected at the entry of the furnace by means of a pipe system crossing the refractory bricks, between the water pipes. The sludges fall by gravity and the incineration time and mixing of material are the same as with ordinary municipal solid waste (see Figure 8.4).

One of the most important points of those processes is the calibration of the systems. If the sludge was injected in too large amounts, it would risk being incompletely incinerated; the elements are burnt on the surface and not incinerated at the centre. The dry material content of the sludge required when pumping is 18 to 30 % DS**.** Different systems can treat a total sludge mass of approximately 20% in comparison with municipal solid waste. If the sludges are very wet, vaporisation occurs after injection so that the total solid waste tonnage treated does not change very much.

Figure 8.3.

Injectors of sludges used in the incineration plant of Monaco (France)

Another method is also used, consisting of mixing sludge with municipal solid waste in the hauler. This may result in some problems of volume and odours.

8.3. Advantages and Disadvantages

Advantages

- A significant reduction of the sludge volume, after incineration
- Energetic valorisation of sludges
- Recycling of sludge treatment sub-products such as ashes and inert material, which can be used in filler material for asphalt and concrete production and in the fabrication of bricks
- Low sensitivity to sludge composition
- Reliable systems
- Minimisation of odours, due to closed systems and high temperature

Disadvantages

- Incinerators are capital intensive and usually justified only in larger volume situations; installations treating 2,000 to 5,000 TDS (in France, for instance, this means stations from 200,000 to 800,000 equivalent inhabitants, but in any case, the sludge production depends on the waste water treatment plant). In the Netherlands higher capacities are required: 10 000 to 40 000 TDS or more, whether the plant is combined with a waste water treatment plant (or integrated with another waste treatment plant) or not due to the complex flue gas cleaning and operating efficiency.
- In case of co-incineration, the treatment capacity and treatment efficiency depend on the saturation of the incinerator by other solid waste streams and / or the ratio of sludge mass to solid waste mass.

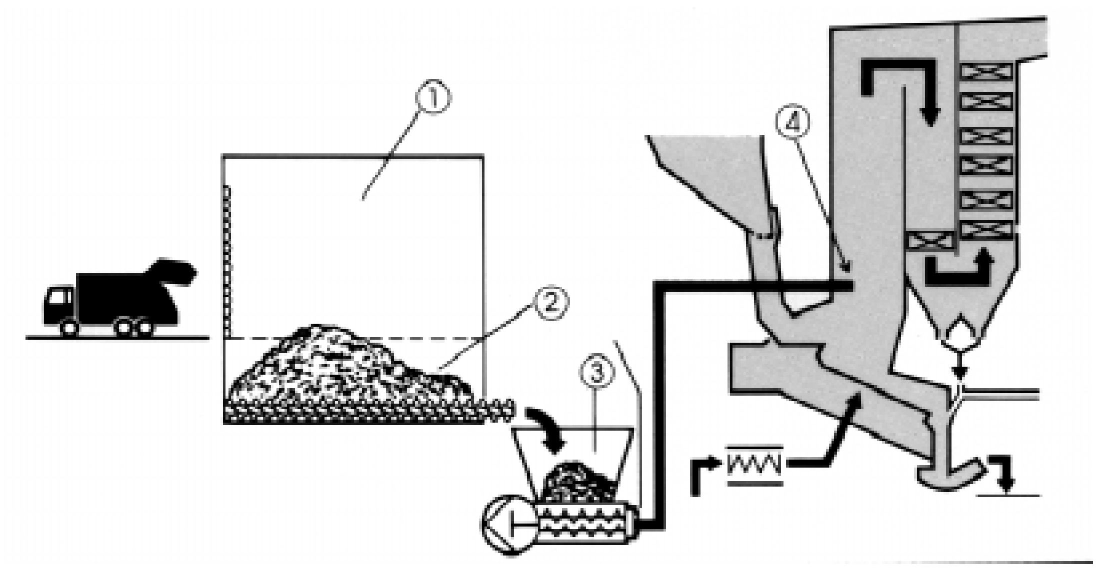
8.4. Financial Estimate

The following costs have to be considered in the decision making process for treatment of sludges by incineration:

- Cost of storage systems necessary
- Cost of furnace
- Treatment of off-gas and other incineration residues, i.e. bottom ash, fly ash, clinker
- Other peripheral costs either for existing plants or in the case of new plants

Figure 8.4.

Process scheme of the sludge incineration plant of Monaco



- Fixed, proportional operating costs: personnel, consumables (i.e. fuel, electricity and chemicals for flue gas cleaning), maintenance, taxes, etc.

- Cost of transporting the sludge to the treatment site

- Cost of quality control (raw sludge and sub-products)

- Marketing costs generated by the recycling of some sub-products

On a first estimate basis, designated incineration of sludge costs between 1,500 and 2,550 FFR (440-750 DEM) per tonne of dry material, excluding taxes. This price includes the investment costs, the up-grading of existing systems, the operating cost, and the final disposal of residues in a class I landfill. This is relevant to units capable of treating from 2,000 to 5,000 tonnes of dry material per year, which represents water treatment stations from 200,000 to 800,000 equivalent inhabitants. The investment will be higher for incinerators with pre-drying, but a benefit for operating costs can be accounted for. In the Netherlands where incinerators, designated with larger capacities (i.e. 5 tonnes of evaporated water per hour per incineration line in the Dordrecht plant), have pre-drying of the sludge and complex flue gas cleaning, costs are in the upper range (550-750 DEM). The lower range applies to countries where regulations concerning flue gas cleaning are less stringent.

Concerning co-incineration with adapted injectors (e.g. the incineration plant of Monaco), the total cost, not including the transport of sludges, but including provisions for depreciation, treatment of residues, etc., is approximately 80 DEM/tonne of untreated sludge, excluding taxes. This equals approximately 300 -425 DEM for a tonne of dry solid, taking into account, of course, the installation size and the site conditions, making the process attractive as an effective method.

Those prices correspond to an extra injection of sludge without any decrease of the full incineration capacity of municipal solid waste. Investment and operating costs are then limited to the injection systems. When the municipal solid waste capacity decreases because more than approximately 20% of sludge in comparison with municipal solid waste is injected, total costs of incineration should be equally allocated to the sludge and the other waste material. Prices will then be higher than previously mentioned (530 - 750 DEM/tonne of dry solid).

8.5. Concluding Remarks

Even though investment costs appear to be more intensive than the cost of the other sludge treatment options, thermal treatment of sludges by incineration is expected to develop considerably in the years to come. Units of significant size can balance investment costs, making it a technically and economically viable treatment process.

The combination of different waste streams, municipal solid waste and waste sludges, also enables optimisation of the incinerator operations. One of the best examples is incineration of sludge granulate resulting from thermal drying. This material is easy to store and can act as incinerator feed when no other local treatment method is available.

Incineration units with either excess capacity or irregular flows (seaside or mountain locations) are particularly interested in the possibilities offered by sludge drying and incineration since they can store hygienic waste products with a high calorific value.

Incineration results in a large volume reduction of the waste. Depending on the possibilities of re-using ashes, the decrease of the amount of material to be landfilled will be more or less important.

9. Landfilling

By Béla Déak[10]

9.1. Conditions for Application

A (wet) sludge production of 230 million tonnes was estimated in the European Union in 1993 (Korrespondenz Abwasser, 1993, 40, Jahrgang, Linder: Anforderungen an die Klarschlammentsorgung in Europe). In Germany, 25% of the production was used in agriculture, 65% was landfilled, and 10% was incinerated. The corresponding figures in Switzerland were 50, 30 and 20, respectively, whereas the figures in France were 55, 25 and 20, thus demonstrating large variations from country to country. However, in the future the use of landfills will have the lowest priority in the waste hierarchy and will only be chosen when no other ways to dispose of the sludge exist. The directions today are towards agricultural use and incineration.

In the process of siting landfills it has always been taken into account that even in case of the most careful setting and proper operation, some degree of subsurface pollution might occur. This is the reason why geologically vulnerable sites are avoided when locating landfill sites.

Vulnerable geological media, such as open karstic areas and gravel terraces forming subsurface aquifer layers, are strictly protected for this reason.

Apart from the protection of the presently used and future aquifers another factor in the selection of the site for landfills is that the landfill itself has to be on a ‘dry’ location, i.e. it should be located above the ground water level. Minimization of environmental pollution can be achieved by proper selection of the site, organized disposal of the solid wastes, professional surface protection and continuous recultivation of the disposal area, as the leaching of the pollutants by the ground water and surface precipitation towards the aquifer layers is minimized.

It is also an important factor in the selection of the location of the landfill site that the distance between the bottom of the landfill and the unsaturated zone should be as great as possible.

9.1.1. The Character and Treatment of Sludge before Final Disposal on Landfill

The waste water sludge at the waste water treatment plants has different origins: it is produced at the preliminary settling tanks (raw sludge), as excess sludge at the biological plant (activated sludge process), and it can be the mixture of both of the above sludge types. Waste water sludge can contain all the pollutants contained in the raw (inflow) waste water, and the content of organic material varies depending on the proportion of the industrial waste water, but usually it falls to the range of 60-70%.

Organic material is readily biodegradable (fat, proteins and carbohydrates), putrescible and causes odour problems during the storage period. The sludge is also considered to be an infectious material.

Sludges are classified as stabilized when they have undergone either aerobic or anaerobic stabilization processes or been chemically treated, which usually includes a liming step. The addition of the lime to the sludge for stabilization theoretically results in a better disinfection efficiency (pathogen removal rate) than for example anaerobic digestion. The disinfection effect of the aerobic stabilization (total oxidation process) is most uncertain in that respect. Nowadays, thermal aerobic stabilization processes are also used for pathogen removal, and this system is considered to be much more efficient in that respect than the previously used systems.

In smaller plants, sludge drying beds are still in use, but mechanical dewatering is becoming more and more widespread. As a result of the mechanical dewatering, the original dry material content (2-3%) of the liquid sludge is increased to 20-30%, which means that the sludge can be shoveled already at this point. Dewatering machines require chemical preconditioning/treatment of the sludge. Stabilized, dewatered sludge always contains pathogenic microorganisms, which have to be taken into account. Lime treatment can increase the pH of the sludge up to pH 12, but the inactivation effect on the pathogens is only temporary.

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9.1.2. Regulations Governing the Construction of Sludge Disposal Sites

In recent decades landfilling of sludge was a favoured method, however, as explained below, the relatively low cost of sludge disposal is becoming more and more questionable under the present conditions.

There are two alternatives for disposal of sludge: mono-deposits where only sludge is disposed of, and mixed deposits where the sludge from the municipal waste water treatment plant is disposed of together with the municipal solid waste. In the latter case, it is customary to utilize the gases from the deposit (methane and CO_2).

Conditions for sludge disposal (sanitary landfill) are regulated by the 'Technical Directives' in each country. Considering the present strict regulations and the limited number of the potentially suitable disposal sites only regional sludge deposits can be considered. It is also desired / required that below the deposit a water tight (e.g. clay) layer should be established to prevent infiltration into the ground water.

Selection of the feasible site has to fulfill other criteria as well. Among these the most important ones are the safety distance from various establishments such as residential areas, public roads, river dikes, etc. It is of paramount importance that the selected site should not be covered even temporarily by inland waters, or be located on the area of water bases (aquifers). Another point is that the land should not be of high value from an agricultural point of view and the future development plan is not to be intercepted by the establishment of the sludge deposit.

Finally, economic points have to be considered as well. Among these the distance of transportation should be minimized, but occasionally the presence of natural depressions, or pits of former mines are taken into account. Traffic should be planned so as to avoid large trucks in residential areas.

Upon selection of the location of the sludge deposit site the technical design follows. The most important elements of the design are the artificial water insulation and drainage. Percolation into the ground and surface water must be prevented at all costs. Therefore the landfill should have water tight layers or lines on the sides (horizontal or sloping).

Establishment of the water insulation layer starts with the formation of a protective fine (sand) layer below the plastic foil layer. Foils are welded together on site. Above these layers the drainage layer is established consisting of a system of drainage pipes, with appropriate slope (for gravitational water drainage). Then a protective layer of sand follows, protecting the underlying drainage-foil system from mechanical damage and consequent leakage.

Actual setting of the deposit site can be realized in different ways. Depending on the characteristics of the area, fill-up deposits are designed in valleys or in other natural depressions in artificial pits or in plane areas by hill building methods. A combination of the above-mentioned methods is also possible, i.e., upon filling up the depression a hill is established on top.

The remaining water content of the dewatered sludge usually does not reach the bottom of the deposit as a result of the microbiological activity. Leachate water is generated from rain water and it is removed by the help of the built-in drainage system. Leachate water is highly polluted, therefore its treatment is indispensable. This treatment can be carried out by traditional waste water treatment methods, but occasionally the leachate is used for irrigation in forestry. Deposit sites has not only to be fenced, but a protective forest range has to be established around it as well.

Operation of the deposit will be discussed later, but already here it is stressed that a monitoring well system has to be established around the area for the detection of potential pollutant migration. Sampled ground water has to be analyzed in laboratories.

Finally, recultivation of the deposit has to be taken into account when designing such an establishment. Usually, upon finishing disposal operations shrubs and forest are planted on the top of the area. As it appears from the conditions described above, the establishment of a sludge deposit site is extremely costly, requiring a useful life (filling up capacity) of at least 10 years to achieve cost effectiveness.

9.2. Practical Solutions

There are two alternatives for disposal of sludge: mono-deposits where only sludge is disposed of, and mixed deposits where the sludge from the municipal waste water treatment plant is disposed of together with the municipal solid waste.

9.2.1. Mono-deposits

The largest constraint on the establishment of a mono-deposit system in the temperate climate is the provision of the appropriate water content of the sludge. Usually, this cannot be above the 65% percent value as a higher water content impedes the mechanical means of transportation and handling. Suitable consistency of the sludge is checked by the special shearing-force measuring apparatus. Dried sludge has - at least so far- not been disposed of on waste deposits where the largest problem is the efficiency of the dewatering process. Among the dewatering processes described in detail in chapter 7, the chamber press machine and a new generation of centrifuges can theoretically fulfill or exceed the criteria, after lime-iron salt conditioning.

As an example, the dry material content of the lime and iron salt conditioned sludge on chamber press is about 40-50% in the Northern-Budapest WWTP. The sludge cake produced here is disposed of on an appropriately designed deposit near the capital (20 kms away) in the vicinity of the municipality of Fótcsomád. This deposit is acknowledged as the most advanced sludge deposit in Central Europe.

There are strict rules for the operation of mono-deposits. In theory, these rules already apply when loading the trucks with sludge at the waste water treatment plant. The most important task is the organization of the disposal on the deposit, transport vehicles movement, and the material movement on the deposit. All of these processes have to be in harmony with each other. Strict regulations apply to the width of the deposited sludge layer (this depends on the consistency of the sludge), the storage and distribution of the cover layer (soil) for the control of odour and infection as well as the availability to animals (rodents). Collection of leachate and surface precipitation, their collection method, treatment and disposal have to be regularly checked. Should the water sample in the monitoring wells indicate ground water contamination, the technology has to be modified. Apart from these rules a wide range of occupational health, hygienic and labour safety rules have to be followed.

Although the physical conditions in a compactly sludge deposit are not really favorable for gas formation, as in the mixed deposits to be discussed later, some gas formation is expected to occur in mono-deposits as well. The gas contains 50-60% methane, 40-50% carbon dioxide (in traces other gases also). The methane is considered a dangerous gas, therefore surface gas evaporation on the surface of the deposit has to be controlled and checked. The most important task is to avoid gas accumulation in closed (covered) spaces (i.e. in rain water collection shafts).

9.2.2. Mixed Deposits

In forming the mixed deposit the predominant ingredient is the municipal solid waste, whereas the sludge is considered as a secondary additive as its proportion is usually only 20-25% (see figure 9.1 and 9.2). As the companies responsible for the collection and treatment of municipal solid waste are not identical to the ones responsible for the sewerage and waste water treatment, the first constraint to be dealt with is the protest of the solid waste management company against receiving and operating with sludge. The reason for this is that the sludge disposal makes the waste disposal more complicated, especially when the water content of the sludge is high. In spite of this, the establishment of mixed deposits is economically desirable, and the requirement for the reduction of the water content of the deposited sludge is not as high as in the case of mono-deposits. The water holding capacity (hygroscopy) of the solid waste is relatively high. For the achievement of the proper microbiological activity within the landfill, a water content in the range of 60-65% is required. The waste itself matures (biologically available organic material content is degraded by the microorganisms, and stabilization takes place) and the already mentioned gas formation is enhanced. In this deposit type the collection and utilization of the formed gas is a desirable (sometimes compulsory) task (see below).

Regulatory principles for mixed deposits were compiled on the basis of the German regulations (LAGA-Deponie Merkblatt 4690, ATV-VKS, Regelwerk, Abwasser-Abfall, Arbeitsblatt A 301):

1. The most important rule of the mixed deposits is that during processing the suitable consistency has to be ensured, for the appropriate work of the mechanical machinery, to compress the solid waste and the sludge in an optimal way.

2. Sludge can only be deposited after dumping an at least 3 meters thick solid

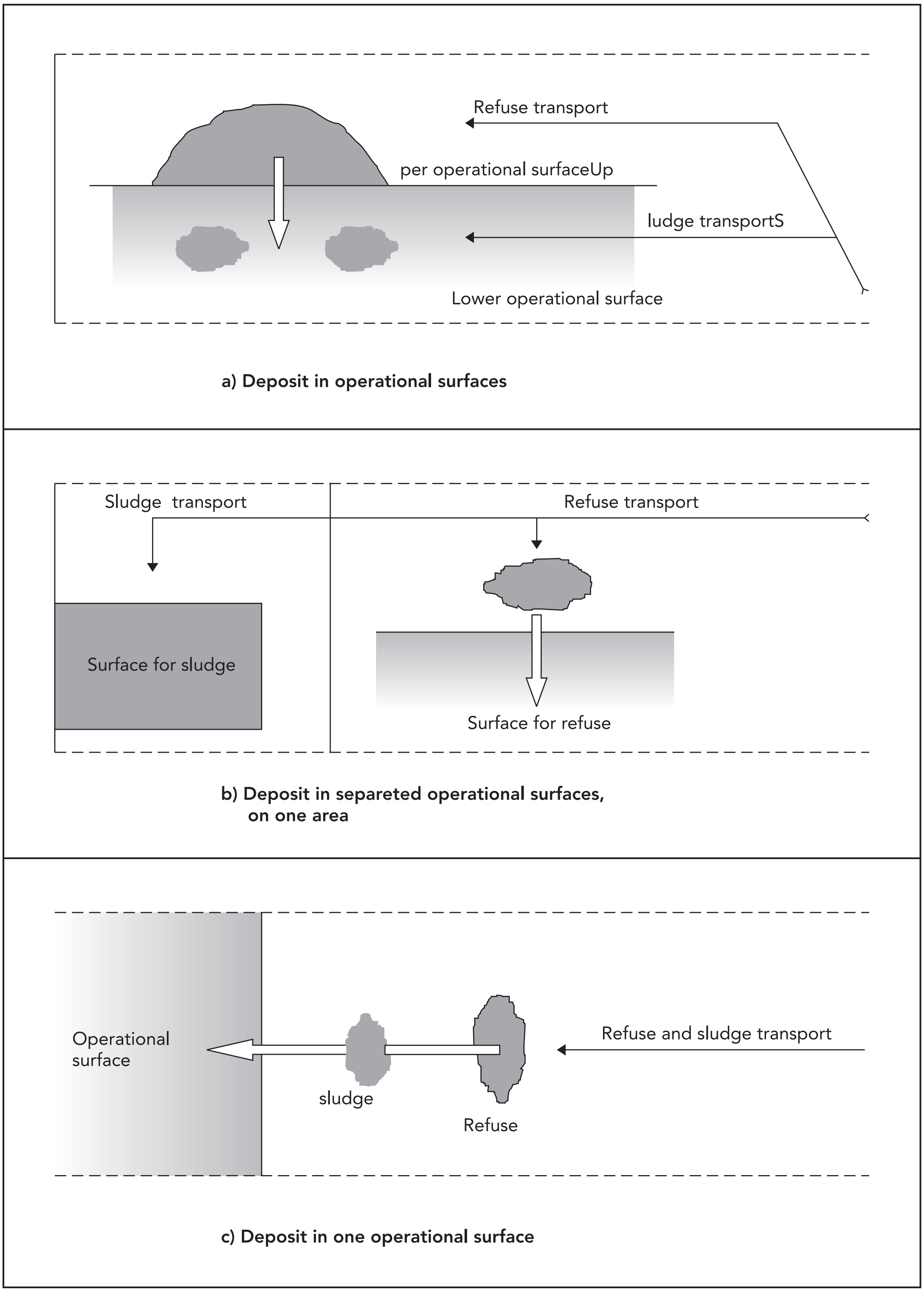
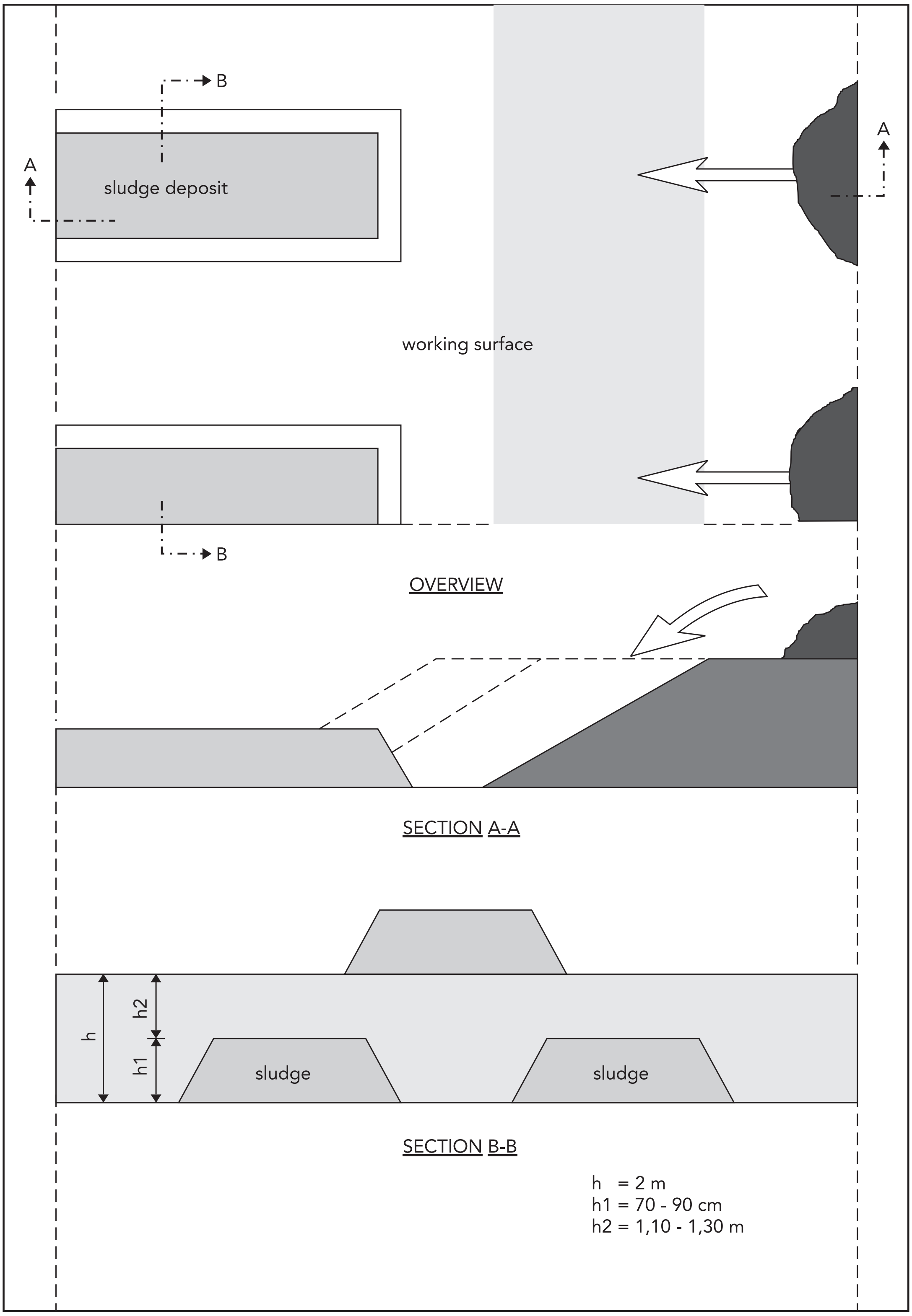


Figure 9.1.

Disposal of sewage sludge and solid waste at mixed deposit

Figure 9.2.

Sewage sludge landfill disposal



waste ground layer. Continuously spread sludge layers have to be avoided.

3. There are three built-in methods applied depending on the way in which the sludge is mixed into the solid waste,
   • Pile deposit. In case of point (pile) disposal the maximum amount of sludge can be 20-25 percent (w)
   • Mixed deposit.
   • Deposit in levels. In two or three levels (see Fig. 9.1). In case of this alternative the mixing ratio is only 10% for the sludge. In the latter case the building in method at the deposit can be freely chosen.

4. Separated (i.e. point like) sludge disposal has to be closely followed in time by the covering up of the sludge pile with solid waste (see Fig. 9.2).

5. During disposal the formation of the off-gases is not a real hazard, as deposit gases though formed in deeper layers are readily ventilated through a large surface area. Upon completing the disposal process by covering the surface layer with soil, significant gas formation is expected to occur. These gases are to be collected and utilized. If utilization of the gases cannot be managed, collection and safe ventilation of these gases have to be ensured in another way (i.e. by ventilation chimneys followed by burning).

6. Leachate water percolating through the deposited waste and sludge layers (it may fluctuate between 0.01-0.1 l/sec quantities) is considered to be highly polluted and its chemical oxygen demand can reach values as high as 50-60,000 mg/l, and the ammonia content might reach several thousand milligrams per liter.

There are two possible ways of reducing such a high pollution level. The first is the well-known waste water treatment, the second is the recirculation of the leachate water to the deposit (not allowed in some countries). The latter method provides twofold benefits: on the one hand it provides the optimal water content necessary for the gas formation and on the other hand via the inner natural biodegradation processes (microbiological degradation) the organic material content is greatly reduced.

Many mixed deposits have been established all over the area of the FRG (regarding it as an example). For details consult MuA 62.

Table 9.1.

Number of Council Directive	Title of rule
75/442/EEC	Waste Framework
94/62/EC	Packaging and packaging waste
91/689/EEC	Hazardous waste
94/67EC	Incineration of hazardous waste
COM (97) 105 final, 97/0085 (SYN)	Landfill waste

EU-Directives on waste

Lfg. IX/81, Rettenberger and Tabasaran: Gemeinsame Ablagerung von Hausmüll und Klärschlamm.

9.3. Evaluation of Cost Efficiency

The specific price of establishing a sludge deposit (including the cost of geological and hydrogeological investigations, area, liner (plastic or clay), leachate and gas collection and treatment systems (drainage systems), fences, planting, soil for covering the sludge, monitoring wells, control and analysis of leachate, weigh bridge, buildings, machines, pumps etc., but excluding the price of the land) is approx. HUF 10,000 or USD 67, or DEM 100 per square meter (1996 price level). There are huge differences between the Austrian and German specific prices with regard to the disposal cost of 1 tonne of waste. The disposal cost in Styria (Austria) varies between 800-3,500 ATS (USD 80-350). In Germany the price was in 1991 DEM 300 - 600, showing a constant increase over the past few years.

Table 9.1 shows the most important Directives applying to waste management.

10. New Technologies (Gasification, Wet Oxidation)

By Ådne Ø. Utvik[11] and Bernhard Matter[12]

10.1. Gasification of Sludge

Gasification of waste water sludge is a rather new method of sludge processing, and detailed information on the method is limited. However, the method is briefly described and discussed in order to make this handbook complete.

10.1.1. The Gasification Process

Gasification is a thermal process whereby a feed stock containing combustible material is converted with air (some times oxygen and/ or steam) to an inflammable gas. Before World War II this technology was applied for the supply of local power in industry and later, due to a shortage of petrol in the war, also as fuel for cars, trucks etc.
The most frequently used reactors for gasification are:

- The fixed bed reactor
- The fluid bed reactor
- The circulating bed reactor

Figure 10.1 shows the main steps in the gasification process.The first stage is to remove most of the remaining water by thermal drying. The dry solid content output from the drier is 85-93% DS, depending on the type of gasifier installed, see below.

Now the sludge is prepared for gasification, i.e. 'incineration' with sub-stoichiometric oxygen input. The various components in the sludge are partly, and some of them completely, oxidised.

A large number of reactions take place in the reduction zone of the gasifier. However, the overall process can be described by the following three main gasification reactions:

- $C + CO_2 \leftrightarrow 2CO$
- $C + H_2O \leftrightarrow CO + H_2$
- $CO + 3H_2 \leftrightarrow CH_4 + H_2O$

The input is mechanically dewatered sludge, digested or undigested.

Since the composition of the sludge varies greatly, the composition of the exit gas from the gasification process will also vary to a great extent.

As mentioned, gasification of sludge is a rather new method and presently at the stage of demonstration. Thus, there is no adequate and long time experience making a reliable comparison between gasification and incineration possible.

10.2. Wet Oxidation

The organic content of sludge (approximately 5% DS) is oxidated in specific reactors at temperatures of between 200_C and 300_C and at pressure levels of between 30 bar and 150 bar (low/high pressure systems).

The necessary pressure may be reached through high pressure pumps or through specially designed reactors: tubes, reaching 1,200 meters deep into the underground, at the bottom of which the fluid sludge passes through a zone of high pressure and temperature before rising up again to the surface. In this application, dewatering is not necessary for the input to the sludge treatment process.

The main output of the process is sludge containing more than 95% of mineral components and less than 3% of low-molecular organic substances. The sludge is dewatered (i.e. beltfilterpress) and then recycled or landfilled.

Since the filtration water is very rich in ammonia, it needs to be treated locally (de-/ nitrification) or led to a public waste water treatment plant.

An upscale oxidation plant is running in the Netherlands. However, this plant seems to have some operational difficulties.

10.3. Plasma Pyrolysis

Plasma arc heaters (torches) makes heating of hydrocarbon waste materials (i.e. sludge) to high temperatures as possible. The hydrocarbon content of the waste is pyrolised at

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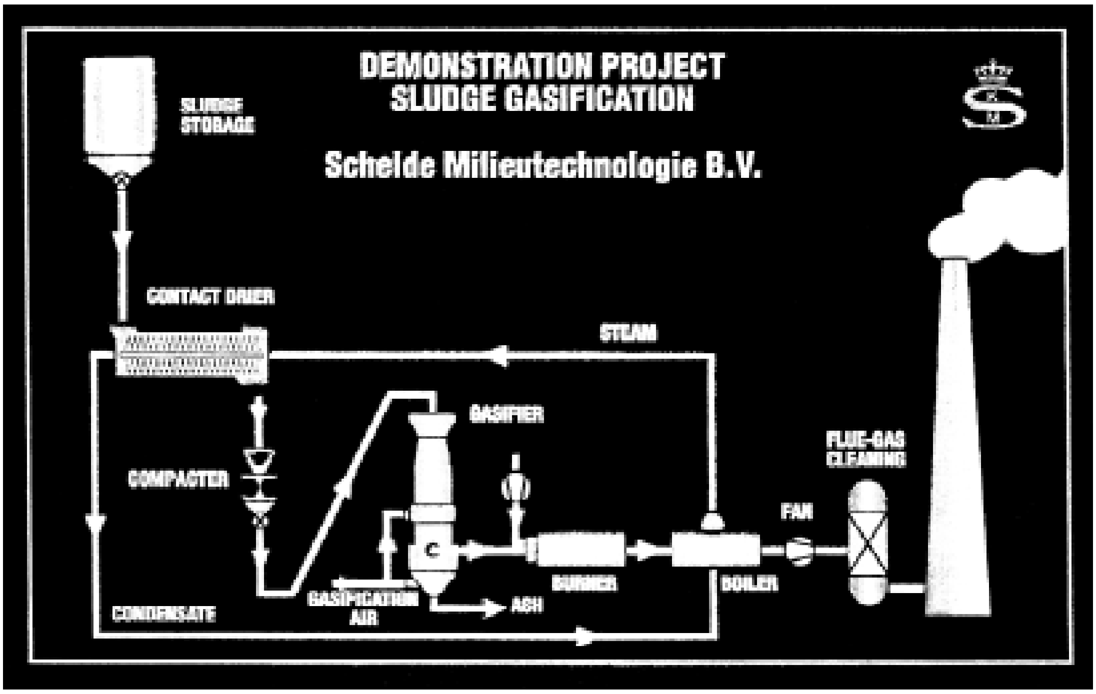
[12] CDS, Colombi Schmutz Dorthe AG, Konsumstrasse 20, 3007 Bern, Switzerland

Figure 10.1.



Sludge gasification - flow sheet. *Courtesy of Schelde Milieutechnologie B.V.*

2,000_C to 4,000_C into a gas mixture (80% CO_2 and H_2) which may be used in the manufacture of methanol or as fuel. The molten slag-metal mixture solidifies into a gas-like non-leachable solid.

The ratio between the energy output and the input of electric energy is around 4.

The technology, widely applied in the metallurgic industry for decades, has been adapted to waste management conditions and requirements since the eighties. Upscale plants treating municipal waste are under construction in the USA. In Europe, several plants are operated mainly to achieve vitrification of slag and ashes as outputs of conventional waste incineration plants.

11. Environmental Impact Assessments

By Albrecht R. Bresters[13], advice by M. Würdemann[14]

11.1. General

The environmental impact assessment study (EIA study) can play an important role in the decision making process of large sludge treatment projects. In the Netherlands, an EIA is obligatory if the sludge amount exceeds 5,000 tonnes of dry solids a year.

This EIA can be applied and executed in two different manners:

- to support decision making at policy level;
- to support the procedure for granting of permits.

The first type of EIA is probably the most effective one as it enables a comparison of alternatives and decision making at a strategic level. This EIA may comprise subjects such as system and site selection.

For projects which may have an extensive environmental impact, a project EIA is usually part of the procedure for granting of permits. The choice which has been made is further evaluated at a project level in terms of its environmental impacts and the possibilities of their mitigation.

In summary, the goal of a policy EIA is to evaluate systems (system selection, stand alone solutions or solutions in combination with other waste or waste water treatment plants or a power station) and to evaluate possible sites.

The goal of the project EIA is to optimise the project within stricter boundary conditions, such as the considered site, the local infrastructure and the existing facilities.

11.2. Set-up of the EIA

An EIA starts with a definition of the problem and the goal to be achieved. Within the context of this paper the EIA will deal with the sludge problem in a certain country or region. Considered on a broader basis sludge is part of the waste water treatment chain and so it may in some cases be incorporated in the EIA on waste water treatment in a certain region. But also in that case, the goal of the EIA is thus defined that in a certain region a large amount of sludge has to be disposed of in an environmentally safe manner. This sludge may originate from municipal waste water treatment plants, from industrial waste water treatment plants or from both.

The goal of a policy EIA is to provide certain boundary conditions for new policies and environmental planning. The goal of the project EIA, on the other hand, is more limited, namely to define an optimal solution within existing planning boundary conditions. For instance, the question whether sewage sludge (or the organic residual products of treated sewage sludge) is still allowed for agricultural purposes or landfilling is quite important for the selection of applicable technologies.

Once the legal and policy boundary conditions have been defined, it is very important that the actual systems and technologies to be considered are evaluated at the same level and in the same depth. This means that all inputs and outputs of the considered techniques (composting, thermal drying, incineration, vitrification, gasification, wet oxidation etc.) should be considered completely in terms of their environmental impacts. Consequently, the effects of sludge transportation as well as the possible environmental impacts of residual materials (for re-use as secondary raw material, fuel or for landfilling) should be included.

A problem may arise when the information available on the various techniques is not readily comparable. This can happen when ‘state-of-the-art’ technologies are compared with ‘prototype’ solutions.

The description of the various techniques (‘alternatives’) should include reliable and comparable information on the following principal environmental criteria:

- air quality and emissions to air;
- surface water quality and resulting waste water streams;
- soil and ground water conditions, residues etc.;

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[14] *Haskoning Consulting Engineers , The Netherlands*

- noise effects;
- ecological impacts;
- safety;
- energy;

In the decision making process, however, also other criteria may play an important role:

- physical planning criteria, such as impact on landscape, required space and infrastructure site requirements;
- technical criteria, such as state-of-the-art, flexibility and technical complexity;
- last but not least, financial criteria, such as investment and operating cost compared to the cost of non-action

The EIA study includes a comparison of the various alternatives, with an indication of unknown factors which may influence the system selection. In a project EIA, once a system has been selected, a number of optimisations within the system may be evaluated in terms of their relative environmental impacts, such as various ways of sludge storage, reactor types or gas treatment systems.

The EIA can be finalised by indicating the method of monitoring and evaluation of the (future) project.

11.3. Procedure

The basic procedure for an EIA in the Netherlands can be summarised as follows:

1. The policy decision (in case of a policy EIA) or the project (for a project EIA) are described by the organisation responsible or taking responsibility for the establishment of policies or for the project itself. The description includes a brief outline of the boundary conditions and the subjects to be studied in the EIA. The comments of the public as well as the parties involved are requested.
2. A national advisory commission presents guidelines for the EIA. These guidelines are finally established by the authority responsible for the policy planning and / or the granting of permits, taking into account also comments from other participants.
3. The actual EIA study is executed, and subsequently the above-mentioned commission advises the authority responsible.
4. The results of the EIA and the advice will finally be used to define the policy and / or the permit conditions. Also during this phase of the procedure the possibility of public participation exists.

The EIA procedure is governed by European (Directive 85 / 337 / EEC) and by national law.

12. How to Decide on Sludge Disposal

By Bernhard Matter[15]

12.1. Legal Boundaries

Legislation has the following impact on sludge disposal,

- Prescriptions as to the allowed disposal of sludge itself; utilisation in agriculture or forestry as sludge or as compost conditions for landfilling
- Prescriptions as to emission standards to be met by sludge incinerators
- Prescriptions as to the quality of outlets from waste water treatment plants affects the amount and quality of sludge produced

Table 12.1.

Utilisation in agriculture/forestry	150 - 400
Composting	250 - 600
Drying	300 - 800
Incineration*	450 - 800
Landfilling	200 - 600
*Lower commercial prices possible in case of paying marginal prices for sludge incineration at waste incineration plants	

Treatment costs in DEM per tonne of dry substance

An overview of legislation on sewage sludge is provided in appendix 14.1.

12.2. Cost

Costs are an important element in deciding on sludge treatment. They vary greatly depending on local conditions and on the size of the treatment facility. In order to achieve appropriate comparison of different choices of sludge treatment and disposal, it is important to take into account the overall annual costs, which are influenced by three main components.

First, annual capital costs, depending on the sum to be invested, the method of financing, the depreciation period and the interest rates on borrowed capital. Second, running costs due to energy, chemicals, maintenance, salaries of the personnel, taxes, insurance. Third, the costs of disposal or re-use of the final product or residue.

The above costs are all generated at the sludge treatment plant or further on in the process. If the sludge treatment is not effected at the sewage treatment plant itself, usually transport costs and costs of storage facilities due to transport methods are not to be neglected. As an order of magnitude, specific treatment costs may vary as indicated in table 12.1.

By making cost comparisons, that fact that the quality requirements of the input sludge and thus the pre-treatment costs may be different from one method to another also has to be considered. For instance, wet oxidation and in some cases also utilisation in agriculture do not require dewatering of the sludge. The above costs do not include transportation and dewatering, nor any other pre-treatment (aerobic or anaerobic stabilisation) of the sludge. The cost of utilisation in agriculture includes hygienisation.

12.3. Decision Tree

A decision tree is presented in figure 12.1. The key words are commented on in table 12.2.

The decision tree shows the different methods for treatment and disposal of fluid, stabilised sludge. Stabilisation means aerobic thermophilic pre-treatment or anaerobic digestion, both resulting in a sludge with little biological activity, thus minimising gas and odour emissions.

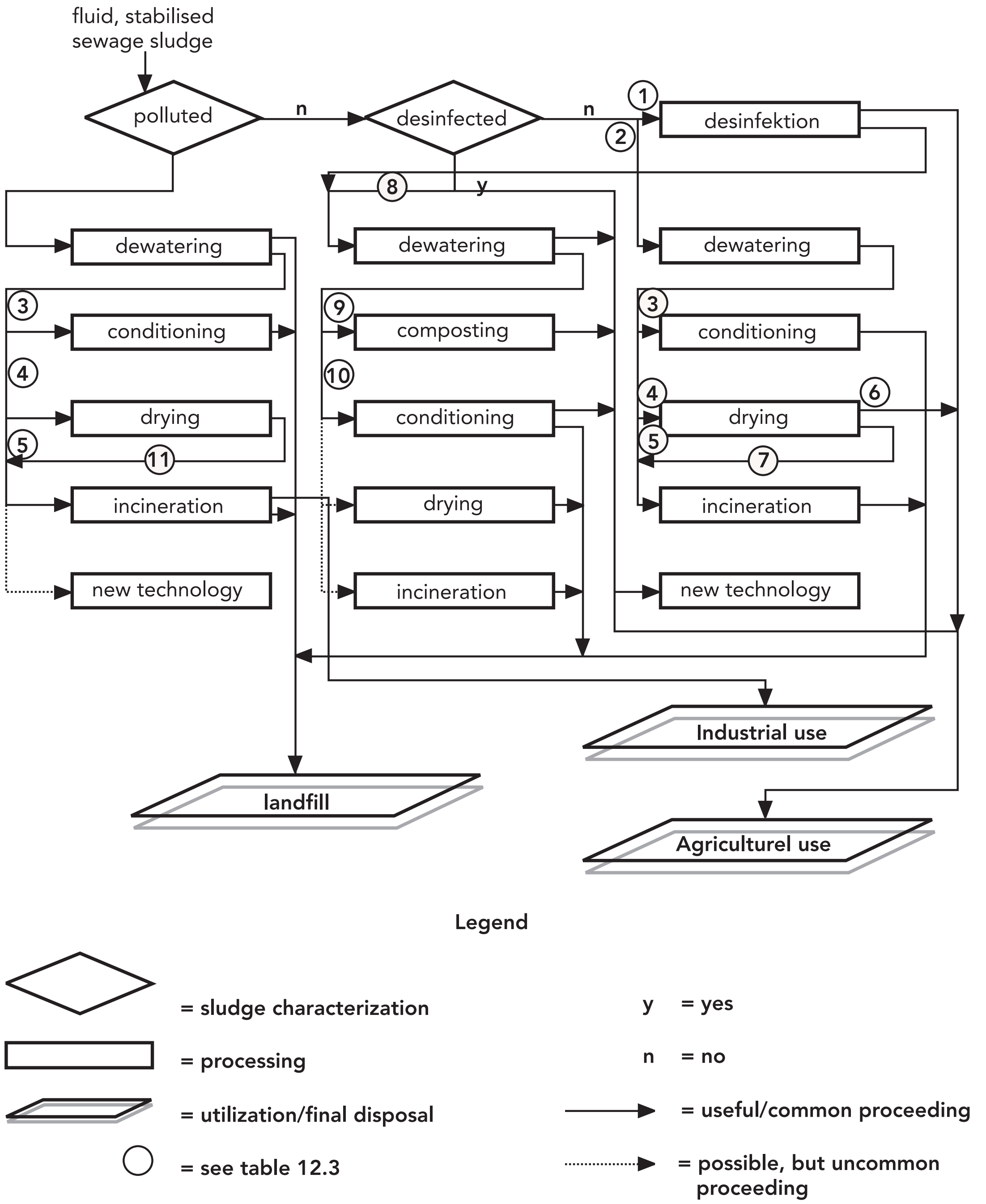
The conditions of deciding which way to go in the decision tree are numbered. Examples of what may be a reason for choosing this way rather than another are listed in table 12.3. This table is neither exhaustive nor are all of the decisions unequivocal. It mainly has a illustrative purposes.

Non-stabilised sludge may be treated in a

15 CDS, Colombi Schmutz Dorthe AG, Konsumstrasse 20, 3007 Bern, Switzerland

Figure 12.1.

Sludge Treatment Decision Tree



similar way as polluted, stabilised sludge. In this case conditioning not only has to improve mechanical properties, but also ensure biological stability. Before such stability is reached, it is important to treat the non-stabilised (fresh) sludge continuously as intermediate storage of fresh sludge may lead to odour and safety problems. In most cases it is therefore reasonable to stabilise the sludge as a first treatment step (e.g. anaerobic digestion).

Table 12.2.

Comments on keywords in figure 12.1
Additional information is provided in the other chapters of this booklet.

Term in figure 12.1	Comment
Polluted	A sludge is polluted if it does not fulfil the legal requirements for agricultural use. Pollution normally consists of an excessive heavy metal content.
Disinfection	Disinfection is necessary for agricultural application of thin or dewatered sludge as anaerobic digestion alone does not guarantee sufficient elimination of germs. Usually pasteurisation is chosen to produce a hygienic sludge.
Dewatering	Thickening of thin sludge by mechanical methods (presses). The dry substance content of dewatered sludge is approximately 15 to 35%
Conditioning	Conditioning is mixing the dewatered sludge with an additive reducing the thyxotropic properties and increasing the mechanical resistance in order to make the sludge easier to store, transport and deposit. Most additives are made on the basis of crushed limestone.
Drying	The dry substance content after thermal drying is usually 80 to 90%. The resulting granular sludge is then biologically stable, easily storable and transportable and may be used as fuel or as fertiliser. In the case of end disposal in a landfill or a waste incineration plant, drying may be reasonable only up to a dry substance content of 40 to 60%, which can also be reached by mixing of dried sludge with dewatered sludge.
Incineration	The purpose of incineration is not only sludge elimination but also recovery of energy. This may be done at a special sludge incineration plant or with dried sludge as a fuel, at an external power plant or cement kiln. When incineration occurs at a nearby waste incineration plant, pre-drying may be less important than for other uses.
New technologies	Gasification, wet oxidation, plasma pyrolysis.
Landfill	Landfilling of dewatered or even partially dried sludge is not or will not be allowed in all countries. Dewatered sludge often has to be conditioned before disposal. The residues (ashes) of incineration plants are usually disposed of at landfills.
Industrial use	Dried sludge may be used in the fertiliser industry, in power plants, incineration ashes in the construction industry.
Agricultural use	Sludge may be used in agriculture as thin, not dewatered sludge or as dewatered sludge, in the latter usually after conditioning. A third way is spreading of dry sludge as a commercial fertiliser, for instance if the sludge is dried and stored during the winter season. Similar to the use in agriculture is the application in forestry, horticulture or viticulture.

Table 12.3.

Explanation of numbers contained in the decision tree

Number in figure 12.1	Examples of conditions influencing the decision
1	Utilisation of thin and/or dewatered sludge in agriculture is possible
2	No use in agriculture or at the most as dry granular sludge
3	Mechanical properties have to be improved for intermediate storage, transportation or landfilling
4	Landfilling is not desired
5	Incineration in a waste incinerator or similar furnace allowing input of dewatered sludge. Limits and variations of dry substance content after dewatering have to be controlled
6	Granular spreading in agriculture, due to seasonal storage of dried sludge or to non-acceptance of other types of sludges by farmers
7	External valorisation of dried sludge as a fuel or disposal of surplus stock of dried sludge or mixing of dried sludge with dewatered sludge in order to reach input limits of dry substance for the furnace
8	Application of thin (non-dewatered) sludge in agriculture
9	Green waste from gardens or other compostable waste is available for mixing with sludge. Utilisation of compost, e.g. as a soil conditioner, is possible
10	Mechanical properties have to be improved for intermediate storage, transportation or application in agriculture. Landfilling of surplus sludge.
11	External valorisation of dried sludge as a fuel or mixing of dried sludge with dewatered sludge in order to reach input limits of dry substance for the furnace.

13. Appendices

13.1. Legislation on Waste Water Sludge as per 1 October 1996

By Alice Saabye[16]

European waste policy is based on a hierarchy of management priorities:

- Minimisation
- Recycling
- Incineration with energy recovery
- Landfilling

The following legislation affects treatment and disposal of waste water sludge.

13.1.1. EU Countries

Urban Waste Water Treatment Directive (91/271/EEC)
As the directive lays down stricter requirements for waste water treatment, it leads to a considerable increase in the amount of waste water sludge.

The directive requires that the EU member countries should establish secondary treatment of waste water for waste water treatment plants exceeding 2000 PE by 31-12-2005. At discharge to fresh receiving waters, the waste water must be treated for nutrients and organic substances (articles 4 and 5).

The directive prohibits discharge of sewage sludge into the sea and freshwater after 31.12.1998 (article 14).

Directive on Protection of the Environment and in particular of the Soil when Waste water sludge is used in Agriculture (86/278/EEC).
This directive concerns the regulations that must be met if sludge is used on farmland. The following requirements are common to these regulations:

- Pre-treatment
- Restriction on the content of heavy metals in sludge
- Restriction on the amount of dry solids and heavy metals spread per unit of land and time
- Restriction on the content of heavy metals in the soil on which sludge is spread, and requirements for the pH of the soil
- Restriction on the content of micro-pollutants
- Restriction on the amount of nutrients added to the soil (N and P)
- Restrictions on the choice of crops
- Restricted access conditions to farmland on which sludge is spread
- Legislative compliance control

Draft Directive on Waste Disposal (95/09/15)
Proposal for a Directive on the landfill of waste. The draft directive describes the requirements for design, establishment, operation and close-down of landfills. Landfills must be environmentally approved by the authorities.

The directive classifies landfills in three categories, which differ in relation to requirements for liners and control:

- Landfills for hazardous waste
- Landfills for non-hazardous waste
- Landfills for inert waste

The landfilling of waste water sludge is not forbidden, but restricted, as it is biodegradable waste. The target for restriction is to have only 25% of the quantities of biodegradable waste produced in 1993 landfilled in 2010 (Article 5).

Draft Directive on Incineration of Waste (94/08/20)
The draft directive includes waste incineration plants as well as sludge incineration plants and lays down requirements for all emissions from these plants, e.g.:

- Air emissions
- Solid residues from incineration and flue gas cleaning (sludge ash)

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- Waste water from flue gas cleaning (scrubber water)
- Leachate from ash deposit

Sludge incineration plants must be environmentally approved by the authorities.

13.1.2. USA

For many years, preparations have been made in the USA to work out sludge regulations covering all fields of application and disposal. On 25 November 1992, the final edition of part 503 'Standards for the Use or Disposal of Waste water sludge' was ready.

In addition to requirements for agricultural use of sludge, the regulations include incineration and landfilling as well as detailed requirements for pre-treatment.

The American regulations contain very specific directions for sludge treatment before disposal including requirements for pathogens and vector attraction reduction. They also divide the sludge into two classes. If a number of further specified requirements are complied with, sludge classified as Class A can be used without restrictions. Less strict requirements on sludge pre-treatment apply to sludge classified as Class B, which must only be used under certain specific site restrictions.

The directions applying to sludge in Class A are split into six alternative methods and those applying to sludge in Class B are split into three alternative methods including site restrictions.

The pathogen reduction processes are divided into two stages:

- Processes to significantly reduce patho gens (PSRP)
- Processes to further reduce pathogens (PFRP)

13.2. Plant Utilisation of Nutrients in Sludge

By Alice Saabye[17]

Sludge contains a number of nutrients. In general, the largest part of the nutrient value is phosphorus, but a considerable amount of nitrogen is also contained in the sludge. However, the content of potassium and magnesium is low. The amount of nutrients contained in the sludge varies a great deal, which may be attributed to different treatment methods. It is therefore important that analyses of the current sludge should be available for inclusion in the fertiliser plans for the fields onto which the sludge is spread.

13.2.1. Nitrogen

Plants cannot make immediate use of the nitrogen contained in the sludge as the main part is organic and needs to be converted into inorganic nitrogen by mineralisation before it can be absorbed by the plants.

Plants generally need addition of nitrogen early in the season of growth, whereas mineralisation of nitrogen is not performed until after the spreading when the soil bacteria have been activated. Consequently, plants with a short season of growth, e.g. grain crops, cannot utilise the nitrogen very well, whereas plants with a longer season of growth, e.g. beets, corn and rye grass, are able to utilise the nitrogen to a greater extent.

The type of nitrogen and its effect on plants depend on sludge type and treatment, cf. table 14.1.

As can be seen from table 14.1, the effect of nitrogen from dewatered sludge on plants is less significant owing to removal of dissolved inorganic nitrogen with the reject water.

13.2.2. Phosphorus

Sludge is generally a good phosphorus fertiliser, even if the phosphorus contained in sludge is much less readily soluble than the phosphorus contained in artificial fertiliser. On well-fertilised soils, the phosphorus state is merely to be maintained. The phosphorus accessibility in sludge depends on the treatment of the sludge. Table 14.2 shows the phosphorus accessibility to the plants. The amount of citrate soluble phosphorus shows how much of the phosphorus is accessible to the plants.

13.3. Basic Characterisation

By Ludovico Spinosa and Vincenzo Lotito[18]

Many parameters and tests are available for the characterisation of sewage sludge. The main problem is that they are generally specific to the method of treatment and disposal and not able to give fundamental information on the sludge in question.

The most important parameters yielding

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Table 14.1.

Utilisation of nitrogen from different types of sludge

Sludge type	1st year uptake in plants	Nitrogen type	Possible effect for several years
Liquid			
Primary sludge	30-35% of total nitrogen if spring spreading 15-20% of total nitrogen if autumn spreading	Mainly organic	Yes
Biological sludge	50% of total nitrogen	Organic	Yes
Anaerobic, digested sludge	100% of NH_4 + 15% of organic nitrogen	Mainly inorganic (ammonia)	No
Dewatered:			
Primary sludge	15-20% of total nitrogen	Organic	Yes
Anaerobic, digested sludge	15% of total nitrogen	Organic	Yes

Table 14.2.

Utilisation of phosphorus and potassium from waste water sludge

Nutrient	1st year uptake in plants	Possible effect for several years
Phosphorus:		
Total phosphorus	50-80%	Yes
Citrate soluble phosphorus	100%	Yes, if surplus
Potassium	100%	Yes, if surplus

basic information are particle size distribution, water retention and rheological properties.

13.3.1. Particle Size Distribution

The main problem in particle size evaluation relates to the measurement difficulty. Three principal methods are known, i.e. direct examination, fractionation and counting, but each of them requires modifications of the sludge before and during measurements, which may result in an alteration by the measurement techniques of the original distribution. A reproducibility problem is also present due to the irregular shapes of sludge flocs, so each step in a sizing procedure must be conducted carefully to preserve the original floc shape, size and structure [2].

The main problem of direct examination is to fix sludge in an inert medium to allow non-disruptive examination. The fractionation with a series of filters or screen could cause the retention of smaller particles by layers where larger ones prevail. Finally, counting methods involve the use of different instruments, which measure signals proportional to particle size: such instruments generally require mixing possibly resulting in a change in the particle size distribution.

13.3.2. Water Retention

Although the names given to the various water fractions can be different, the following classification appears appropriate: free water, capillary water, vicinal water and chemically bound water.

Classical analysis is carried out by thermogravimetry, which consists of submitting a small sample of material to drying at low temperature under standard conditions: the results are presented as drying rate curves consisting of a constant rate period, a first falling rate period and a third one. An alternative method is based on the theory that bound water does not freeze at temperatures below the freezing point temperature of free water, so the free water can be determined by noting the expansion caused by freezing. A differential thermal analysis procedure has also been used [4].

13.3.3. Rheological Properties

A powerful technique in characterising sludges is to classify them according to their flow properties.

The fluidodynamic characterisation of sludges has been widely applied in the past to the study the flow of slurries, but due to the existence of some correlation between the rheological properties and the suitability of sludges to treatments, such as flocculation, thickening and dewatering, and disposal, mainly landfilling has been evidenced [1], [3].

The rheological behaviour of sewage sludges is generally described as non-Newtonian (Ostwald-pseudo-plastic and Bingham-plastic models have been found to be the most recurrent for waste water sludge); activated sludge has also been found to be thixotropic, which means that sludge rheology is also dependent on the shear rate history.

A wide variety of viscometers is available. They fall into the two general categories of tube type and rotating type, whose applicability depends on the sludge physical state (liquid, plastic, solid).

The tube viscometers involve a faraginous procedure and are not commercially available; moreover, the tube diameter must be large enough to prevent clogging.

Rotational viscometers are generally considered to be more reliable. They may have coaxial cylinders, rotating blades and cone-plate geometry. Drawbacks of coaxial cylinder types are that cylinders must have a small gap, so there is a risk of obstructions by solid materials, and slipping may occur at the cylinder/liquid interface. In the case of viscometers with blades (or vane apparatus), the velocity gradient is less well defined, so only a mean value based on the mechanical energy dissipated in the medium can be obtained. The cone-plate geometry rheometers can be excluded on the basis of both the large size of sludge particles relative to the gap and the generally poor sludge consistency.

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