

Course book *Wastewater Sludge Management*



Foreword

This course book is part of the learning material to the module *Wastewater Sludge Management*, the third module of the course *Wastewater treatment for Process Controllers*. The course is developed as a follow-up of the first and second modules, part of the same course as a project under the umbrella of the Centre of Expertise in Durban. This Centre is a joint initiative of the Netherlands and South Africa to implement innovative methods and exchange in Southern Africa.

The course provides a brief overview of the wastewater treatment processes and techniques. The main focus is on sludge. The techniques of handling sludge are discussed in detail, including digestion, dewatering, thickening and drying. The operational aspects and troubleshooting are taken into consideration. The current methods of sludge disposal are discussed. The participants become aware of sustainable ways of using sludge and regarding it as a resource rather than waste.

After attending the course you will understand how their activities in handling sludge links to the efficient performance of the wastewater treatment plant.

To make the course as effective as possible for you, we hope that you will share your knowledge and examples, that you feel free to ask explanations. Please let us know if you have any comments, because with your comments we can improve the training!

We hope you will enjoy the training and wish you lots of success.

Best regards,

Agnes Maenhout (CEO World Water Academy / Wateropleidingen) and the trainers from World Water Academy, Waternet and eThekweni

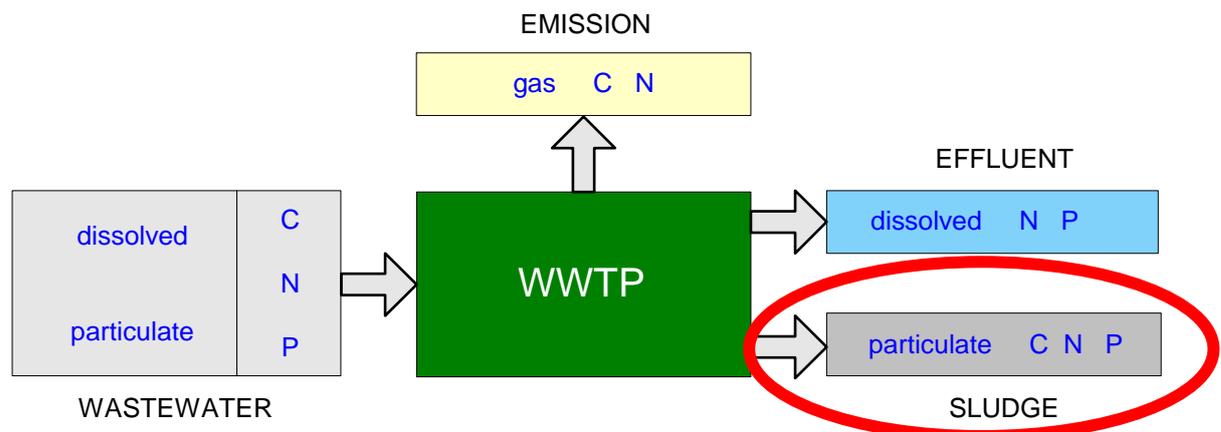
Content

- 1 Introduction..... 7
 - 1.1 Types of sludge 7
 - 1.2 Solids concentration..... 7
 - 1.3 Costs 8
- 2 Thickening..... 9
 - 2.1 Techniques 9
 - 2.2 Equipment 10
 - 2.3 Characteristics 11
 - 2.4 Operational aspects 11
- 3 Digestion..... 14
 - 3.1 Techniques 14
 - 3.2 Equipment 14
 - 3.3 Characteristics 17
 - 3.4 Operational aspects 18
- 4 Dewatering 19
 - 4.1 Techniques 19
 - 4.2 Equipment 19
 - 4.3 Characteristics 21
 - 4.4 Operational aspects 22
- 5 Drying 25
 - 5.1 Techniques 25
 - 5.2 Equipment 25
 - 5.3 Characteristics 26
 - 5.4 Operational aspects 26
- 6 Disposal 28
 - 6.1 Techniques 28
 - 6.2 Laws and regulations..... 29
 - 6.3 Characteristics 30

7	Reuse	31
7.1	Types of reuse of sludge.....	31
7.2	Laws and regulations.....	31
7.3	Costs and benefits	31
7.4	Pollutant removal and sludge reuse in agriculture	32

1 Introduction

Sludge is separated off as a by-product in the treatment of wastewater. The sludge can be used for agricultural purposes since it has value as a fertilizer. However, besides the fertilizing substances, the sludge also contains greater or lesser amounts of polluting substances that may endanger the quality of soil and crops. Increasingly stringent environmental regulations mean that a growing proportion of the sludge produced has to be processed as waste, i.e., it has to be dumped.



1.1 Types of sludge

The following types of sludge can be distinguished:

- primary sludge
- secondary sludge (excess sludge, humus sludge)

The types of sludge can vary in terms of solids content (2-8% dry solids) and degree of stability. Per head of the population about 1 liter per day of liquid sludge is produced, containing about 5% solids.

Sludge (primary sludge, excess sludge from active sludge systems, humus sludge) is usually stabilized by sludge digestion. This process reduces the solids content by about 30%. The excess sludge from ultra-low-loaded active sludge systems is already stabilized as a result of the very low loading in the system.

1.2 Solids concentration

The following quality of sludge in terms of solid concentration is typically produced on a wastewater treatment plant:

Sludge Type	Solids Concentration, % dry solids	
	Range	Typical
Primary Sludge	5 - 9	6
Waste Activated Sludge	0.5 - 1.5	0.8
Waste Activated Sludge (Extended Aeration)	0.8 - 2.5	1.3
Gravity Thickened Primary Sludge	5 - 10	8
DAF Sludge (without polymer)	4 - 6	5

1.3 Costs

The costs of sludge management may be up to 50 % of the total running costs of a waste water treatment plant. Primary and secondary sludge produced at a wastewater treatment plant must be thickened, stabilized, dewatered and disposed of. There are large energy costs for thickening, stabilization and dewatering. These costs vary depending on the type of equipment or process used. Sludge disposal costs also vary depending on where the sludge is disposed of. Onsite disposal is the cheapest with landfill sites being the most costly. Sludge disposal costs also involve transport costs when sludge is disposed both on and off site.

When wastewater is considered as waste, the objective of the processes on WWTP is to meet the requirements for the discharge permit and other environmental licences. When components of the wastewater are reused, the quality requirements for the products can be higher and may cause higher costs. However, there may be advantages by selling the products or just by being more sustainable.

2 Thickening

Thickening is used for removing water from sludge with a higher solids content of the sludge as an objective. The benefit of removing water from the sludge is to reduce the volume of sludge to be treated in downstream processes or disposal.

2.1 Techniques

Thickening is generally accomplished by physical means, including co-settling, gravity settling, flotation, centrifugation, gravity belt and rotary drum. However only two commonly used techniques will be discussed here. These techniques are gravity and flotation thickening.

Gravity thickening

Normally, a circular tank is used, and dilute sludge is fed to a center feed well. The sludge is allowed to settle and compact, and the thickened sludge is withdrawn from the conical tank bottom.

The tank has a sludge-collecting mechanism with deep trusses or vertical pickets to move the sludge gently thereby opening up channels for water to escape and promoting thickening. The tank usually consists of a baffle plate all around to prevent scum from overflowing with a supernatant flow (thickener overflow). Thickener overflow is recycled back to primary settling tanks or the influent of the treatment plant. Thickened sludge is usually pumped to digesters for further treatment.



Gravity thickener

The advantages of vertical pickets are:

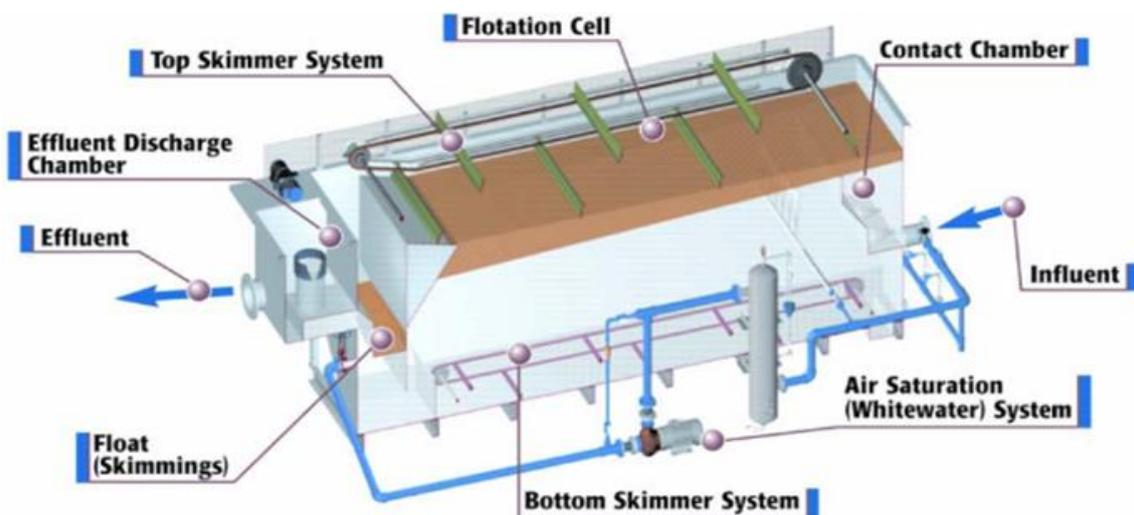
- Gases released as a result of the digestion or denitrification processes can escape more easily;
- The sludge water is better separated;
- The sludge is homogenized.

Flotation thickening

DAF (Dissolved Air Flotation) systems may be designed for pressurization and air dissolution of the total flow or, more commonly, the incoming flow enters the flotation vessel where it comes into contact with a portion of recycled, treated effluent (sometimes termed whitewater). The percentage of the total effluent flow into which air is dissolved under pressure and subsequently recycled will be determined by several factors. Increasing the pressure within the vessel where the air is being dissolved ensures that a higher concentration of air dissolves into the liquid phase than is possible at atmospheric pressure. Once this portion of saturated effluent enters the flotation tank, the pressure is released back to atmospheric pressure. This immediately results in the recycled flow becoming supersaturated, resulting in the generation of micro-bubbles as the dissolved air comes back out of solution. These bubbles attach to, and form within, the solids or flocs entering the vessel, causing them to float to the surface where they are retained and subsequently removed by a mechanical skimmer.

2.2 Equipment

In the case of rectangular flotation tanks, the skimmer mechanism consists of a series of paddles or 'flights' which run on a belt or chain and skim just below the surface of the tank removing the 'float' into a trough for further treatment or, in some instances, recovery of materials



DAF unit

2.3 Characteristics

The table shows different types of thickeners and their applicability for various types of sludge.

Thickening Techniques Used in Sludge Processes		
Most common techniques of thickening in sludge processing are given in Table 1.		
Table 1. Thickening Techniques Used in Sludge Processes [2].		
Method	Sludge type	Frequency and performance
Gravitational settling	Raw primary	Very good results.
Gravitational settling	Raw primary and W.A.S	Frequently used. Small facilities obtain 4-6% solids concentration. Not often used in large facilities.
Gravitational settling	W.A.S	Not frequently used. Low solids concentration (2-3%)
Dissolved Air Flotation (DAF)	Raw primary and W.A.S	Not frequently used. Results seem to gravitational settling
Dissolved Air Flotation (DAF)	W.A.S	Frequently used. Good results obtained (3.5-5% solids concentration)
Basket centrifuge	W.A.S	Limited use. Good results obtained (8-10% solids concentration)
Solid-bowl centrifuge	W.A.S	Usage is increasing. Good results obtained (4-6% solids concentration)
Gravity belt filter	W.A.S	Usage is increasing. Good results obtained (3-6% solids concentration)
Rotary drum	W.A.S	Limited use. Good results obtained (5-9% solids concentration)

2.4 Operational aspects

Gravity thickening

The operator can optimize thickening by monitoring the quality of the supernatant and the total solids concentration in the thickened sludge, while also tracking feed rate, pumping times and rates, and sludge blanket depth, and inspecting the tank surface for potential problems, including gas bubbles and odors. Gas bubbles cling to solid particles, increasing the solids' buoyancy and reducing their settling and thickening capabilities. Odors may be the result of septic conditions, which can also lead to the formation of gas bubbles. The operator should also check for turbulence in the tank. Turbulence can cause the solids to either miss the weirs, or to become unsettled. The solids content depends on the retention time of the sludge in the thickener, in practice controlled by maintaining a specific sludge blanket level. There is an optimum value for the blanket level: too low will cause only partial thickening, too high will cause septic conditions and bad thickening. Recycling of digested sludge, e.g. caused by low sludge recovery in dewatering of digested sludge, may have a bad influence on the thickening process.

The table presents an overview of many factors affecting gravity thickening performance.

TABLE 2 FACTORS AFFECTING GRAVITY THICKENING PERFORMANCE

Factor	Effect
Nature of the solids feed	Affects the thickening process because some solids thicken more easily than others.
Freshness of feed solids	High solids age can result in septic conditions.
High volatile solids concentrations	Hamper gravity settling due to reduced particle specific gravity.
High hydraulic loading rates	Increase velocity and cause turbulence that will disrupt settling and carry the lighter solids past the weirs.
Solids loading rate	If rates are high, there will be insufficient detention time for settling. If rates are too low, septic conditions may arise.
Temperature and variation in temperature of thickener contents	High temperatures will result in septic conditions. Extremely low temperatures will result in lower settling velocities. If temperature varies, settling decreases due to stratification.
High solids blanket depth	Increases the performance of the settling by causing compaction of the lower layers, but it may result in solids being carried over the weir.
Solids residence time	An increase may result in septic conditions. A decrease may result in only partial settling.
Mechanism and rate of solids withdrawal	Must be maintained to produce a smooth and continuous flow. Otherwise, turbulence, septic conditions, altered settling, and other anomalies may occur.
Chemical treatment	Chemicals - such as potassium permanganate, polymers, or ferric chloride - may improve settling and/or supernatant quality.
Presence of bacteriostatic agents or oxidizing agents	Allows for longer detention times before anaerobic conditions create gas bubbles and floating solids.
Cationic polymer addition	Helps thicken waste-activated solids and clarify the supernatant.
Use of metal salt coagulants	Improves overflow clarity but may have little impact on underflow concentration.

Source: Parsons, 2003.

Flotation thickening

Sludge concentration in a DAF unit typically ranges from 3 to 5 % solids. If operated properly, the DAF system can achieve at least 85 percent solids recovery without chemical addition. Chemicals (i.e., polymer, coagulants) will improve solids recovery greater than 90 percent; however, solids concentration may not improve significantly. Important sludge characteristics include sludge type and sludge age.

Air to solids ratio is the quantity of air introduced into the recycle stream. This is a critical parameter to consider when operating the DAF unit. The more air dissolved in the recycle stream, the greater the number of micro bubbles released in the flotation tank. The more micro bubbles produced, the greater the probability of bubble particle contact. This in turn will allow the DAF operation to be more efficient.

Floating sludge depth is controlled by increasing or decreasing the speed of the skimmer. By increasing the skimmer speed, the sludge depth will decrease. Conversely, by decreasing the skimmer speed, the sludge depth will increase.

3 Digestion

3.1 Techniques

Anaerobic digestion is the degradation of sludge using bacteria in the absence of oxygen.

The benefits of digestion are;

- Reduction in organic content.
- Stabilised sludge
- Reduces odour
- Reduce pathogenic bacteria
- Production of biogas

The solids content of the digester feed should be between certain limits: high enough to promote effective digestion, but not too thick to adversely affect pumping and mixing of the sludge in the digester. The main reasons for thickening sludge prior to digestion are:

1. To maximise the use of the available digester capacity in the digestion of the solids, i.e. excess water uses up digester capacity and reduces retention time
2. To reduce the amount of heat required in a heated digester, i.e. excess water with the sludge also requires heating in order to keep the digester contents at the required temperature
3. To prevent the dilution of the generated alkaline buffer in the digester as this could cause pH instability.

Thoroughly digested sludge has a dark colour and a characteristic, tarry smell. It can be more quickly and thoroughly de-watered than fresh sludge and, furthermore, it contains considerably fewer pathogens. The solids in fresh sludge consist of about 75% organic and 25% inorganic matter. During the digestion process about half of the organic matter is transformed into gaseous products, so that the digested sludge contains proportionately less organic matter: about 60% of the solid matter is organic, the remaining 40% being inorganic.

3.2 Equipment

Sludge digestion installations can have two stages:

- A mixed, heated first stage in which the digestion process mainly occurs
- An unmixed, unheated second stage, the main function of which is the separation of digested sludge from sludge water

Two stage digester



Two stage digester

For every addition of fresh sludge to the first tank, an equal volume of sludge is transferred from the first to the second tank. The second stage may be equipped with a floating gas-holder, which is connected to the gas outlet of the first tank.

Modern installations, rather than having the second tank described above, are equipped with a relatively small post-thickener and the gas is accumulated in a separate gas-holder.

The very intense mixing in the mixing tank, coupled with a continuous or semi-continuous fresh sludge feed, leads to the sludge being digested in 15 to 30 days at a digestion temperature of 30-37°C.

Heating

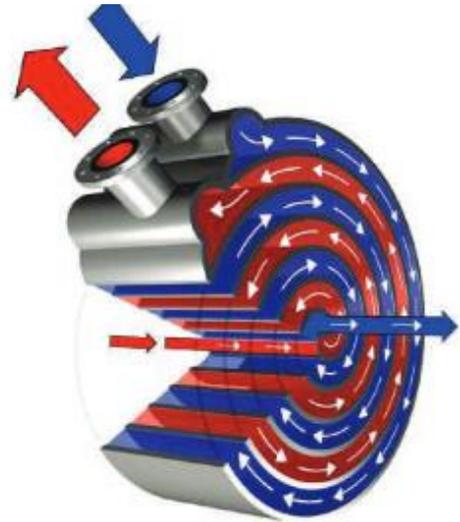
The tank contents are generally heated by the transfer of heat from circulating water, using heat exchangers. The heat exchanger is usually set up outside the digestion tank.

The two main types of external heat exchangers are 'shell and tube' and 'Rosenblatt'.



Shell and tube heat exchanger

The shell and tube heat exchangers consist of 2 concentric pipes. The sludge flows through the smooth inner pipe, the heating water through the outer pipe that contains spacers.



Rosenblatt heat exchanger

The Rosenblatt heat exchanger takes the form of a flat box, the lid of which can be removed for cleaning purposes. The hot water and the sludge to be heated are driven in opposite directions through spiral channels. This heat exchanger can be found in both horizontal and vertical versions.

A heating system in which the heat exchanger is located inside the digestion tank (internal heat exchanger) is the Heatamix system. In this system the heat exchanger consists of a vertical, double-walled cylindrical pipe. Hot water is fed between the walls, supplying heat to the surrounding sludge through the interior and exterior walls. The sludge is driven through the pipe at a relatively high velocity by the use of pressurized gas.

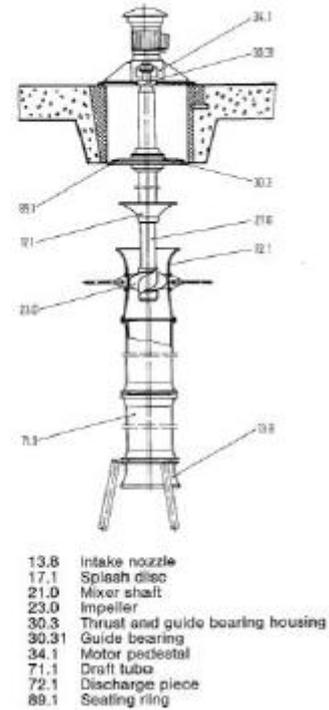
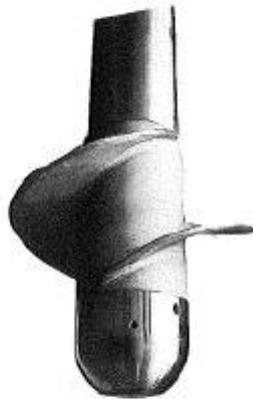
Heat exchangers outside the tank are to be preferred since they can be quickly repaired and cleaned.

Mixing

The tank contents are usually mixed by pressurized gas.

The gas that is released during the digestion process is compressed and blown into the tank through perforated pipes or through a number of vertical gas lances. The rising gas bubbles ensure a circulating liquid flow in the digester.

An older method, which is still in use, is mixing by means of a screw pump in the tank. This screw pump is connected to a motor on top of the tank via a vertical drive shaft. The flow in the digester is guided by a vertical suction pipe. The pump can be hoisted out of the tank for inspection and maintenance.



Screw pump

The useful volume of the digestion tank can be restricted by the formation of a floating layer at the surface of the digesting sludge and by deposition of grit on the bottom. The floating layer consists of fatty particles, hair, corks and other light material that cannot readily be digested. The grit that is found in the digestion tank is the fine fraction, i.e. the diameter of the granules is so small that they cannot be separated in the grit chamber. The intensive mixing produced by blowing with compressed gas gives the lowest risk of floating film formation and grit deposition.

3.3 Characteristics

The final products of sludge digestion are sludge water, biogas (methane) and digested stabilised sludge.

Sludge water

The water released during the digestion process is tapped off via overflow pipes in the second digestion stage or from the post-thickener and, because it is still highly polluted, it is pumped back to the treatment plant inlet. Satisfactory sludge water contains at most 50 mg/L solids, able to settling.

Biogas

The biogas released in a well-conditioned sludge digestion tank contains an average of about 65% methane and 35% carbon dioxide by volume. If the methane fraction is lower this is a

sign that the digestion process is becoming disturbed (e.g. by over-loading, feed of poisonous substances, or excessive temperature fluctuations).

Gas production is roughly 1000 L per kg degraded organic matter. Related to the amount of sludge to be digested per inhabitant, gas production is 15-25 L/day.

In smaller treatment plants the biogas is frequently used as fuel for a hot water boiler, used to heat the sludge digester and the buildings. In larger plants the gas is used as fuel for gas engines, which are coupled to a generator and used to produce electricity. A gas engine/generator set supplies 2.5-3 kWh per m³ gas. Besides electrical energy, gas engines also produce heat. This heat, in the form of hot cooling water, is used for heating purposes (sludge digestion, space heating).

3.4 Operational aspects

Operation of a digester involves controlling the feed rate, solids loading, good mixing and digester temperature. Before sludge is fed to the digester, it needs to be pre-treated to increase its solids content. Preferred concentration of feed sludge to an anaerobic digester should be between 3% - 6% in solids. The retention time which considers the relation between the volume of the feed and the effective digester volume is a key operation aspect. Operation of a digester also involves constant monitoring key process indicators. The indicators are used to measure the progress of sludge digestion and gives early warning of impending upsets to the anaerobic digestion process. Process control parameters such as pH, volatile acids to alkalinity ratio, temperature and biogas production rate are monitored. These control parameters gives early indication of possible digester failure.

4 Dewatering

4.1 Techniques

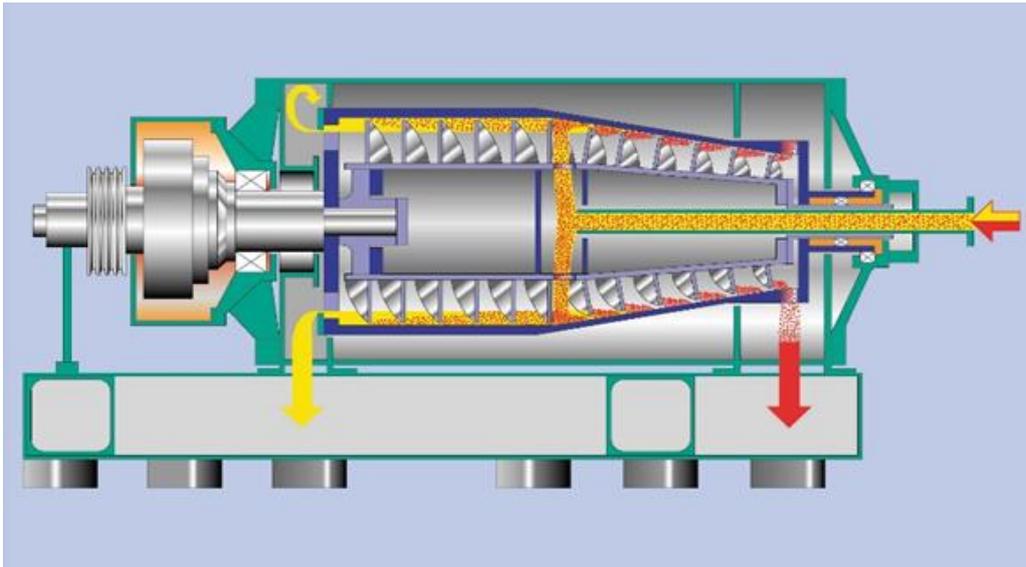
Dewatering is a physical process used for removing water from sludge with a higher solids content of the sludge as an objective. The benefit of removing water from the sludge is to reduce the amount of sludge for one or more of the following reasons:

1. The costs for trucking sludge to the ultimate disposal site become substantially lower when the volume is reduced by dewatering
2. Dewatered sludge is generally easier to handle than thickened or liquid sludge. In most cases, dewatered sludge may be shovelled, moved about with tractors fitted with buckets and blades and transported by belt conveyors.
3. Dewatering is required normally prior to the incineration of the sludge to increase the calorific value by removal of excess moisture.
4. Dewatering is required before composting to reduce the requirements for supplemental bulking agents or amendments.
5. In some cases, removal of excess moisture may be required to render sludge odourless and nonputrescible.
6. Dewatering is required prior to landfilling sludge in monofills to reduce leachate production at the landfill site.

4.2 Equipment

Centrifuge

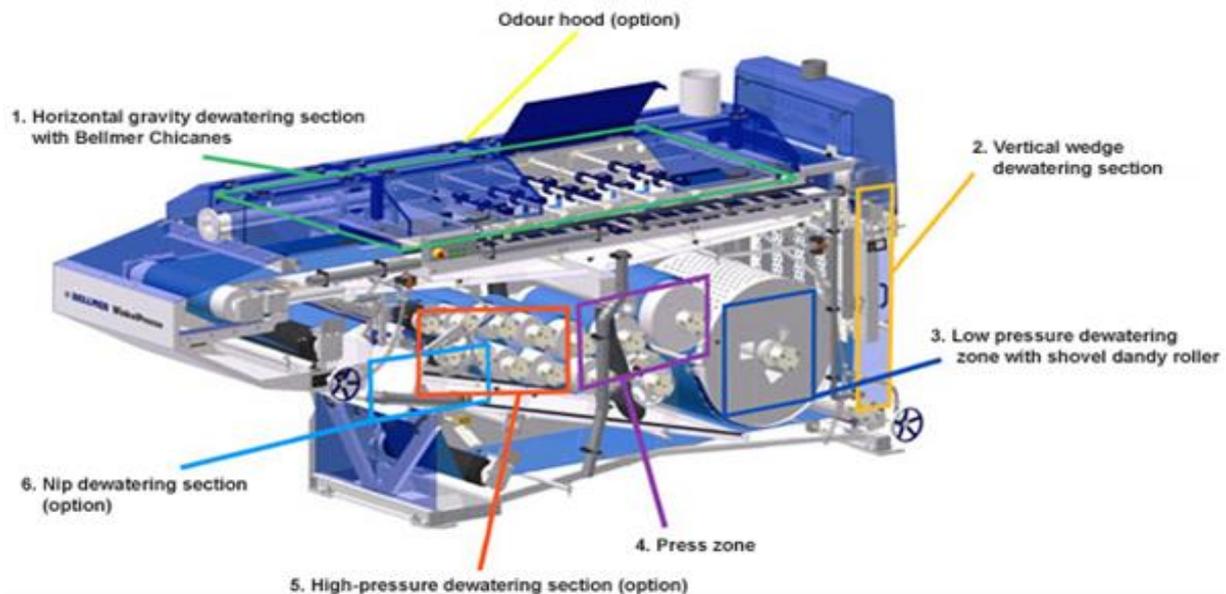
Many types of centrifuges exist. In wastewater treatment the decanter is the common type to be used for thickening of activated sludge (without polymers) or dewatering of all types of sludge (with polymers for conditioning). The principle is separation by density as a result of the artificial high gravity that is obtained by the fast rotation of the bowl of the centrifuge. The sludge is fed in the centre of the bowl and will be spread to the wall of the bowl. The separation by gravity will result in a layer of thickened sludge close to the wall and a layer of separated water on top. The water is discharged from the centrifuge by openings in the rear end of the bowl. The sludge is removed from the centrifuge on the front end by a slowly rotating screw (rotating with a few rpm's difference compared to the bowl).



Decanter

Belt press

Belt presses are continuous presses used for dewatering of sludge. The principle is that water soaks through the pores of the belt and that the larger sludge flocs are retained on the surface of the belt. To enable this process the sludge is conditioned with polymers. Belt presses have a number of stages. The first stage is comparable to the thickening belt. The water can be easily separated here. In the next stages the sludge is contained within two parallel belts and subjected to increasing pressing forces, finally by moving over rolls with decreasing diameters. The water is pressed through the belts and the dewatered sludge is released.



Belt press

4.3 Characteristics

Centrifuge

The table shows typical dewatering performance for various types of sludge.

Type of sludge	Cake solids (%)	Solids recovery (%)	
		Without Chemicals	With Chemicals
Raw Primary (P)	25-35	75-90	95+
Raw Primary and trickling filter	20-25	60-80	95+
Raw Primary and WAS	12-20	55-65	92+
Anaerobically digested P	25-35	65-80	92+
Anaerobically digested (P+WAS)	15-20	50-65	90+

Belt press

The table shows typical dewatering performance for various types of sludge.

Type of sludge	Feed solids concentration (%)	Cake solids (%)
Raw Primary (P)	3-10	28-44
Waste Activated (WAS)	0.5-4	20-35
Raw Primary and WAS	3-6	20-35
Anaerobically digested P	3-10	25-36
Anaerobically digested WAS	3-4	12-22
Anaerobically digested (P+WAS)	3-9	18-44

4.4 Operational aspects

Centrifuge

It is a lot more difficult to control the flocculation quality on a centrifuge than on a belt press since everything takes place inside pipes or inside the machine. The flocs can be quickly destroyed if the polymer has not been well chosen or dosed.

The three main operating problems of a decanter are:

1. Black centrate

The centrate has an unusual dark color. This color is due to the presence of numerous particles that are evacuated with the diaphragm overflow (low solids recovery) and are going back to the start of the process.

2. Gray, foaming centrate

Only an excessive foaming is indicative of a problem. Slight foaming is a normal occurrence due to the high agitation level inside the centrifuge. Degassing eliminates this foam.

3. Low solids content

The sludge cake has a lower than expected solids content.

When the centrate has too many solids (low solids recovery), the following points must be checked:

- Solids flow - Each centrifuge is designed for a specific solids flow load. If it is overloaded, the centrifuge will never work well.
- Relative speed - The lower the relative speeds, the longer the residence time of the sludge in the centrifuge. The pressure applied to the flocs will have time to destroy them and the fine particles will exit with the centrate. Increasing the relative speed should clarify the centrate.
- Polymer flow - The flocs have to be solid enough to resist the shearing generated inside the centrifuge by the pressure and the screw. The dosage of the polymer should be exactly right to prevent destruction inside the centrifuge. The polymer dosing has an optimum value, overdosing as well as underdosing decreases the solids content of the dewatered sludge.
- Polymer dosing rate - In any case, the dosages of polymer for a centrifuge application is always higher than for belt filters.

Adjusting the following parameters may enhance the cake solids content:

- Torque - Adjusting the torque and/or the relative speed to the sludge concentration must be systematic.
- Liquid ring - A smaller liquid ring diameter ensures a better drying of the sludge since the water height in the conical part of the centrifuge is lower.
- Floc stability - Floc stability is a key parameter in the performance of a centrifuge because of the high shear forces involved.

Belt Press

The quality of the sludge flocculation plays a major role in the end results of filtrate quality and cake solids content. On belt presses, it is easy to check the quality of the flocculation in the drainage zone.

The three main operating problems that can be observed are:

1. Bad drainage - The sludge reaches the progressive compression zone without being fully drained.
2. Sludge creep - In the compression zone, the sludge has a tendency to run away on the sides of the belt.
3. Low cake solids content - The sludge cake's solids content is too low.

Bad drainage

When the drainage is insufficient, the following parameters must be checked:

- Mixing conditions - The mixing of the sludge with the flocculant solution must be optimal to obtain the best floc size. To achieve this, it is necessary to:
 - have a good mixing intensity: speed of the flocculator.
 - determine the best injection point: before or after the sludge pump or in the flocculator or having several injection points.
 - check the sludge distribution on the belt.
- Belt cleaning - If the belts themselves are not perfectly clean, it is impossible to have a good drainage since the pores are plugged. So the following parameters have to be checked:
 - cleaning water flow may be too low
 - cleaning water pressure may be too low
 - cleaning nozzles may be blocked
- Belt pressure - The belt pressure can also influence pore plugging. The higher the pressure the more sludge goes through the belt and dirties it.

- Flows - If the flocculation quality is not optimal, drainage will be low. Adjusting the sludge flow and the flocculant flow must be done. The flocculant post-dilution is also an important step; it allows for a better dispersion in the sludge.

Sludge creep

Sludge creep (squeeze out) happens frequently on biological sludge which are difficult to dewater and sensitive to pressure. The following parameters must be checked:

- Flocculation - Optimal dosage is necessary for the best results. In order to determine the optimal dosage, lower to the minimal dosage and slightly increase it. Structured polymers can be used to obtain a better drainage and a better floc structure.
- Drainage - The faster water is released, the dryer the sludge is when reaching the compression zone.
- Belt cleaning - Checking the initial drainage in order to obtain a maximum water release and checking the cleaning of the belts should resolve this problem.
- Sludge feeding - A high solids content can induce creep. Lowering of the sludge flow, reducing the width of the drainage zone and optimizing the cake thickness are the parameters to check.

Low solids content

It is sometimes possible to have a better cake solids content when modifying the following parameters:

- Mixing conditions - If mixing is not good, the solids content may be low. Rearrange the mixing conditions and the injection points.
- Belt speed and tension - If the belt speed is high, the drainage time is short. By reducing the speed, the drainage time is longer and therefore the drainage is better. The belt pressure is an important factor to get a good solids content. By increasing the belt pressure a better dewatering is obtained.
- Polymer selection - An accurate polymer selection will give the best results. Changing the molecular weight, the structure of the polymer and its dosage; all these parameters, although preselected in the lab tests, can be optimized on a plant scale.
- Cake thickness - The cake thickness should be adjusted taking into account the intrinsic characteristics of the sludge.

5 Drying

5.1 Techniques

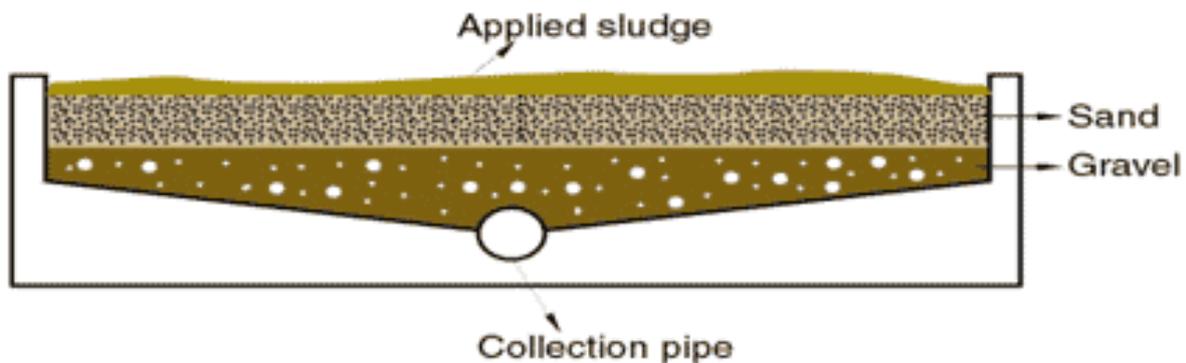
Drying involves the application of heat to evaporate water and to reduce the moisture content of sludge below that achievable by conventional dewatering methods. The advantages of drying include reduced product transportation costs, further pathogen reduction, improved storage capability and marketability.

5.2 Equipment

Sludge drying beds

In natural de-watering the fluid, digested sludge is spread out over drained sand beds. Part of the sludge water can be carried away via the drains to the treatment plant. The rest of the water evaporates under the influence of the sun and the wind.

The fluid, stabilized sludge is de-watered and dried on the drained sand beds. These sand beds consist of 10-15 cm thick layers of sharp sand, the drainage pipes being located underneath in a layer of gravel.



Sludge drying bed

The wet sludge is introduced over the sand bed in a layer of at most 25 cm thickness. Part of the water seeps away through the sand layer and the remainder of the water evaporates under the influence of sun and wind. It is clear that the drying time depends strongly on the weather.

The volume of the sludge is drastically reduced by de-watering. For example, 1 m³ of sludge containing 5% solids, after de-watering to a solids content of 20%, will occupy a volume of less than 0.25 m³ (solids content four times higher, thus volume 4 times less). If the solids content rises to 25-30%, one can use a fork on the sludge. If it dries out yet further it can be scattered (at about 60% solids content).

Dried sludge can be removed by hand (with shovels) or by using motorized mechanical sludge removers. Front loaders are also used for removal. After the dried sludge has been removed the sand layer is well raked over and replenished with fresh sharp sand, if necessary, before the bed is used again. If the wastewater is treated both mechanically and biologically, then, as a guide, one can state that the sludge from 8-15 population equivalents can be dried per m² of drying bed in a dry climate. Drying beds are principally used in smaller installations due to the large area needed for the beds.

Sludge lagoons

Besides drying beds, sludge lagoons are also used for the natural drying of sludge. These lagoons are drained areas, surrounded by a dyke of 1,5-2 m in height. The stabilized, thickened sludge is introduced into the center or over one of the sides in such quantities that as thin a layer as possible is created. Outlets are provided in one or more corners to allow surface water to flow out. There are also ways of introducing the sludge in such a way that the intervening water layers can be drained off.

The sludge dries in the lagoons until a forkable product is obtained after 1 to 2 years. This product is very suitable for the improvement of heavy soils. Sludge lagoons can also be used as buffers or in order to obtain a better thickening of the sludge, in which case the retention time is about 1-3 months. These lagoons are utilized for the sludge from both oxidation beds and oxidation ditches. Their size is such that a total sludge layer of about 75 cm thickness is introduced per year.

5.3 Characteristics

Drying beds

A cake of 40–45% solids might be achieved in 2–6 weeks in good weather and with well-digested secondary, primary, or mixed sludges. With chemical conditioning, dewatering time may be reduced by 50% or more. Solids contents as high as 85–90% have been achieved on sand beds, but normally, the times required to achieve such dry sludge cakes are impractical. The mechanisms for water removal impose a number of operating variables that affect the design of drying beds, such as:

- Sludge condition.
- Sludge characteristics.
- Soil permeability.
- Land availability and cost.

5.4 Operational aspects

Drying beds

A common mistake made by operators is that the operation of drying beds consists only of applying and removing the sludge. The routine maintenance of the drying beds and the optimisation of the process are often neglected. The following aspects have to be taken into consideration:

- Raking of the Bed - An important aspect of bed maintenance is the raking and levelling of the bed. Water that drains from the sludge will cement the sand particles. This will lead to increased resistance to filtration in the sand and eventually, complete blockage.
- Levelling of the Bed - Levelling is necessary to allow the sludge to settle in even layers across the bed. Drying beds are often gauged out in the centre or around the sludge application point. This allows thicker layers of sludge to settle there, which will take longer to dewater and dry. The raking exercise described above would also fulfil a levelling function, but it might be necessary to do some finishing work.
- Repair of Cracks - The walls and floors of beds will need to be inspected regularly and maintained. Cracks that form due to settlement or for any other reason, should be repaired as soon as possible in order to prevent leakage of sludge or drainage water.
- Removal of Weeds - The bed should be weeded on a regular basis as weeds slow down the drying process. Unwanted plant growth outside the beds should also be removed so as to allow access to the beds and to avoid any shadows on the sludge.

Sludge Lagoons

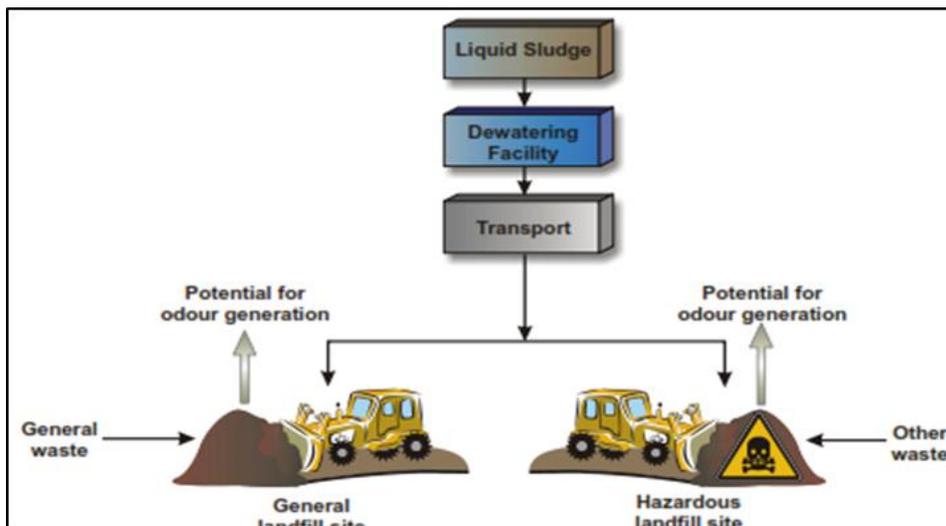
Most of the maintenance issues for lagoons are related to groundskeeping. Dikes must be maintained regularly.

6 Disposal

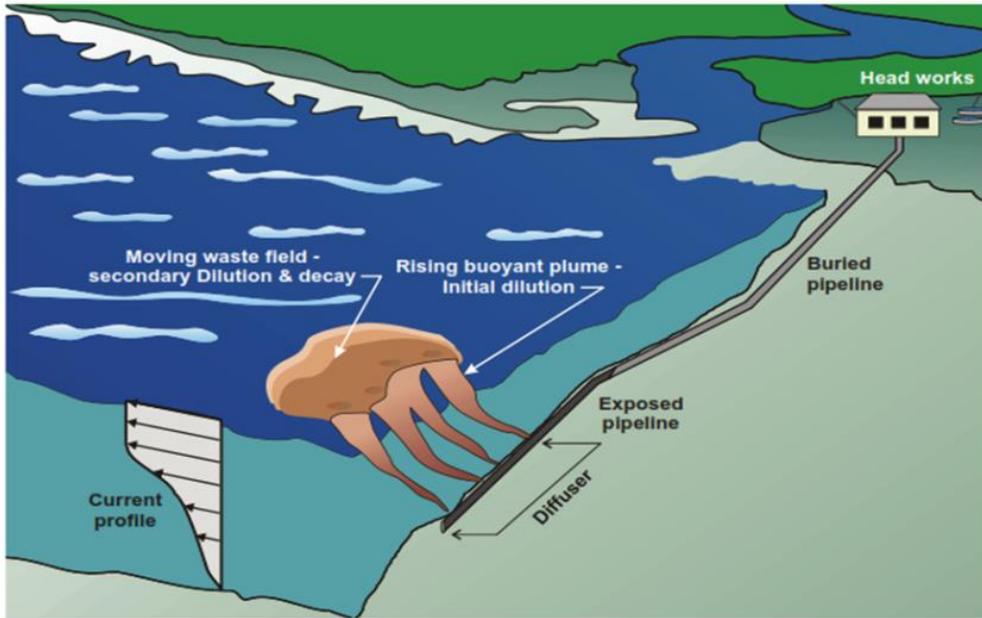
Sludge disposal is the removal of sludge from a wastewater treatment plant to its final destination. The reasons for sludge disposal include to get rid of solids produced on a WWTP and reduce on-site stockpiling of sludge.

6.1 Techniques

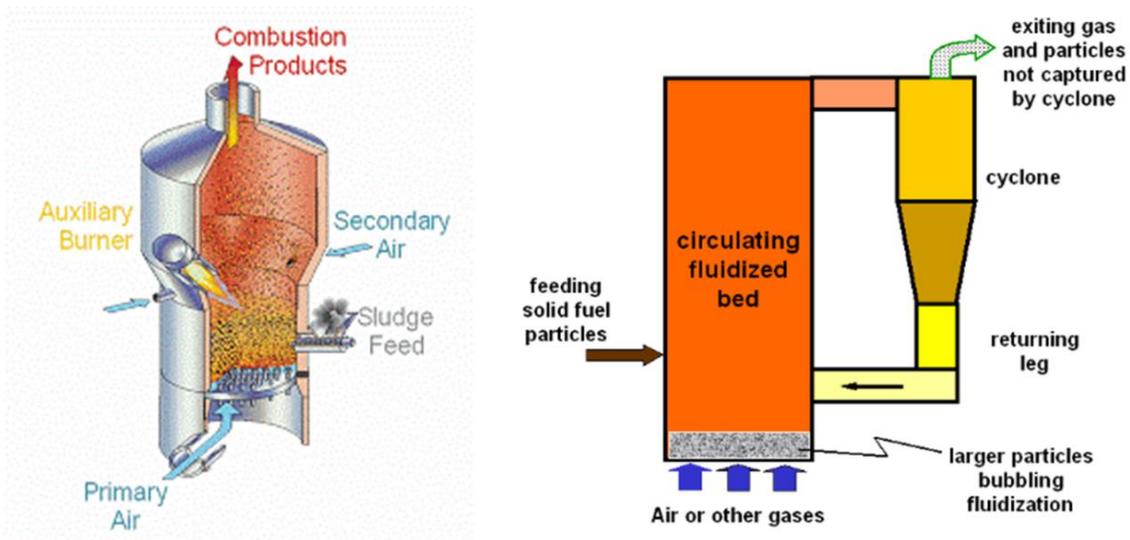
Sludge that cannot be reused must be disposed of. This can be done in the form of sanitary landfill or sea disposal. Another possibility is that sludge is incinerated. The benefits of the very expensive incineration includes reduced sludge volumes, sludge is converted into mineral ash.



Landfill disposal – disposal of sludge into a licensed site



Sea disposal / outfall - the discharge of sludge via a marine outfall



Incineration – Involves burning sludge at high temperatures in an incinerator

6.2 Laws and regulations

The requirements for the on-site and off-site disposal of sludge are set by the Department of Water Affairs: Guidelines for the utilisation and Disposal of Wastewater Sludge's. Volume 3 of the guidelines deals with the requirements for the on-site and off-site disposal of sludge and it includes:

- Classification of sludge
- Legal requirements for disposal
- General information on sludge co-disposal on landfill

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

South African Sludge Classification		Is disposal an option?	Notes
Microbiological Class	A	Maybe (iii)	Disinfection technologies are costly and this management option therefore represents wasting of potential resource recovery.
	B	Maybe (iii)	It could potentially be used beneficially.
	C	Yes (i)	General restrictions/requirements as well as stringent monitoring requirements will apply.
Stability Class	1	Yes (i)	General restrictions/requirements apply.
	2	Qualified yes (ii)	Depending on the reliability of the vector attraction reduction measures implemented, additional management systems may be required.
	3	Qualified no (iv)	Unstable sludge will not be accepted at landfill sites and land disposal would not be permissible. At least one vector attraction reduction option should be implemented.
Pollutant Class	a	Qualified no (iv)	Beneficial use is recommended.
	b	Maybe (iii)	Delisting according to Minimum Requirements is required.
	c	Maybe (iii)	Disposal of Pollutant class c sludge will only be allowed on hazardous landfills. Stringent restrictions, management and monitoring requirements will apply for land disposal.

Classification of sludge

6.3 Characteristics

Thickening and dewatering helps increase solids content and help minimize transportation volumes and costs. An arid climate is highly suitable for the drying of sludge in drying beds and dumping grounds. In a wetter climate the sludge has to be mechanically de-watered before they are removed from site. Thickening and dewatering helps increase solids content and help minimize transportation volumes and costs.

7 Reuse

Wastewater and sludge can be considered as a source for valuable components. This way of thinking reflects the growing attention for sustainable development. Wastewater contains substances that can be used for power generation (organic matter), for fertilizer (phosphorus and nitrogen) and of course for reuse of the effluent for industry, agriculture and even drinking water.

7.1 Types of reuse of sludge

Sludge may be reused in more than one way. Some of the most important types of reuse are:

- In agriculture
- Manufacturing compost
- Capping of landfill
- Rehabilitation of mine deposits

7.2 Laws and regulations

Guidelines for the Utilisation and Disposal of Wastewater sludge was developed by the Department of Water Affairs to better manage sludge disposal or reuse methods in SA. These Guidelines aim to simplify the legal complexities related to sludge use and disposal.

The use and disposal of wastewater sludge are influenced by, amongst others, the following Acts and guidelines:

- The National Water Act (Act 36 of 1998) (NWA)
- The Water Act (Act 54 of 1956) (WA)
- The Environment Conservation Act (Act 73 of 1989) (ECA)
- The Fertilisers, Farm Feeds, Agricultural Remedies and Stock Remedies Act (Act 36 of 1947)
- The Conservation of Agricultural Resources Act (Act 43 of 1983) (CARA)
- The National Health Act (Act 61 of 2003) (HA)
- The Water Services Act (Act 108 of 1997) (WSA)
- The National Environmental Management Act (Act 107 of 1998) (NEMA)
- Minimum Requirements: (Second Edition) 1998

7.3 Costs and benefits

Costs of sludge reuse may vary depending on the method used. For example the cost of reuse may be higher than the cost for a landfill. However there are great benefits of sludge reuse. Sludge reuse in agriculture improves the productivity of the land by adding organic matter and nutrients to the soil. In addition there are a number of indirect advantages to human health and the environment. Secondary benefits of sludge reuse include a reduction

of the adverse health effects of incineration and a decreased dependence on chemical fertilizers.

7.4 Pollutant removal and sludge reuse in agriculture

The reuse of treated sludge in agriculture can be divided into:

- application as agricultural fertilizer;
- application as raw material for composting and the improvement of heavy soils (beneficiation).

The reuse of sludge for agricultural purposes has the following advantages:

- presence of nitrogen and phosphorus compounds means that the sludge is a satisfactory fertilizer;
- organic matter in the sludge improves the structure of the soil;
- sludge is a source of trace elements, including copper, iron, and molybdenum;
- agricultural use is a cheap way to reuse the sludge.

There are disadvantages to the agricultural use of sludge, however:

- sludge may contain pathogens (such as salmonella bacteria) and the eggs of intestinal worms;
- sludge contains heavy metals and other micro-pollutants that may be harmful to plant and animal life.

