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Options for the treatment of organic sludge - The move towards thermal processing

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Options for the treatment of organic sludge – The move towards thermal processing

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RESULT (summary)

Sludge production continues to increase worldwide, as more countries become industrialised and growing populations increase wastewater volumes. Consequently, many countries have to find suitable solutions for the disposal of large quantities of sludge.

Historically the most important disposal routes for sludge treatment have been landfilling, agricultural use, incineration and dumping into sea. However, environmental concerns have led to the introduction of increasingly stringent legislation, which has already reduced disposal options in many countries. In Europe a total ban to dumping into sea became effective in 1998. Agricultural use is already forbidden in some parts of western Europe due to the presence of contaminants (such as heavy metals and pharmaceutical substances) in sludge, and also landfilling are facing restrictions. There is, therefore, a drive to find more environmentally ways to dispose sludge.

Dewatering has long been used to reduce the mass and volume of sludge for disposal, but disposal is still an issue. As a result, there is growing interest in thermal processes for the treatment of sludge, and the utilization of such processes for sludge treatment has increased. The main purpose of the existing methods is destruction of the organic materials, preventing the spread of disease, as well as reduction of weight and volume. Other important aspects are energy recovery as well as recycling of important materials like phosphorus or metals.

This report examines current technologies available for sludge treatment. It considers the various techniques for removing water from sludge, listing key parameters for operation and performance. It also looks at thermal processes for treating sludge, giving details of the associated reactor technologies and key characteristics of proven incineration processes, to enable comparison and process selection.

KEYWORDS

SELECTED BY AUTHOR(S)	Sludge	Thermal processes
	Technology status	Water removal

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1 INTRODUCTION

As a by-product of many industrial processes and wastewater cleaning processes, sludge production is increasing worldwide, and many countries have problems to find suitable ways to dispose the large volumes of it.

Historically the most important disposal routes for sludge treatment have been landfilling, agricultural use, incineration and dumping into sea. Figure 1 shows the selected methods for sludge treatment for all countries within the European Union (EU) in 1992 /1/.

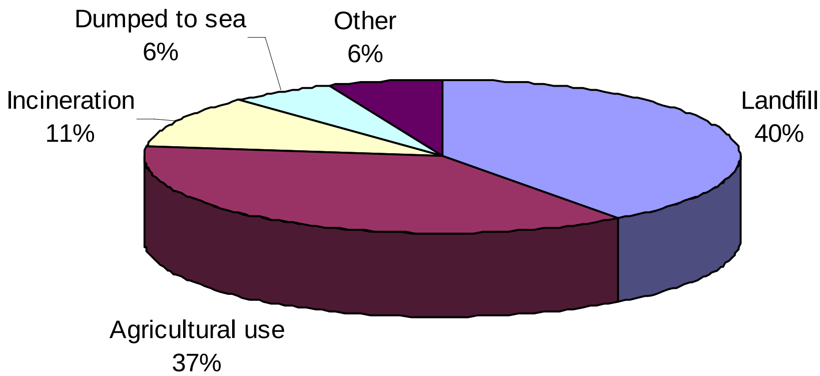

Figure 1: Distribution of sludge treatment methods in the EU, 1992 /1/.

The later years stricter regulations have been introduced across Europe, forcing countries towards more environmentally friendly methods of treatment. For example, the EU's 'Urban Wastewater Directive' imposed a total ban on dumping sludge to sea in 1998. Disposal to landfill that was a major method in 1992, has decreased considerably, with tighter regulations in many countries now restricting this practice, and landfill space also becoming scarce. Agricultural use is already prohibited in some parts of Western Europe (eg the Netherlands) due to the presence of contaminants, such as heavy metals and pharmaceutical substances, in sludge. In Germany and Austria, regulations introduced in 2005 prohibit the disposal of sewage sludge containing more than 5% organic dry solids /2/. As a result of all these changes, thermal treatment processes have become more important and their use for sludge treatment has increased.

The costs associated with sludge treatment or disposal depend largely on the national legislation, but are significant (Figure 2). In recent years there has been a considerable increase in disposal costs, resulting from regulatory changes which have limited disposal routes, and a lack of suitable areas for sludge disposal. Consequently it has become more important to reduce sludge volumes in order to reduce transportation and storage costs for all treatment/disposal options. Major volume reduction can be achieved by mechanical dewatering, but further reduction is possible only with thermal drying and other thermal processes. The greater use of thermal treatment will demand the development and use of technologies that minimise primary energy use and fully utilize the inherent caloric value of the sludge.

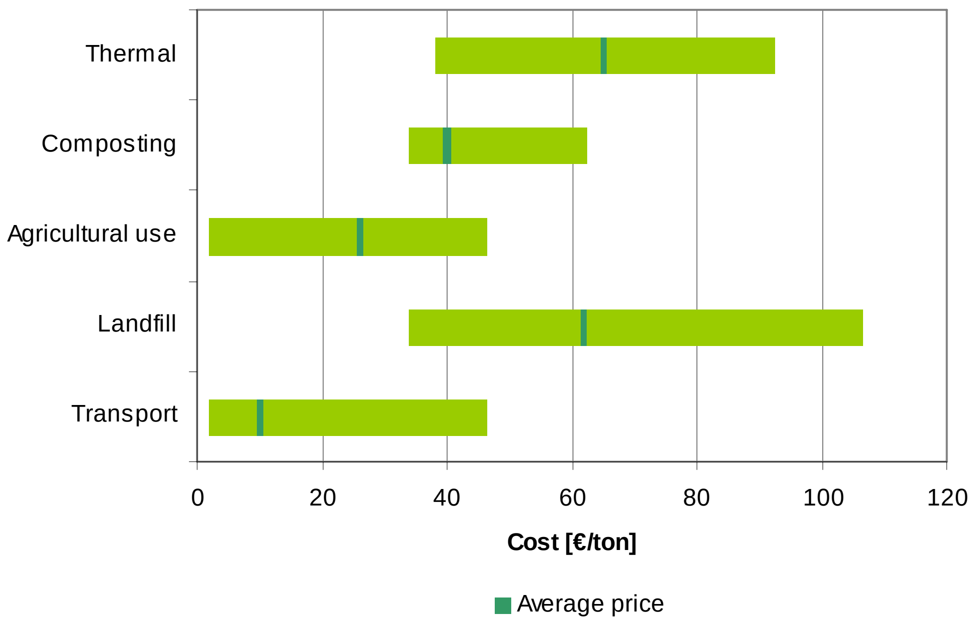

Figure 2: Range of costs for sludge handling services in the EU, 2002 /2/.

This report examines current technologies available for removing water from sludge, listing key parameters for operation and performance. Thermal processes for treating sludge are also described, along with details of the associated reactor technology and key characteristics of proven incineration processes, to enable comparison and process selection.

2 WATER REMOVAL FROM SLUDGE

The volume and mass of sludge can be significantly reduced by removing water. Typically the water content of untreated sludge varies between 90 and 99 %. The water removal can be a mechanical dewatering process, an evaporating process or (thermal) drying. Some key parameters associated with these three processes are given in Table 1.

Table 1: Typical energy need and water content achieved on a dry basis, for the three categories of water removal processes.

Type of process	Energy need (kWh/kg water)	Minimum water content achieved (%)
Mechanical dewatering	0.0001-0.03	70-80
Evaporation	0.1-1	50
Drying (thermal)	0.8-1.5	Approaching zero

The amount of solids in the rejected water varies considerably, and it is difficult to give typical values for each process. The size of the process equipment, the investment and operating costs, including those independent of the energy need, also vary. For instance, most mechanical dewatering processes need an addition of polymers to work efficiently. In order to choose the type of equipment that is best suited to dewater a given sludge, all these parameters need to be considered.

2.1 Mechanical dewatering

When selecting mechanical dewatering equipment to dewater a given sludge, the most important parameters to consider are:

- Amount of particles in the rejected water should be as low as possible. In general, sludge contains a substantial amount of very small particles. Single particles of colloidal size (1-10 µm) are negatively charged and act repulsive. In most mechanical dewatering processes today, a polymer is added to the inlet water to neutralize the particles negative charge repulsive forces. Iron oxide, aluminium sulphate and other chemicals have also been used as flocculant, normally in the order of 2 – 10 kg/tonne dry matter.
- Water content in the cake should be as low as possible
- Investment and operating costs need to be looked at together to ensure good value for money
- Reliable operation

In this chapter, some important key values are given for the most common types of equipment.

2.1.1 Decanter, tricanter, separator

Separators and decanters normally separate a liquid and the solids, while tricanters can further separate the liquid in two fractions with different density; for instance water and oil. Generally, decanters and tricanters operate horizontally, while separator bowls rotate on a vertical axis.

The decanter is the most common type of mechanical dewatering equipment used for sludge treatment. A typical decanter is shown in Figure 3.

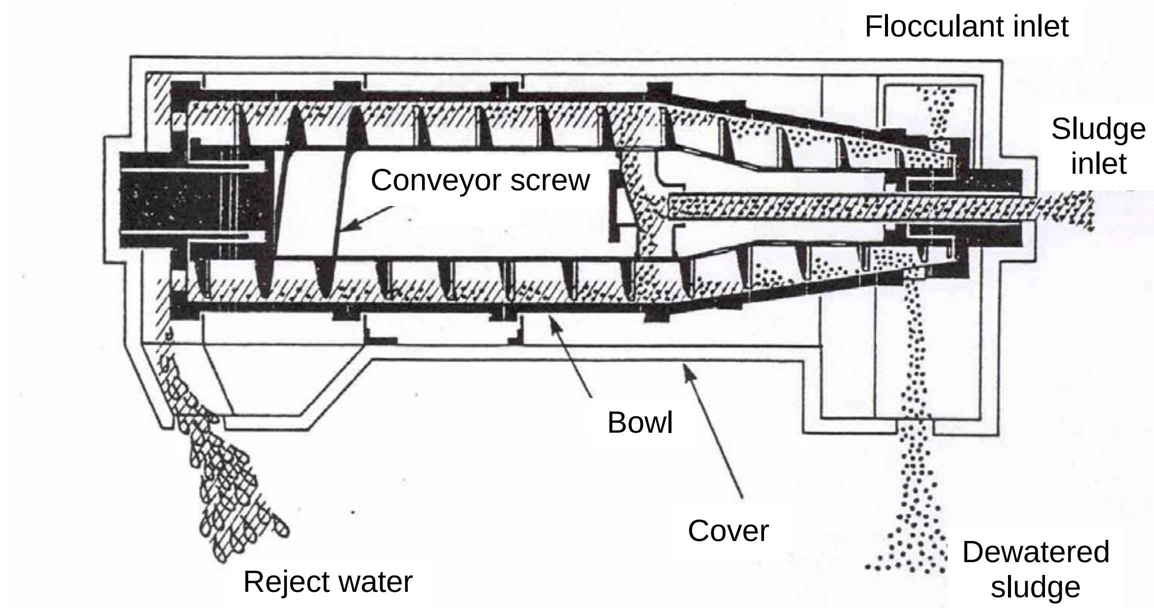

Figure 3: Components of a typical decanter /3/.

A decanter can be used to separate solids from a liquid if there is a difference in density between the components. In Figure 3, the sludge is fed into the decanter through the hollow shaft at its right end. At the end of the inlet tube, the sludge is transported through holes in the bowl wall and into the conveyer screw. The bowl and the screw are both rotating fast, and the screw rotates slightly faster than the bowl, a typical rotation speed equals 1000 – 3000 g for the sludge. This difference in rotational speed is forcing the sludge from the left to the right. As the solid has lower density than the liquid, a separation takes place in the cylindrical part of the bowl, and further as the sludge is transported up into the conical part of the bowl. Separated water is following the inside of the bowl wall and is drained out through openings at the left end of the cylindrical bowl.

Several design and operational parameters can be altered to optimise decanter performance for dewatering a given sludge:

- the diameter and length of the bowl
- the angle and length of the bowl's conical end
- the rotational speed of the bowl
- the rotational speed of the screw compared to the bowl
- the thickness of the sludge layer
- the location of dosage point for flocculants in the sludge inlet section

In terms of mechanical dewatering equipment, decanters yield the lowest amount of solids in the rejected water. For example, in the rendering industry, reject water typically has a chemical oxygen demand (COD) value of 28 000-37 000 mg/litre. The energy requirements for decanters typically range from 1 – 2 kWh/tonnes water removed.

2.1.2 Filter belt presses

Figure 4 illustrates the working principle of belt presses and Figure 5 gives an example of a modern belt press.

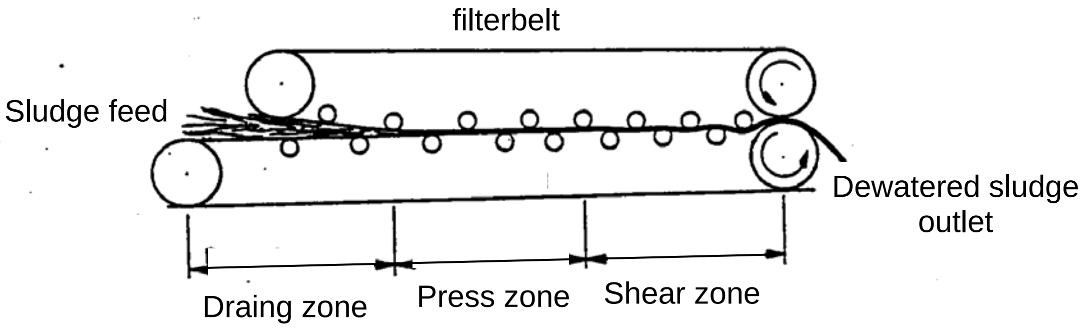

Figure 4: Features of a typical filter belt presses /3/.

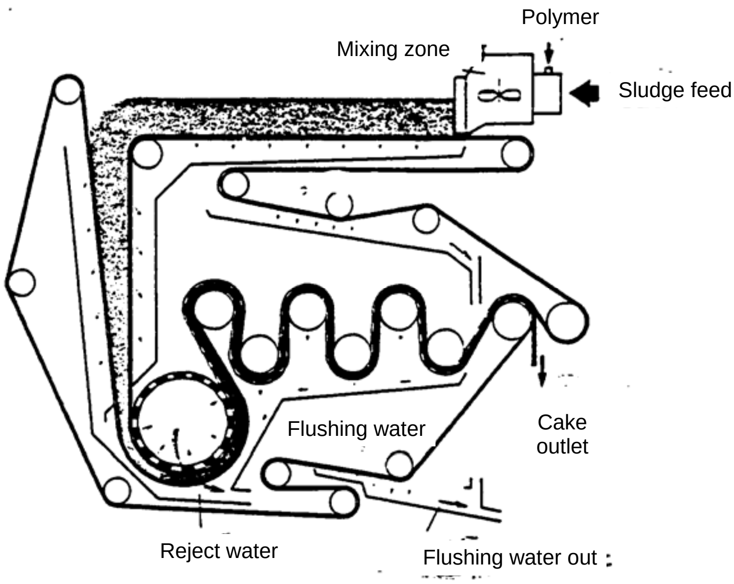

Figure 5: A modern, compact belt press for dewatering sludge /3/.

In a filter belt press the sludge is fed between two perforated belts, an upper and a lower belt. As pressure is applied to the sludge, water is squeezed out through the belts and drained from the equipment. The arrangement of the rollers ensures that the pressure increases as the sludge gets drier, moving through three different zones; drainage, compression and shear. Several methods exist to clean the belt after the cake has been separated.

The energy requirements for belt presses are low; in the order of 1.1 kWh/tonne water removed, with more than 99% of solids recovered. The design of belt presses has been continuously improved the last decade, and modern machines can achieve as much around 25 – 30 % solids in the cake. Flocculants are needed for efficient water removal, with organic polymers most commonly used. Flocculant consumption rate can be as low as 1.5 – 3 kg/tonne solids, although rates of 6 kg/tonne solids are not uncommon /3/.

2.1.3 Chamber filter presses

Chamber filter presses are batch-operated equipment, containing a number of chambers with flexible, rubber membrane walls. When the chambers have been filled with wet sludge, pressure is applied through the rubber membranes. Sludge feeding takes around 20 – 30 minutes, and a pressure of 7 to 17 bars is then applied for 1 – 4 hours. Special methods are needed to remove the cake at the end of a dewatering cycle.

This type of press yields the highest amount of solids in the cake, with 35 – 50% typically achieved, and on average more than 95% of solids are recovered. The equipment is, however, relatively expensive. As for belt presses, flocculants are needed for efficient water removal. In the past, iron chloride and lime have been used, although polymers are more common now.

2.1.4 Screw presses

Screw presses are frequently used to dewater sludge, especially when the fibre content is high. Figure 6 shows the screws in a twin screw press, along with the associated geometry and volume characteristics.

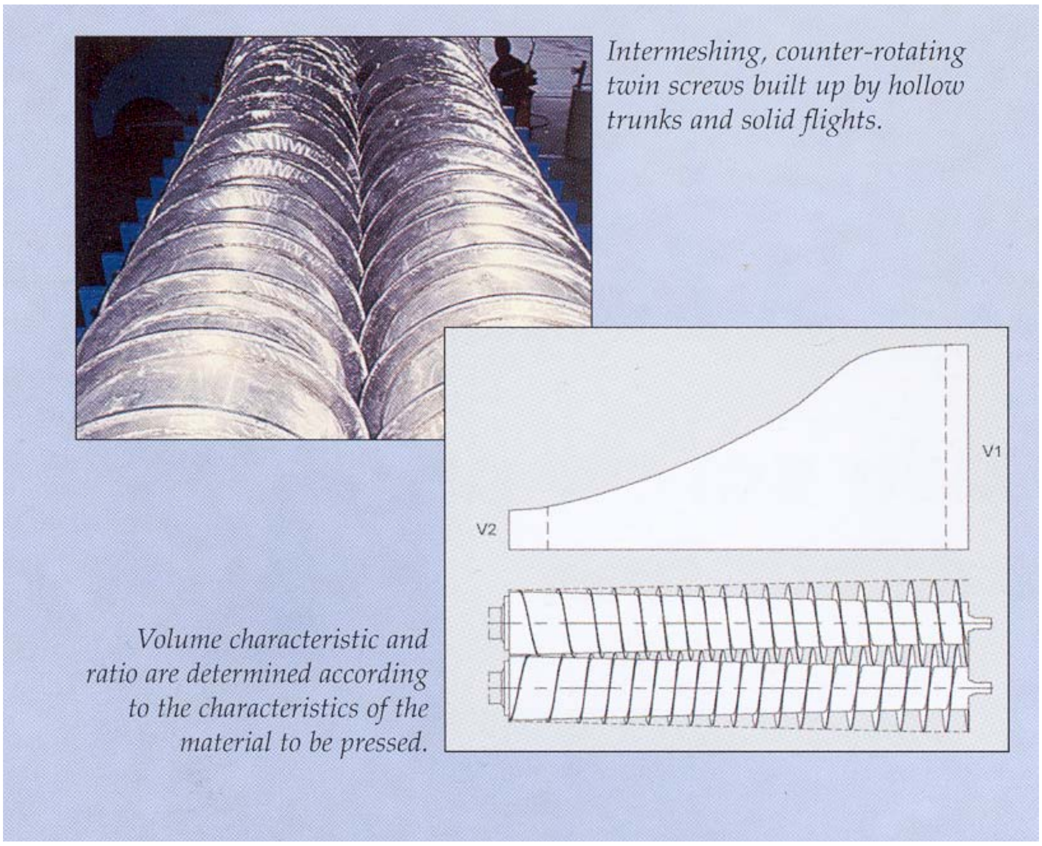

Figure 6: Twin screw press rotors and the associated volume characteristics /4/.

Sludge is fed between the screws, entering at the end where the space between the screws is largest. As the sludge moves along the screws, the inter-screw space gets smaller, increasing the pressure on the sludge and forcing out water, which is drained off through the perforated walls of the screw jackets.

Screw presses are efficient when the design and operation have been optimised for a particular sludge. Screw length, screw speed, screw thread ratio, screw core surface angle and perforation size will all have an impact on performance and must be selected to suit the sludge characteristics.

2.1.5 Vacuum filters

Vacuum filters are not used in Norway, but they are frequently found in sludge treatment plants in many other countries. A typical vacuum filter is shown in Figure 7.

Vacuum filters typically comprise a slowly-rotating, perforated cylindrical drum that is partly immersed in an open-topped vessel containing sludge. Most of the outer surface of the drum is covered by a flexible filter band. An internal vacuum is applied to the drum, which draws the sludge to the filter band. The water in the sludge passes through, allowing cake to build up on the band surface. As the drum rotates and the band moves out of the sludge bath, the cake dries as water continues to be drawn out through the band. The dewatered cake is released by a scraper, and the band is washed clean before it re-enters the sludge vessel /3/.

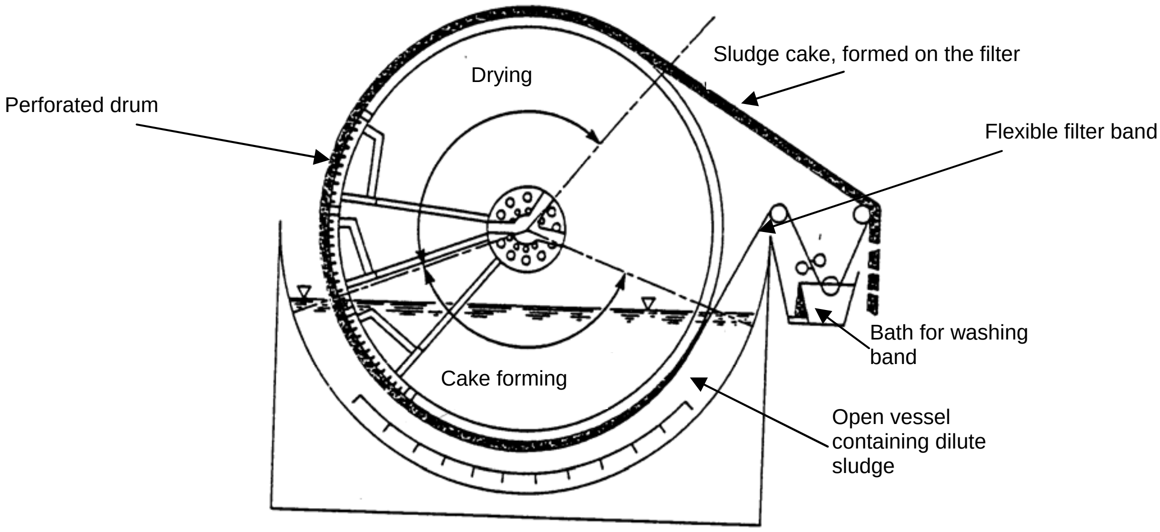

Figure 7: Sketch of a typical vacuum filter used for sludge dewatering /3/.

An alternative design uses a filter disk in place of drum. Vacuum filters recover a high percentage of solids, typically more than 95%, with usually 20 – 25% of solids in the cake

2.2 Evaporators

The energy demand for evaporators is much higher than for mechanical dewatering equipment (see Table 1), and consequently they are generally not used in sludge treatment plants. In municipal waste water plants, the reject water can be redirected to a settling tank, but in industrial water cleaning plants, this is not normally an option. In some cities, the reject water can be let into the municipal drainage system, where sufficient capacity exists. In other cities, however, this is not allowed and a policy of “zero emission” must be pursued.

In these latter cases, an evaporator can be used to reduce the water content of the sludge and hence the amount of sludge itself. The amount of pollutants in the condensed water vapour from an evaporator is usually sufficiently low for it to be let into the municipal drainage system, although exceptions exist. In central Europe, the regulations for emissions into rivers have become increasingly strict in an effort to clean the water, such that even the condensed waste vapour from evaporators is not clean enough to be discharged directly into rivers.

In Norway, several local regulations allow water with COD values of up to 300 - 350 mg/litre to be let into the drainage system. Such values should not pose a problem for evaporators, unless foaming or excessive boiling with overflow occurs during operation. In the main, the COD value of the condensed vapour cannot be reduced by altering the design or operation of the evaporator, as the entrained matter is a result of volatile components.

European limits for emissions can be found in the EU's Integrated Pollution Prevention and Control (IPPC) directive, which is also implemented in several countries outside the EU, such as Norway.

2.2.1 Falling film evaporators

For sludge treatment applications, falling film evaporators are the preferred design. A typical single stage falling film evaporator is shown in Figure 8.

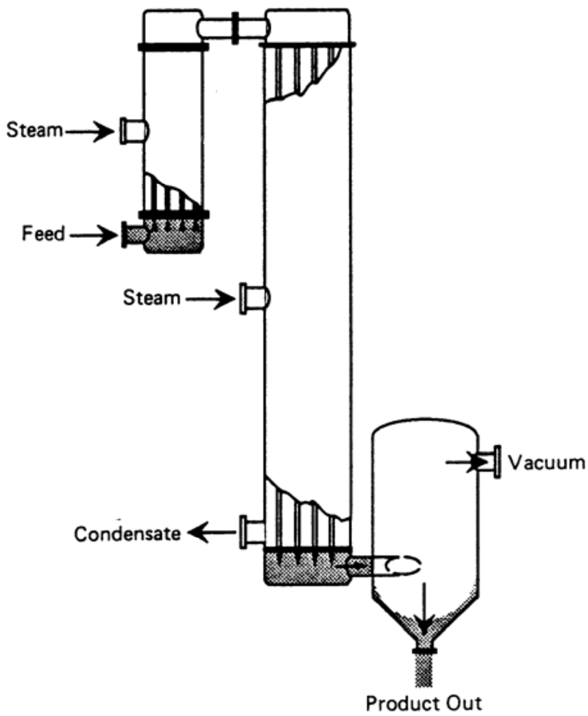

Figure 8: Falling film evaporator with externally heated tubes /5/.

As sludge treatment generally involves high volume flow and the energy requirements for evaporation are substantial, more elaborate designs with energy-saving features tend to be used. The evaporators can have three, four or five stages, or they can be supplied with mechanical vapour recompression (MVR) or thermal vapour recompression (TVR) equipment. The energy-saving potential of multistage evaporator designs is shown in Figure 9.

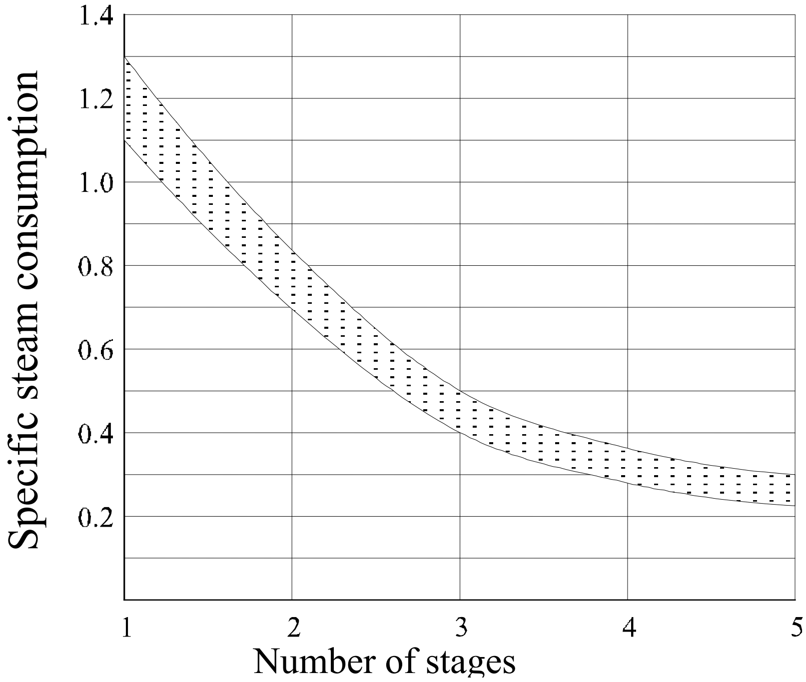

Figure 9: Energy need for multistage evaporators /5/.

Recompression of the exhaust steam is considered viable if the alternative is a three to five stage unit, and the rise in boiling point is low. MVR uses less energy than TVR, but the energy for the compressor must come from an external source, usually electricity, whereas steam is used to power the compressor in TVR systems. Consequently, the energy demands *and* costs must be evaluated for each plant under consideration.

Depending on the viscosity and flow properties of the sludge concentrate, the water content can be lowered to 50 - 60% in a falling film evaporator. 50 % is the minimum water content for low viscosity sludge concentrates.

2.3 Drying (thermal)

When the water content of the sludge needs to be lower than 30 – 50 %, the sludge (concentrate) must be dried. Several types of dryers have been tried, but problems still remain with their design and operating. The most severe problems are fire and explosion hazards, dust emissions, consistency problems with the partially-dried sludge, and very high investment and operating costs.

For example, the sulphur content of municipal sludge poses an increased fire risk, with a self igniting temperature of 130 °C, and the dried product must be cooled before being moved to a storage system.

2.3.1 Rotary dryer

Rotary dryers are the most commonly used dryers for sludge applications. The main components of such a dryer are shown in Figure 10.

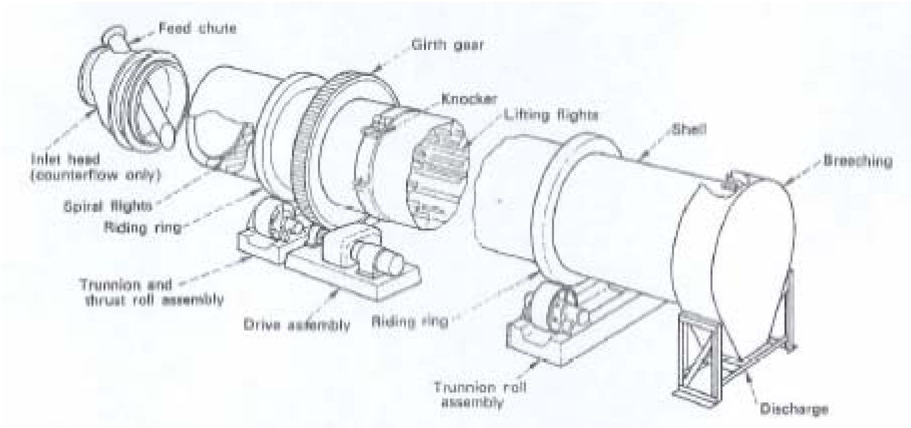

Figure 10: Rotary dryer /6/.

The product to be dried is fed through a chute into the slowly rotating drum. As the drum rotates, the wet material is continually lifted by the internal flights before falling through the hot air stream as it moves towards the discharge point. When there is a fire risk, the temperature in the dryer must be limited. As a result, rotary sludge dryers tend to be very long, typically some 20 – 30 metres in length. Long length may also be needed to dry at lower temperatures and agglomerate the product into small lumps to avoid dust, which increases the drying time needed for the thicker product. To ensure safe operation, flame or heat detectors are installed, and fire extinguishing systems are built in to the dryer, making these installations expensive. Typical energy requirements are in the order of 1 – 1.2 kWh/kg of water removed.

2.3.2 Disc- and heater coil dryers

Several designs of disc and heating coil dryers are used in sludge treatment applications. These dryers typically have rotating, heated surfaces that are immersed in the product to be dried. The rotor is also designed to stir the product and move it along the dryer, from inlet to outlet, during a specified retention period. A typical disc dryer is shown in Figure 11.

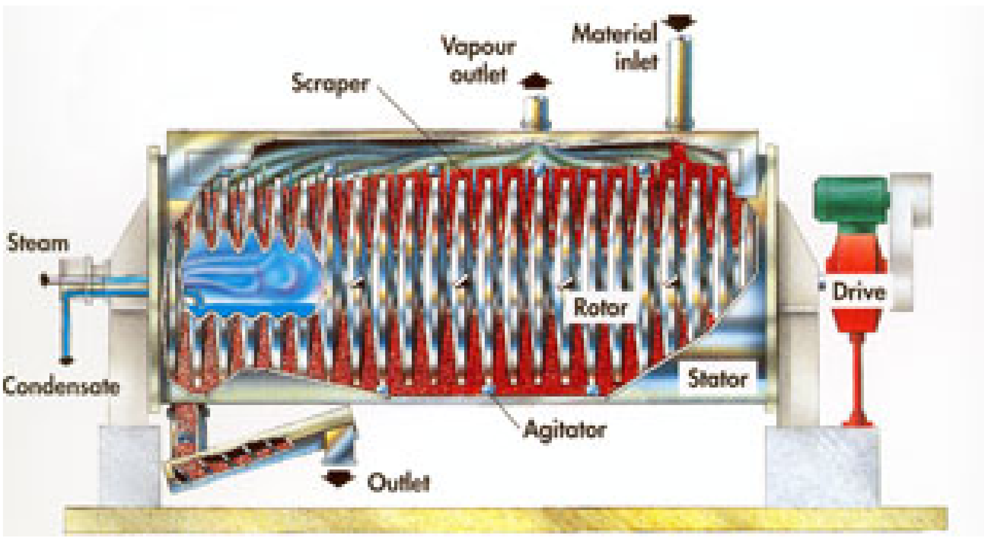

Figure 11: Rotadisc® dryer /4/.

Heat recovery from the condensation of exhaust steam is made easier without all the excess air usually exhausted from hot air dryers. In addition, as the heat for evaporation comes from the heater surfaces and not hot air, air circulation in these dryers can be fairly low, necessitating much smaller exhaust air cleaning devices. However, even with low air circulation, these dryers often have problems with dust emissions. The dried material may also contain high amounts of fine particles, and it is difficult to avoid dust problems during the storage and transport processes. On some plants, pelletisers are installed to eliminate dust problems in the post-dryer handling processes, but these increase plant cost and complexity. The energy requirements are generally lower for these dryers compared with hot air types, typically being as low as 0.8 kWh/kg of water removed.

2.3.3 Special sludge dryers

2.3.3.1 Thin film dryers

Thin film dryers are specially designed for very viscous products. There are several designs available. These dryers are expensive and generally have high energy requirements.

2.3.3.2 Paddle dryers

Paddle dryers have become popular for on board sludge handling plants on cruise liners and passenger ships. Due to very good mixing abilities, wide variation in the consistency of the incoming wet material is possible, with the dryers able to handle grinded solid waste, wet sludge or mixtures of the two.

2.3.3.3 Belt dryers

Belt dryers are capable of handling any consistence of wet material as long as the product feeder can transport it onto the belt. The retention or drying period can easily be adjusted by varying the belt speed. However, these are costly installations for sludge applications, and potential problems with dust and fire/explosion hazards also need to be considered.

3 THERMAL PROCESSES

Tighter environmental regulations in industrialised countries have led to greater interest in thermal processing of sludge and its use is becoming more widespread. It has several benefits where large volume reduction is needed, although several key factors must be borne in mind when considering its use /1/.

- After incineration, up to 50 % of the dry input mass of the sludge will remain as ash. The major part of any toxic heavy metals will also remain in the ash, which may cause difficulties when disposing of the residue.
- Components such as nitrogen, chlorine, sulphur, dioxins and furans that are present in the sludge will be released during combustion. Extensive flue gas treatment will be needed to meet the very strict emission limits normally imposed on waste incineration.
- With 70-80 wt % moisture content (after mechanical dewatering) the lower heating value will not be high enough to maintain the combustion, and supplementary fuel may be necessary.

This section gives a brief description of the different thermal processes that it is feasible to use in connection with sludge treatment. Direct combustion and co-combustion with other fuels are currently the most commonly used processes. Combustion (including co-combustion with other fuels) constitutes 24 % of the Danish production, 20 % of the French, 15 % of the Belgian, and 14 % of the German. Alternative processes, such as gasification and pyrolysis, reduce the volume of flue gas which has to be cleaned and also reduce the volume of ash generated after (a potential) combustion, thereby reducing the thermal treatment costs.

3.1 COMBUSTION

Restrictions in recycling of sludge, lack of suitable areas for its deposit and new environmental regulations, have all made combustion of sludge a more attractive concept. The advantages of combustion of sludge are:

- Large volume reduction and a stable residue is produced (ash constitutes only 10 % of the volume of the mechanically dewatered sludge, and approximately 50 % of the solid fraction).
- Thermal destruction of toxic organic components.
- The heating value of dried sludge is approximately the same as of brown coal, which means that combustion of sludge may result in recovery of energy.
- In urban districts it is easier to dispose ash than sludge. This gives less problems connected to evil-smelling neighbourhoods.
- Combustion is a conventional technology which has been tested and improved over a number of years, resulting in lower operating expenses.

Three special furnace types are generally used for the direct incineration of sludge; fluidized bed furnace (FBF), multiple chamber furnaces or multiple hearth furnaces (MHF) and rotary kilns, with FBFs being most common in Western Europe /8/. Other technologies, such as cyclones and different types of melting furnaces are occasionally used /1/. More details of reactor technology are given in Section 4.

3.2 CO-COMBUSTION

Co-combustion of sludge with other types of fuel is a useful option when seeking a fast method for destruction of the sludge. In most cases the sludge constitutes only a small part of the fuel composition. Sludge can be co-fired in a coal fired power station, in a waste-to-energy plant (WtE) or a cement works. The advantages of co-firing include /1/:

- Well-trained and experienced personal are available, with extensive knowledge of handling the existing plant.
- It is a relatively quick method for destruction of sludge.
- It is not necessary to apply to the authorities for new approval permits when co-firing with waste in existing waste incinerators.
- The existing plant is already equipped with a flue gas treatment system able to handle the expected increase in emissions during co-firing with sewage sludge.

3.2.1 Co-combustion with coal

Combustion in a coal power plant will, in some cases, require some modifications, such as modification of the burners and pre-treatment of the fuel. In such cases the sludge will need to be dried prior to combustion. In plants where pulverized coal is used, the sludge will also need to be pulverised. Drying of the sludge will require extra modifications, such as new equipment, as well as ways to handle condensate, smell, dust and carbon monoxide emissions. Transport, storage and feeding systems for the dried sludge also need consideration. In addition to odour problems, dried sludge dusts can self-ignite, and are explosive as a dust-air mixture.

Co-combustion with pulverized coal may take place in separate sludge-burners or in the same burners that are used for the coal. In these plants, sludge combustion will take place at high temperatures, and the ash will be removed in molten form. For bituminous coal, it is possible to co-fire sludge with a maximum of 10 wt % of water. With other types of coal, such as brown coal, a higher fraction of moisture is acceptable (typically up to 50 wt%), as the boilers already are dimensioned to handle this.

3.2.2 Co-combustion with waste

The advantage of co-combustion of sludge and waste is reduced costs compared with having separate combustion plants. This process can generate the energy (heat) needed for all the sub-processes; drying, supporting the combustion of solid wastes and sludge, and steam generation. A further benefit is the possibility of using the existing flue gas treatment system with no need for modifications.

Several types of plants are considered suitable for co-combustion of waste and sludge. The grate furnace is most commonly used, suitable for co-firing of de-watered or dried sewage sludge with municipal solid waste (MSW). De-watered sludge should generally not exceed 15% of the furnace capacity, to prevent the formation of slag and increased fouling of the furnace. Different systems for feeding sludge into MSW are commercially available, such as feeding de-watered sludge through a bin or by direct feeding to the grate. Dry sludge is normally fed directly into the feed bin of the furnace /8/. The energy from the grate chamber might be used for drying the sludge.

The WtE plant at Thun, Switzerland, consisting of a MSW grate furnace with a 46MW boiler and energy recovery has been in operation since the end of 2003. The annual capacity is 100 000 tonnes including 10 000 tonnes of dewatered sewage sludge (25% dry solids) /8/.

Alternatively fluidized bed or MHF can be used, but this requires crushing of the waste into smaller particles, and mixing of the waste and the wet sludge prior to combustion.

3.2.3 Co-combustion in other processes

Sludge is also used as an additional fuel in other types of processes, e.g. in the production of clay bricks. In order to reduce the energy demand in the production of bricks (heating of rock), several organic substances including sawdust, coal dust and waste oil have been added to clay. Sludge has also been used as organic substance, and when the bricks are heated in the kiln, at a certain temperature, the organic matter in the sludge will ignite and thus cause a rapid increase in the bricks' temperature. At the point along the kiln when the sludge has completely burnt and the temperature gradient decreases, an external fuel is needed. Bricks produced in this way have proved to have certain advantages compared to the common production method /1/.

The use of sewage sludge as an alternative (additional) fuel in suitable equipped cement works requires the sludge to be dried before it is combusted. The ash produced from the combustion is bound in the clinker from the kiln, thus eliminating the need to dispose any incineration residues /8/.

3.3 PYROLYSIS

Pyrolysis involves heating organic material under inert conditions, in such a way that oil and gas are generated alongside a solid residue. The process is endothermic, requiring an external source of energy to reach the required temperature of 300 - 900ºC. The three products can all be used as fuel. The gas produced is combustible and can be burned to generate the heat required for the pyrolysis reaction. The oil produced can either be burned or used in the chemical industry for the production of chemicals. The solid residue can be used as fuel, since it also contains a remainder of carbon mass, be disposed of or, if appropriate, be used as fertiliser.

3.4 GASIFICATION

Gasification is a process that converts carbonaceous materials into carbon monoxide and hydrogen. During gasification, sludge is combusted with a controlled and limited oxygen supply, considerably reducing the flue gas flow that has to go through the treatment system.

Gasification with pure oxygen instead of air results in a mass flow reduction due to the absence of nitrogen in the flue gas products. In addition, synthesis gas is produced with a higher heating value, which might be used in a gas engine or in a gas turbine, enabling production of electric power in addition to heat energy.

The flue gas production during combustion is 24 - 30 m^3 flue gas per kilo of dried sludge burned. By comparison, the flue gas production is as low as 1.7 m^3/kg of dry sludge during gasification with oxygen /1/. In a gasification process, air, oxygen, steam or a combination can be used as oxidizing agent. The products of gasification are generally carbon monoxide, carbon dioxide, nitrogen, hydrogen, water, methane and other light hydrocarbons and tar components.

3.5 WET OXIDATION

Wet oxidation has historically been used for municipal wastewater sludge applications and is particularly effective for treating wastes with high organic matter. The process involves the oxidation of soluble or suspended components in water, using oxygen as the oxidizing agent.

Wet oxidation is a thermal process taking place at temperatures of 150 –330 ºC and pressures of 1 – 22 MPa with the presence of water. Under these conditions the thermo-physical and chemical properties of the water differs from those under normal conditions. Several gases such as oxygen and nitrogen become water-soluble, while inorganic salts and metal oxides remains insoluble, enabling them to be easily eliminated from other components in the gas phase /9/.

Two different processes are used in industry, one sub-critical process (below 374 ºC and pressure of 10 MPa) and one super-critical process (higher than 374 ºC and a pressure of 21.8 MPa) /1/. The sub-critical conditions are easily achieved and the reactions controlled, and as a result various processes are commercially available. The high pressure required can be achieved above the ground using in-vessel technology or by using deep-well technology.

4 REACTOR TECHNOLOGY

For thermal treatment of sludge it is possible to use various types of reactors. Dependent on the choice of technology, the reactors may be used for pyrolysis, gasification or combustion. In some types of reactors, such as multiple heart furnaces, it is possible to have separate zones for pyrolysis and combustion within the same reactor. If the sludge is dried to a solid fuel, several conventional technologies can be used for treatment, such as furnaces with fixed or movable grate. These can also be used for co-combustion of sludge with other types of solid fuel. For small scale systems, updraft and downdraft gasifiers are the most commonly used reactor types for solid fuel. These will not be elaborated further.

This section gives a brief description of the main reactor technologies currently used for thermal processing of sludge.

4.1 MULTIPLE HEARTH FURNACE (MHF)

Multiple heart furnaces consist of several fixed chambers or hearths, and an agitator at the centre as shown schematically in Figure 12. The sludge is fed into the top of the furnace and drops from hearth to hearth, conveyed by the agitator or rotating shaft. The reactor is divided into different zones where drying takes place in the upper hearts, followed by pyrolysis, combustion and finally ash-cooling. The main advantage of MHFs is good internal energy usage, since the hot flue gas comes in direct contact with the sludge /1/.

The control, sludge feeding system and functionality of this type of furnace are all straight forward. An additional energy source (supplementary fuel) is needed to maintain the combustion process, and this leads to additional operational expenses associated with fuel consumption. Annual combustion of at least 2000 tonnes dry solids is required for technically and economically efficient operation /8/.

As an alternative to having own flue gas treatment system, a MHF can be couplet to a MSW incinerator. The flue gas from the MHF can then be fed to the waste furnace for post combustion and also be treated in the MSW flue gas treatment system. This approach is used at the KVA/SVA plant at Limmattal (Switzerland), and it allows partial recovery of the external energy supplied to the MHF /8/.

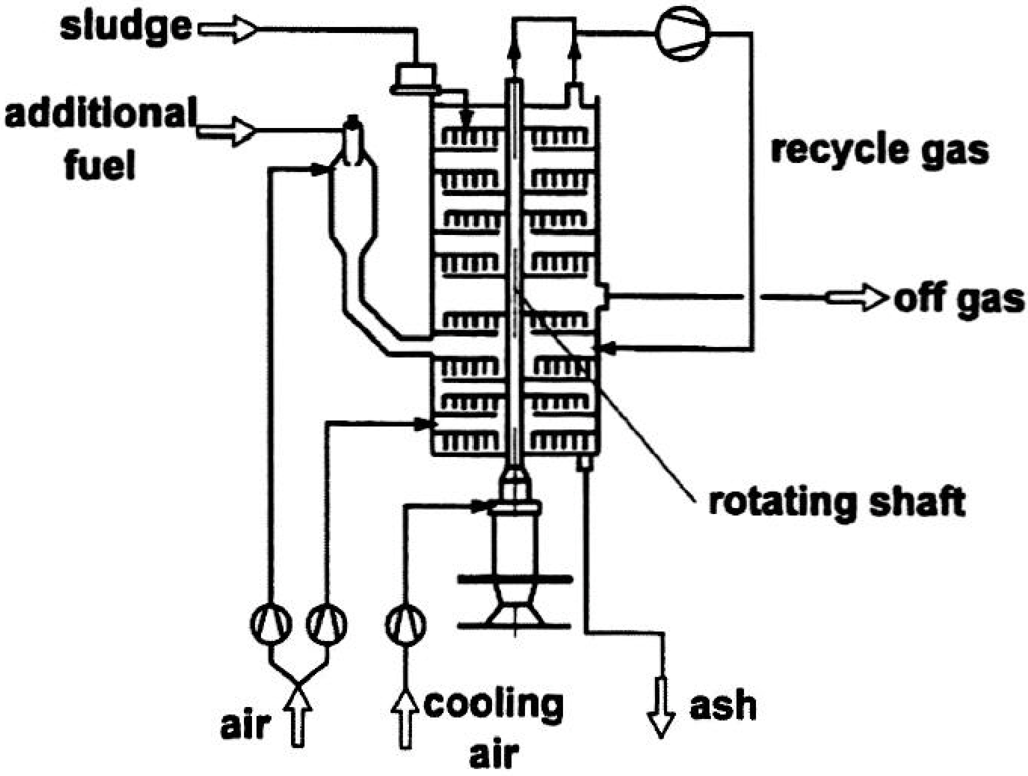

Figure 12: Sketch of a multiple hearth furnace (MHF) /1/.

4.2 FLUIDIZED BED

Fluidized bed technology is widely used for incineration of coal, low quality fuels and waste. In Europe, the first fluidized bed sludge incinerator was installed in 1964 in Germany for the combustion of refinery sludge, and in 1965 another one was installed in Switzerland for the combustion of sewage sludge /1/.

Generally, both mechanically dewatered and pre-dried sludge can be incinerated in fluidized bed furnaces. Figure 13 shows a sketch of a fluidized bed reactor burning dewatered sludge at the Berlin-Ruhleben plant in Germany. In the plant 5 000 m^3 /day of sludge (2 – 3.5 wt % dry mass) is received and mechanically dewatered to 24 – 28 wt % dry mass before being fed into the reactors. The plant has three incinerating units, each having four feed points. Each unit can take a maximum of 3.7 tonnes/hour of dry sludge (equivalent to 15 tonnes/hour of sludge with 25 wt % d.m.). Additional heating with oil is used to maintain the 35 tonne bed of sand at a temperature of 750 ºC. The flue gas leaves the furnace at 850 – 870 ºC, and waste heat is recovered in a boiler and air preheater /1/.

The flue gas cleaning system includes electrostatic precipitators and wet scrubbing. In the desulphurization unit about 2.5 tons/day of CaO is consumed and 7 tons/day of gypsum is formed. About 45 tonnes of ash is being produced daily.

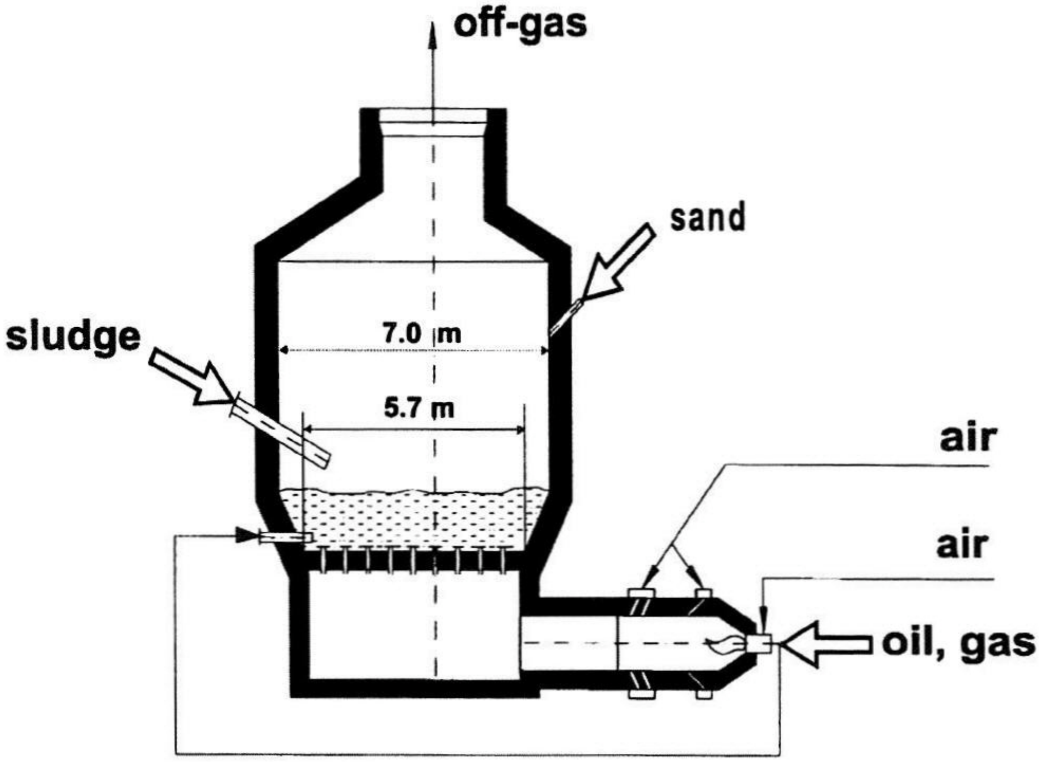

Figure 13: Sketch of a typical fluidized bed furnace for thermal treatment of sludge /1/.

Fluidized bed technology is well suited for combustion of sludge, offering the following advantages /1/:

- Good mixing of the bed material, high turbulence and large surface area of the inert bed material available for heat transfer result in complete combustion at relatively low temperatures and excess air ratios (25-50%).
- The residence time of the sludge particles in the hot bed is long enough to ensure sufficient burn-out (larger particles do not leave the reactor until they have transformed into smaller particles).
- The freeboard acts like a post-combustion chamber where the organic materials are completely destructed.
- The large amounts of inert bed material can store much heat, thus preventing sudden variations in temperature.
- The slow cooling-down rate (5 ºC/hour) permits intermittent operation at the plant if desirable.
- Strain on the refractory material caused by thermal shock is eliminated due to small variations in temperature inside the reactor.
- The absence of moving parts in the hot zone results in low maintenance costs.

4.3 ROTARY FURNACES

Rotary furnaces have been used in the cement industry and for drying applications. In Japan, rotary furnaces have been popularly used for sewage sludge incineration, with about 20 such installations in operation in 1988. However, the number of units has not increased over the last few years, indicating that other types of technology have become preferable.

Typically, rotary furnaces consist of a horizontal steel drum which is lined internally with a high resistance refractory material. Normally the cylinder rotates at low speed, and tilts at a slight angle to the horizontal plane so that the solid material in the cylinder is set in motion by the rotation. During combustion, the fuel passes through several phases, such as drying, pyrolysis and combustion. The remaining ash falls off and is collected at the end of the kiln. The combustion takes place at temperatures around 800 – 1 000 ºC, and energy recovered from the flue gas and ash cooling is used to pre-heat the combustion air and generate process steam. Installations using rotary furnaces for combustion of sludge, usually do not have sufficiently high sludge burn-out efficiency due to agglomeration of sludge particles, which are being burnt and sintered on the surface while the core still remains unburned /1/.

Annual sludge quantities of at least 5000 tonnes dry solids are required for efficient combustion in a rotary furnace. Unlike multiple hearth furnaces, rotary furnaces do not tolerate significant variations in sludge quality /8/.

4.4 ETAGENWIRBLER OF LURGI

The 'Etagenwirbler' reactor utilizes the advantages of both fluidized bed and multiple heart technology. It has a multiple hearth section in the upper part, where the sludge is dried, and a fluidized bed at the bottom, where the combustion takes place. Figure 14 shows a sketch of the reactor. The drying stage prior to combustion makes it possible to operate the reactor without additional heating.

A reactor of this type has been operating at the sewage treatment plant in Frankfurt since 1981. The reactor has a capacity of 2 tons/hour dried sludge. The MHF part consists of five hearts. Sludge with 28 – 30 wt % d.m. is fed from the top, and 50 – 60 % of the flue gas from the combustion zone is used for drying. The final hearth acts like a fuel feeder for the fluidized bed underneath /1/.

During the drying stage, 50 % of the moisture in the sludge is removed. Vapours from the drying region are returned to the bed where they are deodorized. The flue gas is passing a cleaning process where the ash is removed, being bled off in a waste kettle and then into an electrostatic filter. The flue gas undergoes a two-stage wet scrubbing process, and the second scrubbing stage operates at temperatures below dew point to enable condensation of all the vapour in the flue gas.

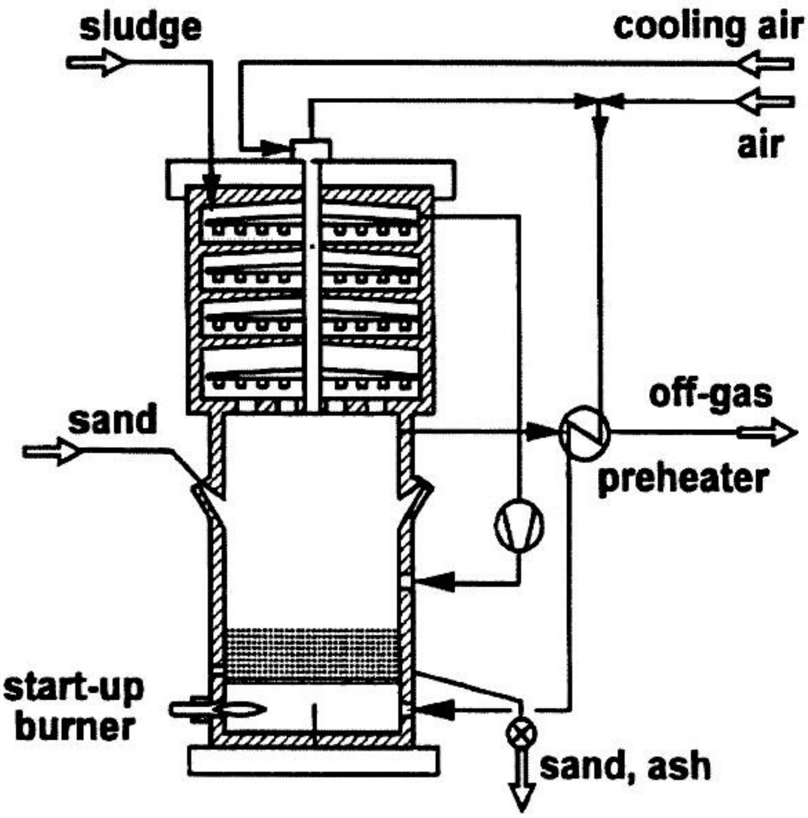

Figure 14: "Etagenwirbler of Lurgi" reactor /1/.

4.5 MELTING FURNACES

Combustion of sludge results in the production of large amounts of ash with high content of heavy metals. Such ash usually needs to be deposited in special areas, and this amounts to increased disposal costs. Melting technologies avoid this problem by incinerating pre-dried sludge at higher temperatures (up to 1500 ºC) thereby producing molten ash instead. Molten ash has a density which is two- to three- times higher than that of incinerated sludge ash, and hence a significant volume reduction is achieved. Furthermore, melting converts the ash into a glasslike or crystallized material, and the heavy metals are bound into the crystals in a stable state where they are no longer leachable. This material can be used in the construction work, road constructions or as an insulation material.

4.6 CYCLON FURNACES

The characteristic features of a cyclone furnace are that the primary and secondary combustion air, as well as the pre-dried sludge, are fed into the combustion chamber tangentially. This creates a rotating gas stream and enables a long residence time, with complete combustion of the sludge particles. Pre-drying of the sludge is required for the furnace to function properly.

Figure 15 shows a process utilizing a cyclone chamber for combustion and a fluidized bed combustion for pre-drying of the sludge. Exhaust gas from the drying stage is used as combustion air in the cyclone chamber. The flue gas treatment consists of dry scrubbing using $Ca(OH)_2$, a baghouse filter and activated coal adsorber, to reduce emissions of heavy metals, dioxins and furans. Figure 15 shows a sketch of the process of the German company "Hugo Petersen GmbH" which has a capacity of 300/600/1200 kg (dry sludge) per hour. The plant is able to handle sludge generated from a population of 50 000 – 200 000 /1/.

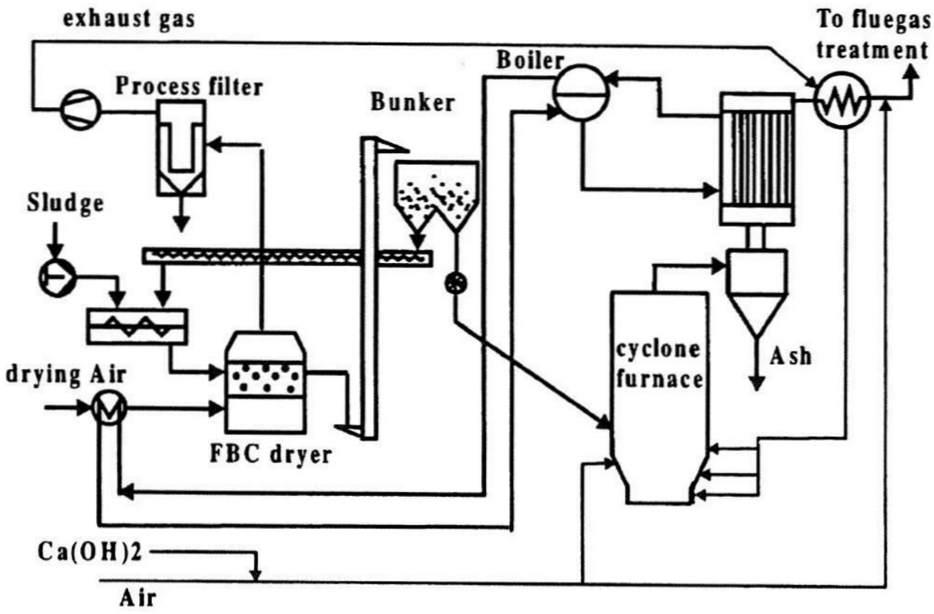

Figure 15: Process with drying of sludge in a fluidized bed drier and combustion in a cyclone chamber /1/.

4.7 INTERNAL DRYER OF NORSK INOVA

Norsk Inova AS has developed a concept for co-combustion of wet sludge and waste. Waste (dry fractions) is fed in batches into the top and is burned at the bottom of the furnace. Pre-treated food waste or wet sludge can be pumped into the furnace for destruction. This feeding is continuously.

The wet sludge and food waste are not dewatered prior to entering into the furnace, and have typical water content at the inlet of ~ 90%. The sludge/food waste is dried inside the furnace prior to combustion by the hot flue gas and radiation from combustion of the dry waste. Typical capacity will be up to 350 kg sludge or food waste/hr and 350 kg dry waste/hour.

An oil burner is used for start-up and also to maintain the temperature level in the furnace between the batches of dry waste, if necessary. The flue gas temperature is typically around 900oC, and water is injected in the combustion chamber if the flue gas temperature is too high.
This concept is developed for combustion of waste and sludge at cruise ships. By now this furnace is installed at one ship, and several new installations are planned in the near future. At the installed furnace the heat in the flue gas is not utilized, but this is a process with net heat production.

The major advantages with this concept are:

- No separate dewatering or drying is needed.
- Combustion of dry waste and wet waste and sludge in the same furnace
- Sealed system that gives no smell
- Relatively low cost

5 CURRENT PRACTICE/PROVEN TECHNOLOGIES

There are two alternative paths for the incineration of de-watered or dried sludge:

- Direct incineration in a separate furnace with individual or combined flue gas treatment
- Combined incineration in a WtE plant, in a cement work or a coal fired power station

These paths are illustrated in Figure 16.

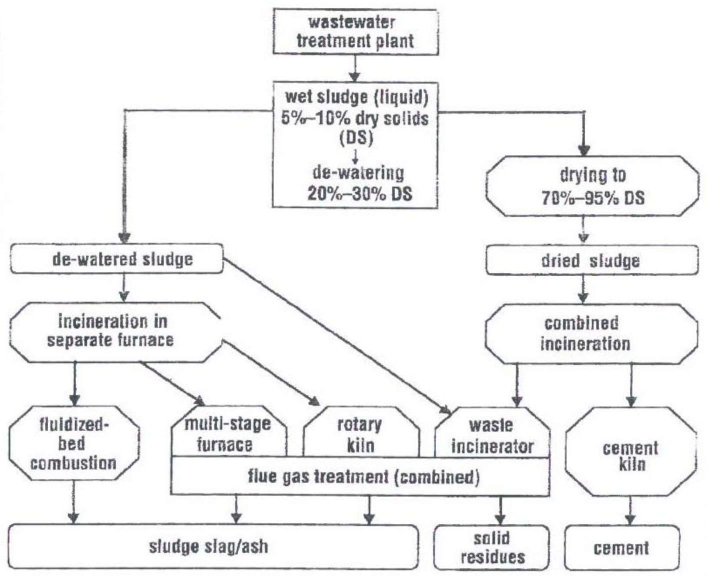

Figure 16: Alternative paths for the incineration of sewage sludge /8/.

Several technologies currently exist both for direct (mono-) and co-combustion of sewage sludge in which high combustion efficiencies are achievable. Müller and Pfeiffer /8/ have summarized the characteristics of some proven alternative technologies for the incineration of sludge (Table 2). The most likely challenge for the future is the incineration of sewage sludge with maximum energy recovery, but at low cost and with an environmentally sound performance.

Table 2: Characteristics of incineration alternatives for sewage sludge /8/.

Parameter	Mono-incineration of de-watered sludge in special furnaces			Co-incineration		
				Sludge/waste		Cement works
	Fluidized bed	Multi-stage	Rotary kiln	De-watered sludge	Dry sludge	Dry sludge
Capacity (tonnes DS/year)	> 5000	>2000-3000	>5000	<15% of waste incineration capacity	<15% of waste incineration capacity	
Operation conditions						
Continuous feed required ?	Yes	Yes	Yes	Not necessarily	Not necessarily	No (stacking)
Sludge quality	Constant	Slightly varying	Constant	Slightly varying	Slightly varying	Constant
Energy Balance	Neutral	Negative (external energy)	Negative (external energy)	Neutral	Positive (partial heat recovery)	Positive
Disposal of residues	Straightforward on adequate sites	Straightforward on adequate sites	Straightforward on adequate sites	Mixed together with slag/ash	Mixed together with slag/ash	No residues
Remarks			Suitable for different waste types	Limited sludge fraction in waste	Limited sludge fraction in waste	Specific quality standard

Other thermal waste-processing techniques such as pyrolysis and gasification has been proposed as alternatives to the classical incineration processes, however the technical reliability of such processes has yet to be proved.

6 SUMMARY

Sludge production continues to increase worldwide, as more countries become industrialised and growing populations increase wastewater volumes. Consequently, many countries have to find suitable solutions for the disposal of large quantities of sludge.

Historically the most important disposal routes for sludge treatment have been landfilling, agricultural use, incineration and dumping into sea. However, environmental concerns have led to the introduction of increasingly stringent legislation, which has already reduced disposal options in many countries. In Europe a total ban to dumping into sea became effective in 1998. Agricultural use is already forbidden in some parts of Western Europe due to the presence of contaminants (such as heavy metals and pharmaceutical substances) in sludge, and also landfilling are facing restrictions. There is, therefore, a drive to find more environmentally ways to dispose sludge.

This stricter environmental policy has not had the same impact in Norway where agricultural use still is the major disposal route for sludge. The situation may, however, change considerably in the near future since increasing values of heavy metals has been measured in some rural areas. This indicates that it will not be possible to continue with increasing use of sludge in farming. Due to this, the same tendency as in other European countries is expected gradually to be experienced in Norway as well.

Many dewatering techniques are available, and these can significantly reduce the mass and volume of sludge for disposal, although disposal is still an issue. As a result, there is growing interest in thermal processes for the treatment of sludge, and the utilization of such processes for sludge treatment has increased. Several proven thermal processing technologies are now commonly used for sludge treatment, the main purpose most of the existing methods is destruction of the organic materials, preventing the spread of disease, as well as reduction of weight and volume. Other important aspects are energy recovery as well as recycling of important materials like phosphorus or metals. New techniques are being developed with many pilot schemes underway, and these may prove to be viable and reliable alternatives.

Careful consideration of all operational parameters, local regulations, associated investment and operational costs is needed to ensure that the best solution is found for processing a given sludge stream.

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