CONNECT WATER

Memorandum

To: Wellington Water Limited

From: Connect Water Limited

Date: 23 September 2020

Subject: Sludge Process Technologies Overview

1. Purpose

The purpose of this memo is to present the process technologies available for sludge treatment. An overview of these technologies has been incorporated in the *Sludge Minimisation Process Options Assessment Report* issued by Connect Water in June 2020.

2. Concentration Technologies

2.1. Overview

Concentration technologies reduce the amount of moisture from sludge, decreasing the total mass. This includes thickening and dewatering processes that will produce sludge in the range of 2 – 6% dry solids (thickening) and 18 – 28% dry solids (dewatering). The benefit of these technologies is the reduction in total sludge volume, which can decrease unit sizes of other equipment in the downstream sludge processing line or decrease the mass of sludge transported. Therefore, most of the technologies in this category are used for the optimisation of a sludge processing plant, rather than as standalone options.

Sludge which undergoes only a concentration process (with the exception of thermal drying) is difficult to re-use in New Zealand due to the need to manage exposure to the harmful pathogens still present, and thus often ends up in landfill. The following sections describe each of the concentration technologies including some advantages and disadvantages.

2.2. Thickening

2.2.1. Gravity Thickening

Gravity thickeners come in two forms; static thickeners and dynamic thickeners. Static thickeners are similar to sedimentation tanks albeit with a much steeper floor grading. They are usually applied to the excess sludge from the activated sludge process. The sludge is directed to the centre of the tank, where solids settle according to their respective weight forming a concentrated sludge layer at the bottom of the tank. The thickened sludge is removed from the bottom and liquid is removed over a weir at the top of the tank. The solids layer is maintained by controlled removal which may be continuous at a low rate. The tank is equipped with a slow-moving rake which consolidates the sludge for discharge. This method typically produces a sludge with a solids content of 2-3%.

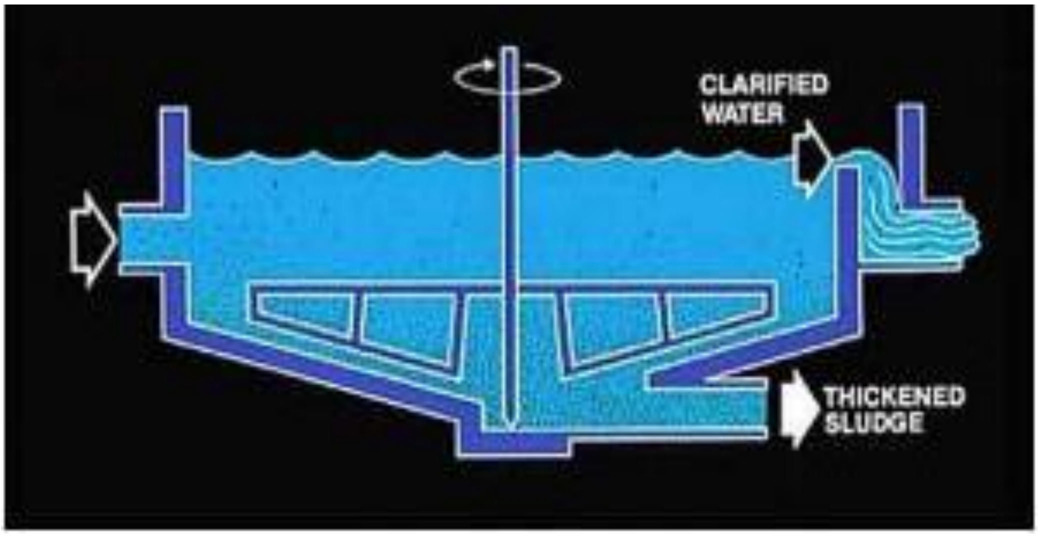

Figure 1: Schematic of a Static Gravity Thickener

2.2.2. Dynamic Thickening

Dynamic thickeners incorporate mechanical means that aid gravity to do its work. Examples are technologies such as dissolved air flotation and gravity belt thickeners.

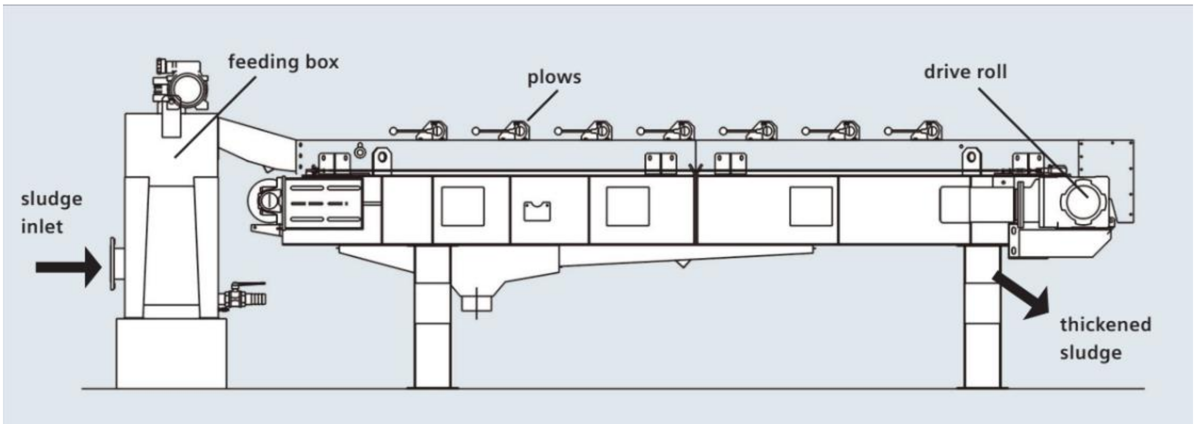

Figure 2 Schematic of a Gravity Belt Thickener

In gravity belt thickening, sludge which has been mixed with a coagulant is applied to a travelling woven belt. Water falls through the gaps in the belt and is collected and returned to treatment, and solids particles are retained on the belt and collected for further treatment. This technology can produce a sludge concentration of between 3% and 7% dry solids, depending on the upstream technologies and coagulant use.

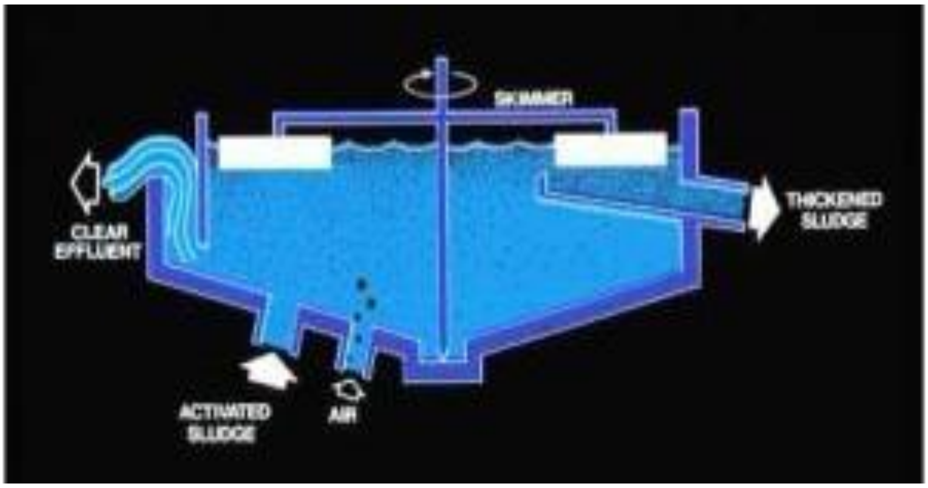

Figure 3: Schematic of a Dissolved Air Flotation Apparatus

Dissolved Air Flotation (DAF) is a gravity separation technology that uses the difference in specific density between air and water to establish a separation. The principle of DAF, as shown in Figure 3, is to inject minute air particles into the system in order to attach to suspended solids, causing the aggregate to have a lower specific gravity than the water. This will enable the solids to rise creating a blanket of thickened sludge which can be skimmed off. DAF is used mostly for secondary sludge. Thickened sludge off a DAF is typically around 3%. Performance of the technology can be improved with the use of chemicals. Note that DAF is not generally suitable for sludges containing primary sludge.

Another example of dynamic thickening is drum thickening, where the sludge is passed through a rotating drum cylinder made of fine mesh, which captures solids and allows water to pass through the mesh. Different zones of the drum can have different size mesh media to augment the capture efficiency as the sludge moves along the length of the cylinder. Polymer is added to the sludge to enhance thickening.

2.3. Dewatering

2.3.1. Belt Filter Press

Belt filter presses use both physical pressure and gravity to drain water from the sludge, resulting in a thicker final product than a gravity-only process. Sludge is typically thickened prior to the belt press, where the influent is pressed between two belts and run through a series of rollers to encourage water to drain away. Typically for organic sludge significant amounts of coagulant are required for optimal performance, though this can vary depending on the type of biological system the sludge has come from, and what upstream sludge treatment technologies are used. Belt presses typically produce a dewatered sludge of between 18 – 25% dry solids.

2.3.2. Centrifugation

Centrifuges are a high-speed technology that uses force from rapid rotation of a cylindrical bowl to separate solids from the wastewater within sludge. Centrifuges spin at very high rates, typically between 1,200 and 2,800 rpm. There are several different types of centrifuges used to dewater and thicken sludge with the solid bowl centrifuge being the most popular. Centrifuging organic sludge typically produces a dewatered product of between 16% - 30% solids.

Figure 4 shows an example of a solid bowl centrifuge used in the wastewater industry.

Figure 4: Example of Solid Bowl Centrifuge.

2.3.3. Electrostatic Belt Filter Press

Electrostatic dewatering is a technology that applies a continuous electric current to a layer of partially dewatered cake through a cathode and anode to increase both the rate and extent of dewatering. These steps increase the rate of filtration at the cathode and decrease blinding of the cloth. Pressure is also required to maintain conductivity. This method of dewatering digested sludge is claimed to produce a cake of 35-39% solids and does not require polymer addition.

2.3.3.1. Heated Filter Press

A regular filter press uses a bank of serial chambers that are lined with filtration cloth. Sludge is pumped in under high pressure. Water is pressed through the cloth while solids stay behind. Once all chambers are full indicated by a threshold pressure, the chambers are opened one by one and the cake drops out into a skip or onto a conveyor. Dryness is typically 30-35% for organic sludge.

Heated filter presses use a combination of hot water and vacuum to both press as well as boil the water out of the sludge. Hot water is circulated through a manifold and cavities in specially designed filter plates. The water pressurises the sludge as to force water out of it and through the filter cloth. When vacuum is used on the filtrate side of the cloth the boiling point of the interstitial water is lowered so the sludge starts to boil, and water vapour is extracted. Dryness over 60% can be achieved.

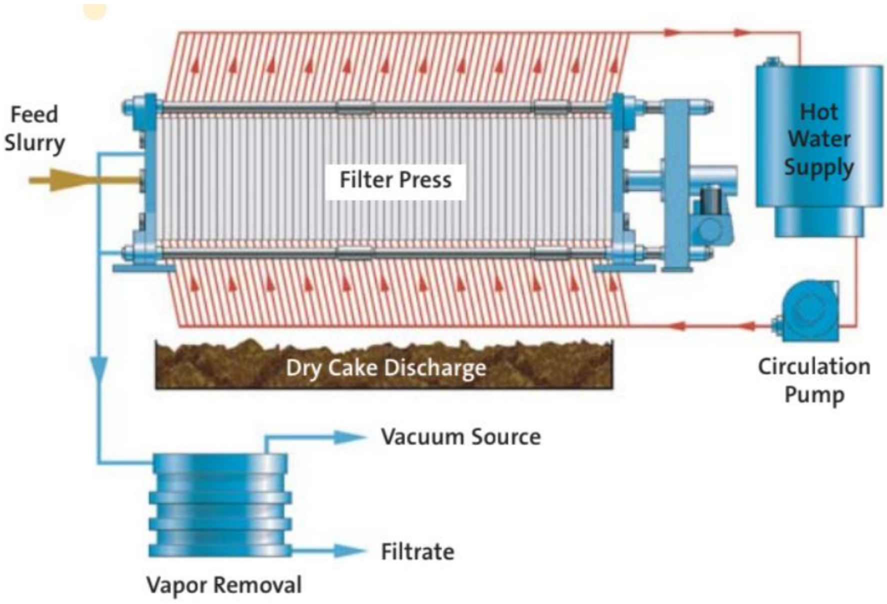

Figure 5: Schematic of a Heated Filter Press

2.3.3.2. Screw Presses

Screw presses utilise a slow-moving drum constructed of fine mesh, through which sludge is passed. Polymer is introduced to the sludge prior to entering the drum, and the sludge is “pressurised” inside the drum by an auger. The pressure inside the drum is usually controlled by a back-pressure plate on the outlet end of the screw press. Screw presses are typically able to produced dewatered sludges in the range of 16 – 22% dry solids, but this is highly dependent on the total volatile solids concentration of the sludge, which can have large bearing on dewaterability.

2.4. Drying

2.4.1.1. Solar drying

A solar dryer uses evaporation from solar radiation to decrease the water content of sludge. Evaporation is enhanced by using a greenhouse-like structure which captures solar energy and increases the ambient air temperature over the Biosolids. A moving rake-type system or mole is used to mix and transport the Biosolids along the length of the solar dryer. The solar drying outcome is highly dependent on the local climate and the quality and moisture content of the feed sludge. Dryness between 30 and 80% have been reported.

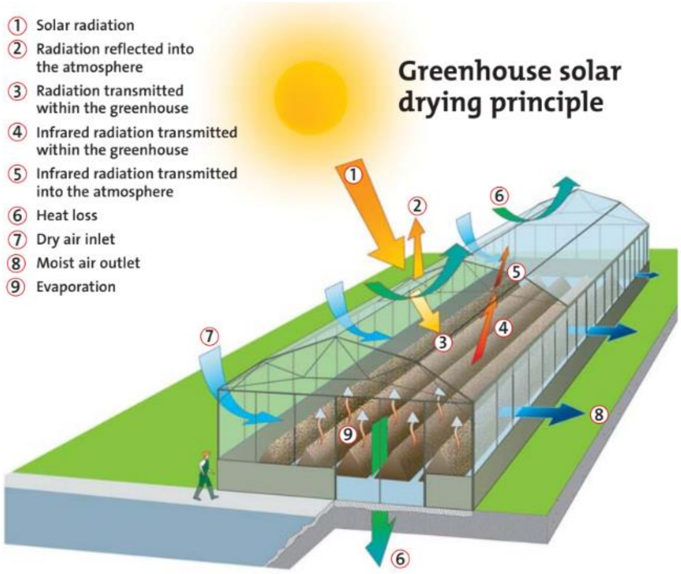

Figure 6: Schematic of a Solar Dryer

2.4.1.2. Thermal Drying

Thermal drying of sludge involves indirectly or directly heating sludge to evaporate moisture. The gaseous water can then diffuse out of the sludge, leaving the solids. The heat travels through the sludge by convection, conduction and radiation. A large number of sub-technologies exist within the category of thermal drying. The dried product may look like pellets or irregular particles depending on the technology selected.

3. Stabilisation Technologies

3.1. Overview

Stabilisation technologies involve the use of microorganisms to digest sludge. Stabilisation is performed to reduce the harmful pathogens present in sludge as well as reducing sludge odours. In New Zealand stabilisation is required for any application of biosolids to land for beneficial use.

Aerobic and anaerobic digestion are the most prominent sludge stabilisation technologies in the wastewater industry. Anaerobic digestion can be further improved by pre-treatment technologies that break up sludge on a cellular level prior to digestion, making the technology more efficient. These pre-treatment technologies will be detailed in Section 4 where hydrolysis technologies are discussed.

3.2. Mesophilic Anaerobic Digestion

Mesophilic anaerobic digestion (MAD) is a common sludge stabilisation technology that involves operating anaerobic digesters at temperatures ranging from 35 °C to 38 °C with a retention time of at least 15 days (with 2% to 4% solids concentration). This conventional type of anaerobic digestion provides an environment in the tank that maintains optimum conditions for microorganisms which convert the organic material into a cell mass and release gaseous product (including methane) as a byproduct. This gas can be utilised as an energy resource and is usually termed ‘Biogas’. Biogas is typically used as fuel source for on-site boilers or cogen units. The waste heat from boilers and cogen units is used to maintain the optimum digester temperature.

Thermophilic anaerobic digestion is a variety on the more common mesophilic pathway. The residence time is shorter, but OPEX is higher due to the higher operating temperature (55°C to 57°C) and extra chemical consumption on the subsequent dewatering step. The two technologies can also be used in series in a process called temperature-phased anaerobic digestion (TPAD) for greater solids destruction and hence gas production. TPAD is most commonly used to augment existing digestion processes when footprint is a constraint or when pathogen reduction is a requirement.

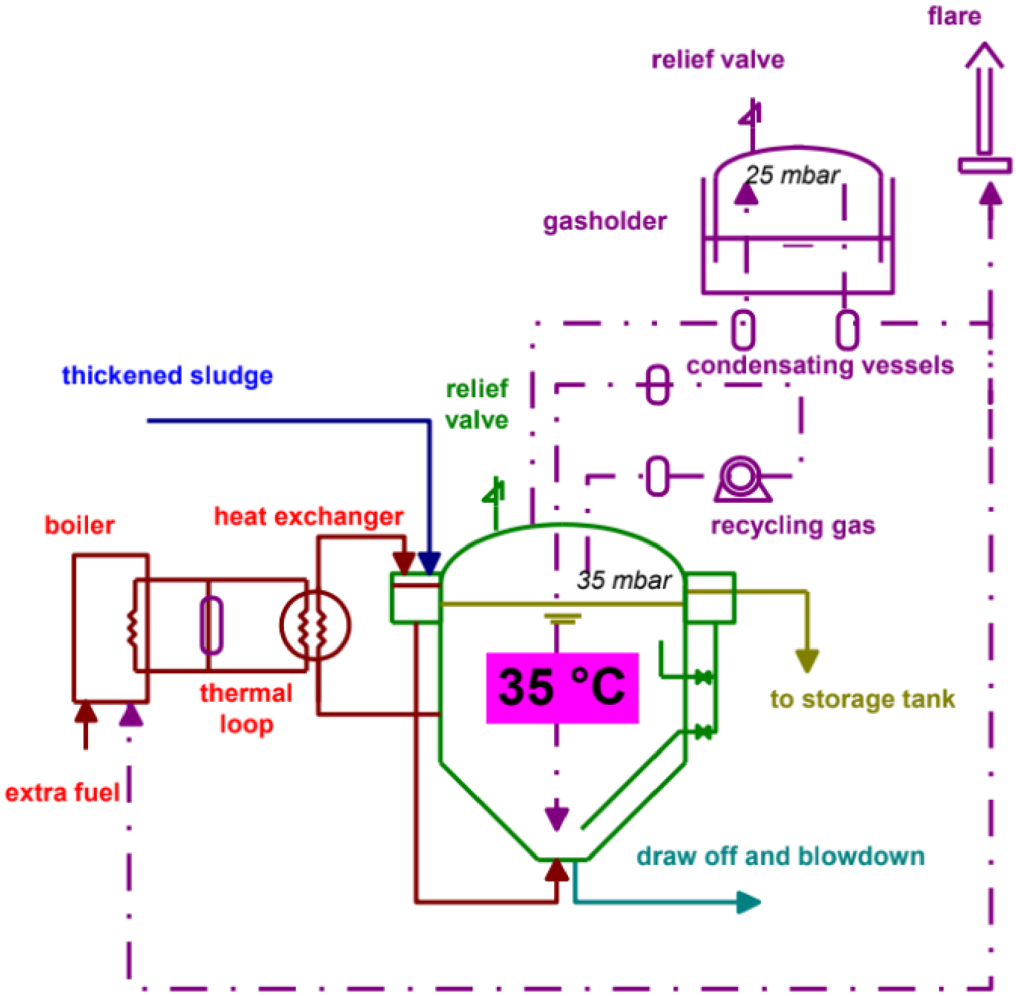

Figure 7: Schematic of a Mesophilic Anaerobic Digester

3.3. Aerobic Digestion

Aerobic digestion is another common method of stabilisation. It involves digestion in completely mixed tanks under aerobic conditions at ambient temperatures for a period of 20 to 45 days (with 1.5%–2% solids concentration). These conditions are optimal for microorganisms which convert organic material into carbon-dioxide. Aerobic conditions are maintained through diffusing either air or high purity oxygen into the digester. Autothermal thermophilic aerobic digestion (ATAD) is a variation on aerobic digestion where the feed sludge is pre-thickened to provide a feed greater than 4% dry solids, and the reactors are insulated to conserve the heat produced from the biological degradation of the organic solids. The aim of these modifications is to maintain thermophilic conditions in the insulated reactors (temperatures in the range of 45 °C - 70 °C) using the heat generated by the biological activity. No supplemental heat is provided (other than the aeration and mixing devices located inside the vessels). Sludge retention time in the digesters is 6-8 days shorter than for the earlier mentioned technologies. ATAD's are used where the digestate is used for fertilisation because retention of nitrogen in the solids is good.

Figure 8: ATAD facility in Nelson, New Zealand

3.4. Composting

Composting is a biological technology that uses naturally occurring microorganisms to convert biodegradable organic matter into a humus-like product, which can be used for agriculture. The composting process destroys pathogens, converts nitrogen from unstable ammonia to stable, organic forms of nitrogen. This technology is controlled by environmental parameters such as moisture content, pH, temperature and aeration. Composting requires a bulking agent to be added to the sludge which enlarges the volume by a factor of 2 – 3 times. Composting can occur in either open fields or in a controlled environment with air-conditioned vessels.

Figure 9: Example of a Traditional Composting Bund

Vermicomposting is a variation on the composting technology which involves digestion and mineralization of organic material. In contrast to composting, it depends on the action of earthworms, and microorganisms. During vermicomposting, the important nutrients such as calcium, nitrogen and phosphorus present in the feed material are converted into forms that are much more soluble and available to plants.

Due to the larger footprint and bulk material handling requirements for both composting and vermicomposting, controlling fugitive odours emissions can be difficult. Consequently, most composting/vermicomposting facilities are positioned away from sensitive receptors.

4. Hydrolysis Technologies

4.1. Overview

The efficiency of anaerobic digestion can be improved by performing sludge hydrolysis prior to anaerobic digestion. This is valid more for secondary sludge (or waste activated sludge) than for Primary Sludge. The reason is the fact that hydrolysis predominantly works on cell material of which there is much in WAS, but not so much in primary sludge. In the case of Wellington's WWTPs the sludges are mixed (Moa Point) or exclusively secondary (Karori). Unless the two Moa Point sludges could be collected and transported separately to the sludge facility there is no possibility to optimise any hydrolysis capacity by utilising it for a side-stream only.

Hydrolysis technologies break-down complex particulate matter into dissolved compounds with low molecular weight. Breakdown of these particulates are usually the rate-limiting step in anaerobic digestion. Hydrolysis pre-treatment improves the sludge dewaterability, improves the yield of biogas during digestion and enables a higher feed concentration into the anaerobic digestion process and a shorter residence time thereby reducing reactor size. Thermal hydrolysis also kills pathogens by sterilisation. Apart from thermal there are three other mechanisms of hydrolysing sludge; also, mechanical, ultrasonic and biological hydrolysis are discussed below.

4.2. Thermal Hydrolysis

Thermal hydrolysis process (THP) is the most common method used in the wastewater industry. It uses high temperature (up to 165 °C) and high pressure (up to 11 bar) to break down cellular structures in the biomass, resulting in a sterilised and more readily digestible sludge.

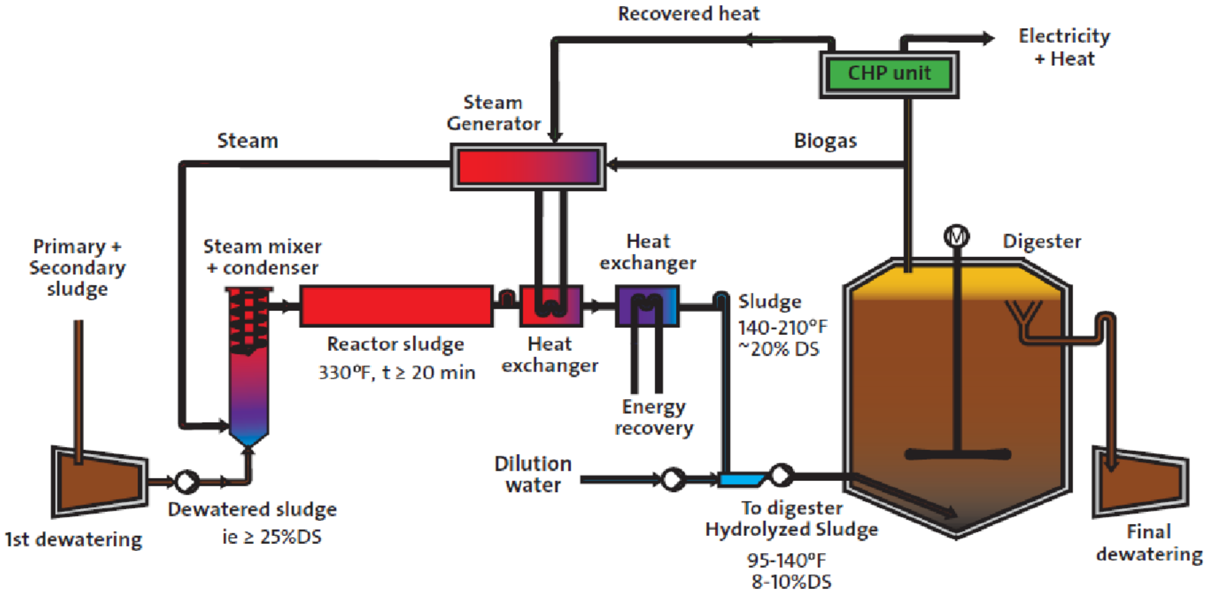

Figure 10: Schematic of a Continuous Thermal Hydrolysis Process

4.3. Mechanical Hydrolysis

Mechanical hydrolysis involves the use of mechanical force to cause cell lysis in sludge. The mechanical forces can be applied in many forms such as, pressure change, shearing or cavitation. It involves significant energy input.

4.4. Ultrasonic Hydrolysis

Ultrasonic hydrolysis uses the application of ultrasonic waves to cause cavitation at a micro scale. This results in high shear forces which break cell walls and release the cellular material, making the sludge more readily digestible. It is demanding on energy and can only be applied on dilute sludge. It has the shortest retention time of all hydrolysis technologies.

4.5. Biological Hydrolysis

Biological hydrolysis of sludge involves the addition of hydrolytic enzymes to sludge prior to anaerobic digestion. These enzymes catalyse the reactions that break down organic molecules like proteins and polysaccharides in the sludge. They also lyse pathogenic cells making them more digestible.

5. Thermal Conversion Technologies

5.1. Overview

Thermal conversion technologies can be performed on sludge once it has been sufficiently dried to reduce its water content and increase the calorific value. As a result, the required dryness for a self-sustaining conversion is dependent on the volatile concentration of the sludge as shown in Figure 11. With a high volatile concentration of sludge, a low dryness level is required to carry out a conversion process.

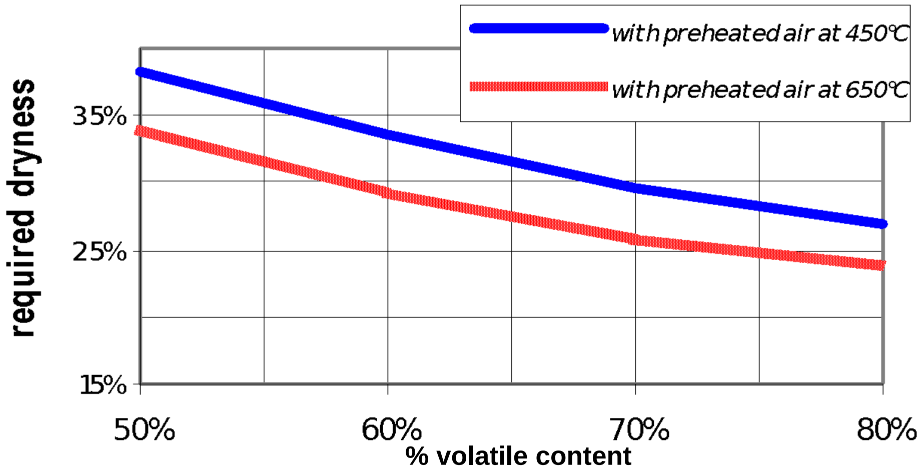

Figure 11: Dryness Requirements for Incineration

Thermal conversion technologies involve exposing sludge to high temperatures in order to chemically convert their structure. In most cases at least one resource is recovered. There will always also be a (waste) product but at a greatly reduced total mass compared to the original sludge. Organic solids in the sludge are either converted into liquids or gases, reducing or almost eliminating the amount of organic material. The high temperatures also kill all micro-organisms in the sludge by sterilising it. There are various technologies in this category, including:

1. Incineration
2. Gasification
3. Pyrolysis
4. Wet air oxidation (WAO)
5. Hydrothermal Liquefaction.

5.2. Incineration

Incineration is the process of combusting sludge in the presence of oxygen. Incineration destroys harmful pathogens and significantly reduces the total mass and volume of the sludge. The high temperature causes the molecules in the sludge to react with oxygen. The products of incineration are ash and waste gases known as flue gas.

The flue gasses created in incineration processes can include compounds which are harmful to either human health or the environment and typically require treatment before discharge to the environment. Treatment typically consists of several steps that involve filtration and chemical dosing. An example of a flue gas treatment set-up is presented in Figure 12.

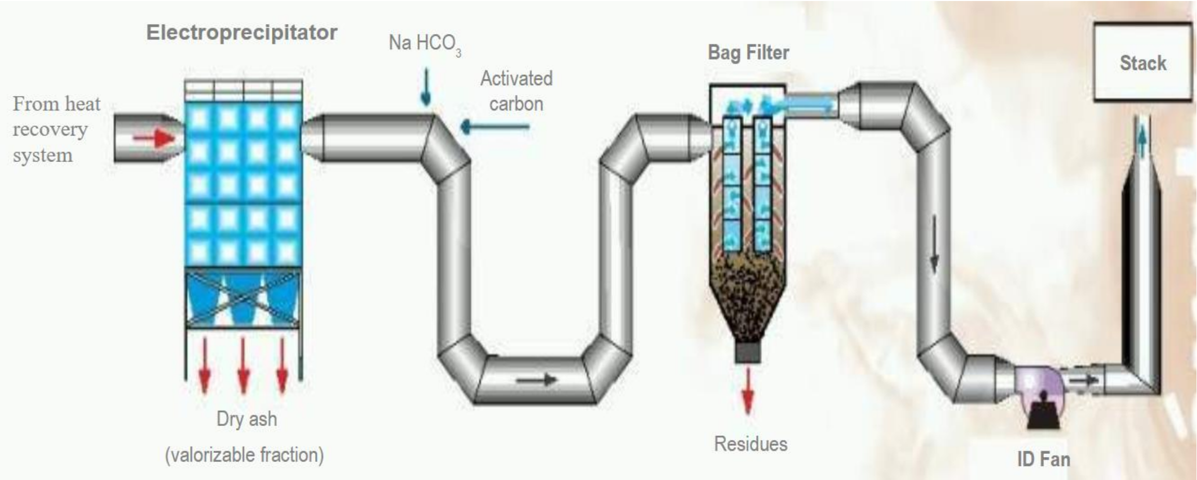

Figure 12: Typical Dry Treatment for Flue Gas

As shown in Figure 12, the sludge will need to be dewatered prior to incineration otherwise a significant amount of external fuel would need to be brought in to evaporate water. The Wellington sludge promises to have a good volatile content which indicates that direct incineration after centrifugation should be possible.

5.3. Gasification

Gasification involves the conversion of organic material into smaller gaseous molecules using high temperatures and a small amount of oxygen being introduced into the system. Gasification mineralises the sludge. The main product of gasification is syngas, which is composed of carbon dioxide (CO2), carbon monoxide (CO), hydrogen (H2), methane (CH4), and nitrogen (N2). A small amount of dry residue similar to ash is also produced. The residue does not hold value.

Sludge will need to be dried prior to gasification.

5.4. Pyrolysis

Pyrolysis is a conversion technology that decomposes sludge by heating it in the absence of oxygen. The technology converts sludge into a high carbon solid called biochar, a mixture of gases known as syngas and a mixture of liquids known as bio-oil. Pyrolysis typically occurs at temperatures higher than 400 °C.

Sludge will need to be dried prior to pyrolysis.

5.5. Wet Air Oxidation

Wet air oxidation (WAO) is the oxidation of sludge in the liquid phase. A feed concentration of 4-8% dry solids is required which means that the sludge must be thickened prior. Often a MAD step precedes the technology to reduce the amount of feed sludge and thereby the capital investment. Either air or oxygen is used to oxidise the organic molecules in sludge and convert them into a clean gaseous effluent consisting of carbon dioxide, water and nitrogen. There is an ammonia rich water stream coming off the process as well as a mineral solid stream which is reusable as construction material. The process occurs under conditions of 54 bar (in case of pure oxygen) and 250 °C.

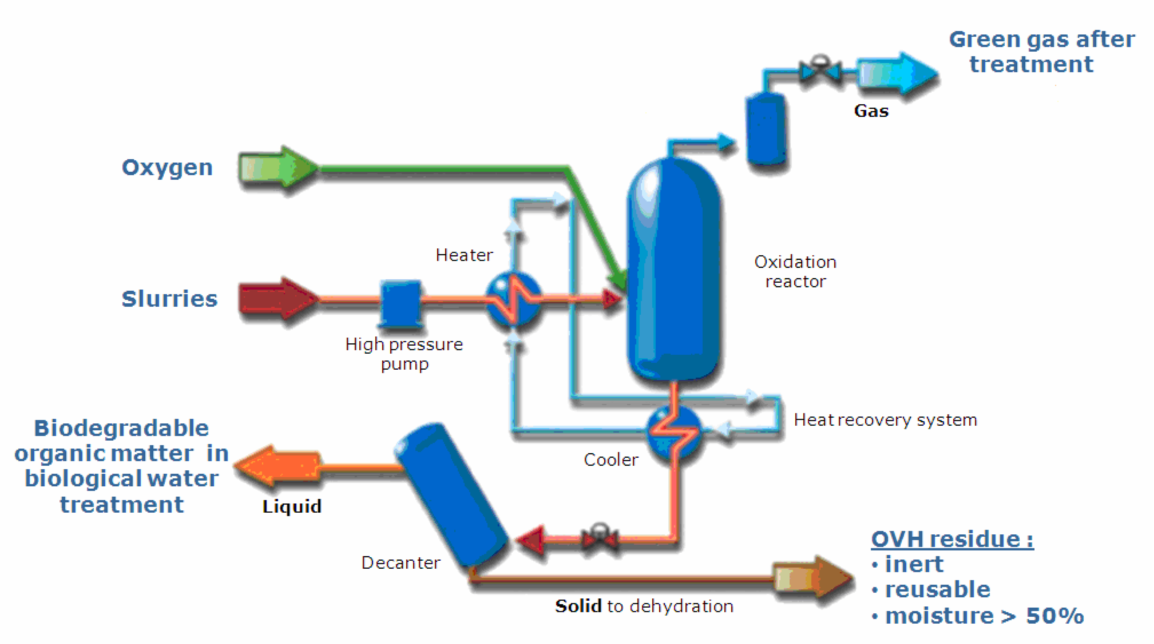

Figure 13: Schematic of the Wet Air Oxidation Process

5.6. Hydrothermal Liquefaction

This technology involves transferring the sludge to a high temperature high pressure reactor which separates the sludge into an organic biocrude phase, aqueous phase and a small number of solids (biochar) and gases. The biocrude is cooled then undergoes biocrude upgrading and the aqueous phase undergoes catalytic hydrothermal gasification. This is a novel technology which entails multiple steps to achieve production of crude oil.