Sewage Sludge – Fluidized Bed Incineration as a Reliable and Proven Treatment Process

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In Europe the arising sewage sludge is treated or reused in different ways. Whereas a quarter of the sludge is used as fertilizer in agriculture, more than one third is thermally treated in power plants (Figure 1). The thermal treatment is performed in mono combustion plants or in conventional power plants (e.g. lignite or hard coal fired power plants) in form of co-firing. Here, co-firing plays a considerable role. In Germany, 33.3 % of the sewage sludge is used for co-firing in conventional power plants, whereas 27.7 % of the sewage sludge is incinerated in mono combustion plants [8].

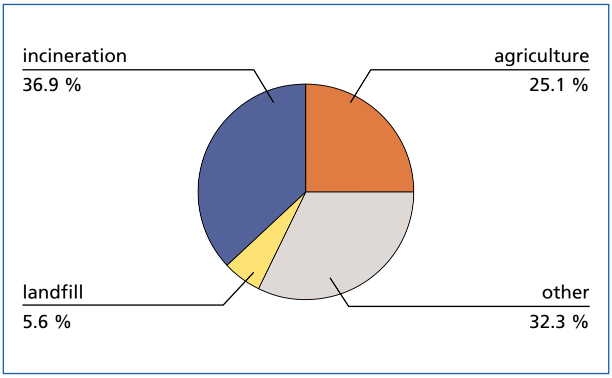

Figure 1:

Disposal of sewage sludge (dry matter) in Europe in 2014

Source: Eurostat, Sewage sludge production and disposal, last update 09.04.2018

Furthermore, the thermal treatment of sewage sludge is a widely used technique. In the most European countries sewage sludge incineration is applied. For example, in the Netherlands the complete produced sewage sludge is disposed by incineration (Figure 2).

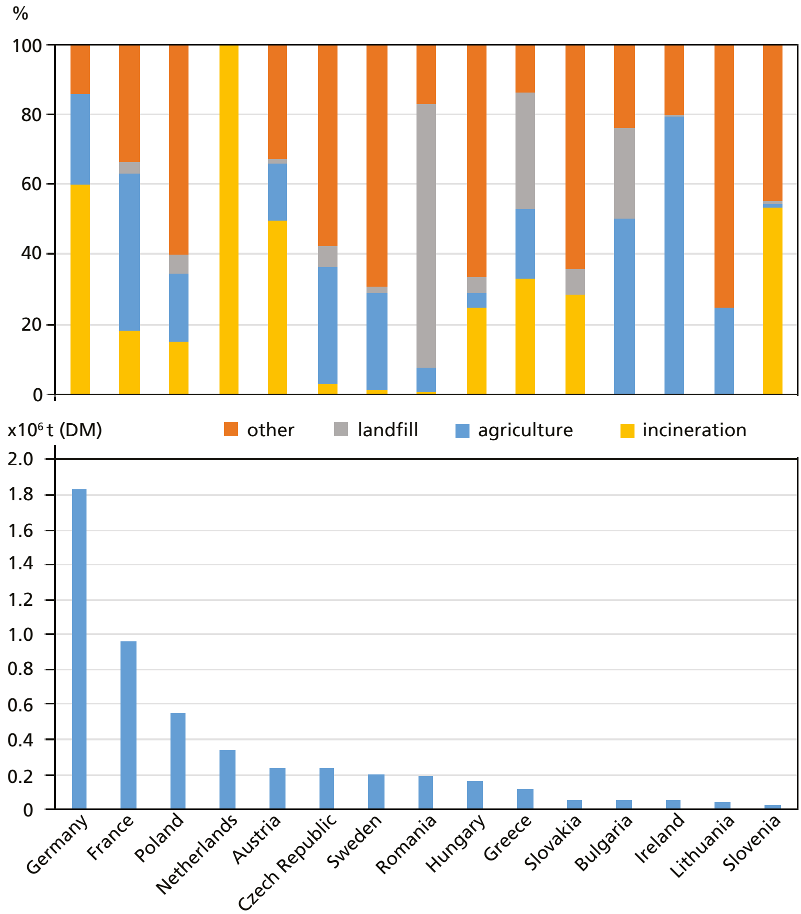

Figure 2: Production and disposal of sewage sludge (dry matter) in individual European countries in 2014

Source: Eurostat, Sewage sludge production and disposal, last update 09.04.2018

With upcoming regulations, not only on individual national level, but also on European level (e.g. European Directive 2008/98/EC), sewage sludge is a waste material which has to be safely disposed. The use of raw sewage sludge as fertiliser in agriculture will be reduced because of inadmissible contents of heavy metals and organic pollutants. Furthermore, phosphor has to be recovered as an important nutrient. This excludes the future co-firing in conventional power plants. Co-firing mixes the incinerated sludge with incombustible residues from the main firing and leads to a sewage sludge ash that is unusable for phosphor recycling. Consequently, the incineration in mono-combustion plants is a well-suited technique to ensure a safe and reliable disposal of sewage sludge. A phosphor-recovery from the sewage sludge ash is possible and in diverse methods (e.g. MEPHREC or LeachPhos) successfully tested, whereas an economic application of phosphor (P) recycling is still not possible [7]. Therefore, the incinerated sewage sludge is intended for a temporary depositing and a later P-recovery from the remaining ash. The companies Raschka and Standardkessel Baumgarte offer turnkey plants for thermal sewage sludge treatment. Through years of experience in fluidized bed technology, sewage sludge treatment and waste incineration the companies form a strong cooperation to provide solutions for future requirements.

1. Technical description of fluidized bed incineration plant

Fluidized bed furnaces have been well established as a reliable treatment process for mono-combustion of sewage sludge. In 2016 a total of 22 fluidized bed furnaces for centralised mono-combustion were installed in Germany. Other technologies like multiple-hearth, multiple-deck fluidized bed or grate firing play a minor role. Here, in sum seven units for centralised mono-combustion are installed in Germany [6].

In Figure 3 an overall sketch of a fluidized bed incineration plant with the main components:

- sludge reception, storage, mixing and feeding system is given,
- foreign body removal,
- sludge drying,
- sludge incineration with fluidized bed incinerator,
- waste heat recovery boiler,
- de-dusting and ash collection for future P-recovery, and
- flue gas cleaning.

The individual components are discussed below.

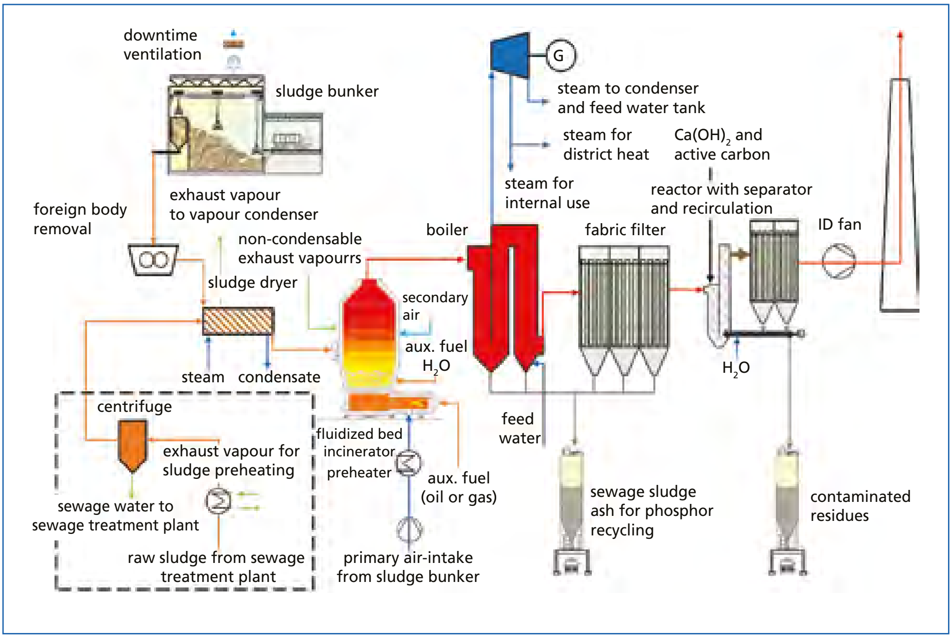

Figure 3: Sketch of mono-combustion plant

1.1. Fuel transportation

The fuel transportation is divided into following units:

- sludge reception hall and sludge bunker,
- crane system,
- sludge feeding buffer,
- foreign body screening and removal device, and
- sludge drying.

Dewatered sewage sludge to a centralised plant is delivered by lorries. The received quantities are recorded by a weighting system located at the access road. For installations on a sewage treatment plant site, the sewage sludge can be conveyed from the dewatering station via pumps, trough chain conveyors or screw conveyors into the fuel bunker of the mono-combustion plant. In general the sludge bunker is divided into a reception bunker in an enclosed sludge unloading hall and a storage bunker. The storage bunker is usually designed for a capacity of 5 to 7 days plant operation. As an option, systems for raw sludge pre-treatment like sludge preheater and centrifuges for dewatering can be added to the treatment process at sewage treatment plants.

The sludge is conveyed from the sludge bunker to the sludge dryer and subsequently to the fluidized bed furnace by a fuel transporting system. For this, the sludge is loaded on a feeding buffer by a crane. The feeding buffer is located in the bunker hall and is equipped with a sliding frame and discharge screw(s). The feeding buffer is the interface between bunker hall and incinerator/boiler house, whereas the fuel transporting system in the incineration/boiler house is completely enclosed and separated from the sludge bunker hall. The entire sludge transportation system includes crane system, feed buffer, foreign body screening, removal device and sludge drying. This part is usually made redundant (2 x 70–100 %) for a maximum plant availability. For the transportation system, common conveyor systems are used like screw conveyors, through chain conveyors or pumps.

1.2. Sewage sludge drying

For a self-sustaining combustion in a fluidized bed furnace a minimum lower heating value of approximately 4 MJ/kg is needed under the assumption of ambient combustion air temperature. Mechanically dewatered sewage sludge with an average dry matter (DM) in the range from 24 to 26 % deliver much lower heating values. In order to achieve the required heating value the mechanically dewatered sludge has to be dewatered further by means of sludge driers. A certain part of the sludge water is evaporated in the steam heated driers in order to obtain a DM-content of 38 to 42 % and by this a sufficient heating value of the sludge. Alternatively, the mechanically dewatered sludge can be mixed with dried sludge. Additionally the combustion air can be pre-heated to guarantee an equilibrated heat balance and to maintain the regularized minimum combustion temperature (in case of lower heating values).

For mixing with dried sewage sludge, additional storage silos and (pneumatic) transportation systems have to be installed. For storage and handling systems of dried sewage sludge (> 85 % DM) ATEX-regulations have to be considered. Dried sewage sludge exhibit lower heating values about 11 to 13 MJ/kg, which is comparable to caloric fuels like lignite.

For partial drying at the plant site, several technologies are available. In German centralised mono-combustion plants, almost exclusively disc dryers and thin film dryers are used [3]. Further technologies are among others drum dryers, fluidized bed dryers or solar dryers, which are mainly used for decentralised drying units [5]. Disc dryers and thin film dryers are indirectly heated contact dryers and can be operated with steam at common stream pressures between 5 to 10 bar. Thin film dryers are equipped with a double skinned stator which is heated with steam. The inner rotor applies a thin layer of sludge by paddles on the inner skin of the stator. The paddles also ensure a forward feed from the inlet to the outlet in axial direction. Disc dryers are equipped with a hollow rotor on which several hollow discs are welded. The rotor and discs are heated with steam. On the outer diameter of the discs paddles are mounted to ensure a forward feed from the inlet to the outlet. Disc dryers contain a significant higher mass of sludge than thin film dryers [1].

The evaporated sludge water (vapours) resulting from the drying process is polluted. The pollution depends on the pre-treatment at the sewage treatment plants and on the temperature during the drying process. With increasing drying temperature increased pollution is to be expected. The pollution occurs because of the ammonia in the sludge and due to the release of volatile organic material. Approximate values are given in [6], for ammonium about 2,500 mg/l and for organic pollutants about 7,000 mg/l (chemical oxygen demand). The exhaust vapours are normally condensed for subsequent disposal. The disposal of the waste water depends on the regulatory at the plant site and may require an additional water purification. The released heat during the condensation can be used for heating purposes, e.g. pre-heating of the sludge before the mechanical dewatering, combustion air pre-heating or district heating. A flow of non-condensable exhaust vapours is normally injected into the furnace.

1.3. Fluidized bed incinerator

Fluidized bed incinerators (FBI) are the worldwide most installed systems for mono-combustion of sewage sludge and are the heart of each plant. The combustion in fluidized bed systems show excellent characteristics regarding heat and material transmission at homogeneous temperatures. The fuel is perfectly mixed with the bed material (silica sand) by the fluidization with combustion air. A safe burnout is guaranteed without hot spots occurring in the fluidized bed. The fluidized bed combustion is thus particularly suitable for low caloric and pasty waste materials such as sewage sludge.

The fluidized bed incinerator is a steel casing with an inner refractory lining and an outer thermal insulation. The main sections are the windbox with the heating-up combustion chamber, the nozzle bottom, the fluidized bed area, the cylindrical freeboard and the upper part with the flue gas outlet.

The nozzle bottom is a special ceramic sandwich construction equipped with air nozzles made of heat resistant cast steel. The combustion air is blown through the nozzles upwards into the sand layer upon the nozzle bottom. The air fluidizes the sand evenly and thus the sand-layer expands to the fluidized bed being ≈1.5 m high.

At plant start-up the combustion air is heated by means of the combustion chamber burner. The hot air heats the fluidized sand and the entire furnace up to a temperature (min. 850 °C) that is higher than the ignition temperature of the sludge. The heating up is supported by special fuel injection lances mounted in the fluidized bed area (see Figure 4). Then the sludge is conveyed evenly and exactly dosed to the sludge spreader. The spreader evenly distributes the sludge across the fluidized bed. In the furnace the moisture of the sludge is evaporated and super-heated, the organic substance combusts and the inorganic dry substance glows out. As soon as stable incineration conditions are achieved, the start-up burner and the lances are switched off and the auto-thermal incineration process continues. The large-dimensioned freeboard area above the fluidized bed area serves as post-combustion zone with long retention time of the flue gas and the fly ash particles. A perfect combustion is achieved this way. The temperature in the upper area of the furnace can be controlled by the injection of secondary air. Thus the incineration process is optimised. The secondary air lances are arranged tangentially to the circumference of the incinerator. This effects a rotation of the flue gas in the furnace and a perfect mixing of flue gas.

The content of the fluidized bed may increase or decrease during operation depending on the condition of the sludge (sand content) or operation conditions. A surplus of bed material can be discharged discontinuously during the operation by the bed material discharge device which is connected to the fluidized bed incinerator. In case of a decrease of bed material, quartz sand is fed into the incinerator.

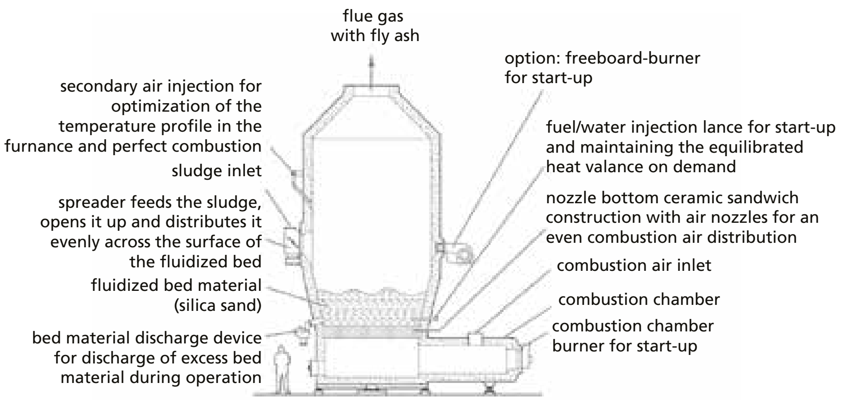

Figure 4: Basic principle of a fluidized bed incinerator

1.4. Possibilities for energy usage

The flue gas and fly ashes leave the FBI at a temperature of about 870 to 950 °C and are led into a waste heat recovery system (for example steam boiler). For steam boilers natural-circulation boilers are used with common steam parameters up to 420 °C and 65 bar. The generated steam can be directly used for process steam or can be used for district heating and/or power generation. The respective usage of the energy depends on the site conditions and has to be individually customised. Therefore, following aspects have to be considered:

- access to a district heating system with a relevant heat requirement,
- access to an industrial location with a relevant steam requirement, and
- power generation only for plant consumption or additional grid feed.

Here, the pre-treatment of the sewage sludge plays an essential role. The partial drying of the sludge requires a considerable amount of energy which cannot be recovered without losses.

1.5. Flue gas treatment

Inside the boiler, the flue gas cools down to 180 to 200 °C and has to pass the flue gas cleaning before it is emitted to the environment. Sewage sludge incineration is categorised as waste incineration and has to meet the respective national emission regulations. Therefore, the following flue gas cleaning processes are applied:

- dedusting,
- desulphurisation, and
- separation of heavy metals, dioxins and furans.

The Raschka fluidized bed incinerators are characterised by very low NO_X emissions due to the low and uniform combustion temperature. In most cases no SNCR is required to comply with the respective national NO_X limits.

The ash of the sewage sludge is discharged from the FBI by the flue gas flow and results in a high fly ash content. The flue gas and ash pass through the boiler and are led to the ash removal unit, where the sewage sludge ash is separated from the flue gas and conveyed into silos. From here, the ash can be landfilled for a later P-recovery. For the ash precipitation, fabric filters or electrostatic precipitators (ESP) are used. By fabric filters a higher separation of ash can be achieved (> 99 % separation efficiency) compared to ESPs (96 to 98 % separation efficiency). Hereby, a larger amount of sewage sludge ash can be recovered for P-recovery, and a smaller amount of contaminated residues accrue in the downstream located sorption filters. Further advantages result from a smaller installation size and lower investment and operation costs compared to ESPs.

For the following flue gas treatment different wet, dry or combined technologies for desulphurisation are used. For wet technologies, scrubbers based on calcium hydroxide or sodium hydroxide are applied. Furthermore, heavy metals and organic pollutants are separated by adding active carbon or activated coke [2]. A well-suited method for flue gas treatment is the conditioned dry sorption based on calcium hydrate. The unit mainly consists of a rector and a fabric filter. The flue gas is led into the reactor and is mixed with calcium hydroxide for desulphurization and active carbon for separation of heavy metals, dioxins and furans. The contaminated additives are separated in a sorption filter. A part of the separated additives is humidified and led back into the reactor. The rest of the contaminated additives is conveyed into silos for disposal. By the conditioned dry sorption a flue gas treatment with low technical effort can be realised, without quench, scrubber or heat transfer systems. In addition, the disposal of waste water after scrubbers or additional aggregates for wastewater treatment are eliminated.

Another option for desulphurisation is a direct desulphurisation by calcium oxide in the FBI. The calcium oxide is introduced chemically bound as calcium carbonate into the furnace, which calcines to calcium oxide and reacts with sulphur dioxide or sulphur trioxide to calcium sulphate. In mono-combustion plants desulphurisation efficiencies about 70 to 75 % can be achieved [4]. As a result, an equivalent lower consumption of calcium hydroxide is required in the subsequent flue gas treatment, and a smaller quantity of contaminated residues accrue in the sorption filters. Calcium sulphate and excess calcium oxide accumulate in the sewage sludge ash, which must be taken into account for later P-recovery.

2. Conclusion

By the end of the agricultural use of sewage sludge, as well as the requirements for a future P-recovery, the disposal of sewage sludge by thermal treatment will increase in the future. Here, the combustion in stationary fluidized bed incinerators is a reliable, future-proof technology for sewage sludge treatment. The concept presented here is based on proven technologies that ensure a safe plant operation with a high availability.

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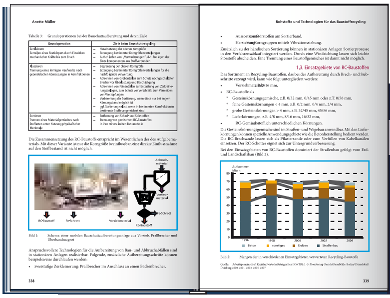

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