

# Upgrading Aspects of Standard Sewage Sludge Mono-Incineration Plants

Dieter Müller and Ludwig Herrmann

1.	Incineration of Manure as Substitute of Sewage Sludge .....	663
1.1.	Purpose of Investigations referring Pig Manure .....	664
1.2.	Samples from Manure Pre-treatment .....	664
1.3.	Analysis of the considered Manure .....	665
1.4.	Sensitivity of Manure Add-on in the Sewage Sludge Incineration .....	666
1.5.	Further Aspects of Viability .....	667
2.	Improved Usage of Waste Heat by New High Pressure Steam System .....	668
2.1.	Technical Concept .....	668
2.2.	Challenges of Realisation .....	668
2.3.	Benefit of the Plant Modification .....	669
3.	Phosphate Recovery .....	669
4.	Conclusion and Outlook .....	672
5.	References .....	672

In the past few decades the disposal of sewage sludge has been subject to the development and testing of various treatment strategies. Beyond the direct exploitation of sewage sludge for agriculture use – which is more and more under critical discussion due to hygienic critical, endocrine and persistent substances endangering the subterranean water resources – the thermal treatment of sludge proved to be a feasible and sustainable solution [1, 2]. At the present time the incineration of sewage sludge became widely accepted against process alternatives like e.g. pyrolysis, gasification, and many more. The incineration of sludge can be executed in form of

- Mono sewage sludge incineration plants,
- Co-incineration of sewage sludge in
  - \* waste incineration plants,
  - \* coal power plants,
  - \* cement kilns.

The co-incineration of sewage sludge has always an impact on the initial *host* thermal process, which has been optimized for another fuel and other purposes. Another subject to be considered referring co-incineration is the environmental impact caused by the discharge of pollutants, which will be brought into the system by sewage sludge. By incorporation into

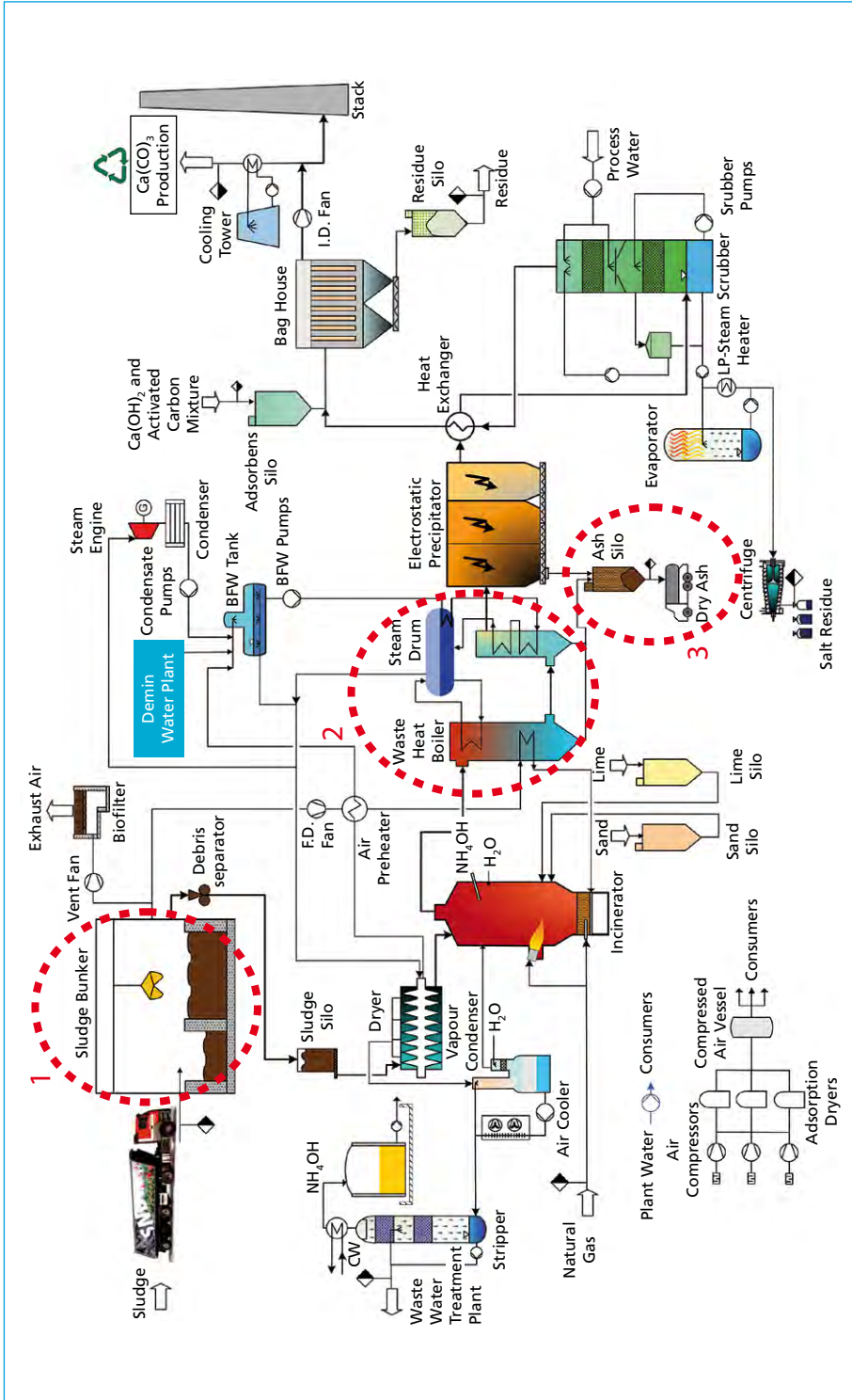


Figure 1: Simplified process flow diagram of a typical mono sludge incineration plant

a process which has a significant bigger throughput and is limited by other regulations and legislation (e.g. coal fired power plants) the emitted flue gas characteristics will keep the legal emission limits. This *dilution effect* cannot hide the fact that the real absolute load of toxic substances (e.g. mercury) will charge the local area much more than emissions from mono sewage sludge incineration plants which have dedicated fluegas treatment systems.

Mono sewage sludge incineration is a proven, environmentally friendly method of utilizing sewage sludge from municipal works. The implemented system has been designed to the legal demands and economic requisitions being valid and commonly accepted at the period of design and approval by Authorities. These basic layout principles are subject to the constant change of sludge characteristic as well as to the adaptations of laws and regulations. In this context we can recognize that e.g. the load of heavy metals in sewage sludge varies over the past decade in Western Europe [3, 4]. Another trend for sewage sludge might be the decrease of quantities as forecast for the next 10 years. Due to improve operation and maintenance some operators of sludge incineration plants have nowadays spare capacity in their facilities and searching for economic ways to utilize this.

Due to the fact that many mono sewage sludge incineration plants have been built in the nineties of the last century it is a reasonable task to listen to the concerns and problems of operation companies how they can modify or upgrade their plants in our days in order to be prepared for the challenges of the future. In this paper 3 different aspects shall be exemplarily presented to show potential improvements of standard mono sludge incinerations plants, as they could be

- Substitute for sewage sludge – manure co-incineration,
- Improvement of waste heat recovery systems – incorporation of HP boiler system,
- Change of a byproduct into a valuable product – phosphorus recycling.

Outotec GmbH as engineering company is not only interested in building new plants with the best available technology, but also in support and solution finding processes according the individual requests of operating companies to adapt their facilities to the market.

As basis for the following considerations we will refer to a standard mono sludge incineration like shown in the picture below (Figure 1). This plant collects sludge from different sources where sewage sludge will be pretreated in form of de-watering. The sludge will be partly dried before feeding to the incineration in order to enable a self-sustaining incineration without any additional fuel. After the combustion the flue gases will be cooled down by a waste heat recovery system. The subsequent flue gas cleaning always starts with a fly ash separation (here ESP) and a system of scrubbers/reactors for the optimized pollutant removal (can be modified to the local boundary limits).

In this simplified process flow diagram the above mentioned 3 modification aspects are marked by red dashed circles for a better orientation.

### 1. Incineration of Manure as Substitute of Sewage Sludge

Prognoses of the sludge production within an exemplary mono sludge incineration plant in the Netherlands predict a possible reduction of sewage sludge. Reasons for this effect are the decline in population and decrease of industrial production as well as of digester plants.

The spare capacity and the reduced availability of feed material would cause a loss of capacity utilisation, which would result in a worse cost-effectiveness and profitability. To avoid any

negative effect on the productivity of the plant a substitution of sewage sludge shall help to keep the profitability. Such a provision of alternative feed materials must have no negative effect on the operation of the plant.

### 1.1. Purpose of Investigations referring Pig Manure

A study by Outotec GmbH investigated if manure is a possible substitute for sludge. Such alternative material should be in respect of quality similar or better compared to the normally used sewage sludge. Furthermore should this material be available in a sufficient quantity and for long-term delivery [5].

Preliminary investigations have shown that animal excrement might be a possible substitute due to

- The extensive industrial meat production produces a significant quantity of manure,
- Manure is a long-term difficulty referring waste disposal and needs a solution,
- The origin of manure is similar to sewage sludge - their characteristics might be similar as well,
- From possible livestock breeding (chicken, cattle, pig, and other) it was decided to examine more closely the pig manure as alternative feed material.

Following these preliminary considerations the study checked if the pig manure is able to substitute sewage sludge in the incineration process without any significant negative effect on the process parameters and the process equipment like e.g. performance data, availability, maintenance, wear and tear (abrasive, chemical), or similar.

### 1.2. Samples from Manure Pre-treatment

The continuous production of pig manure and its discontinuous utilization possibility in agriculture creates a basic problem of storage and further use. Subject to further investigation have been 2 different locations in the Netherlands (anonymized sources later described as type A or B [6]) where pig manure is pre-treated in form of a complex dewatering.



Figure 2:

Samples taken directly from sieve belt filter press

In these facilities pig manure will be pre-treated in mixing tanks under add-on of flocculants. This sludge together with the skimming products of a flotation unit will be mechanically dewatered with multiple stages. The final stage of the considered facilities has been a sieve belt filter press.

Depending on the specific manure treatment system differences in process stages (like e.g. use of polymer) might have significant effects on the final product characteristics. The dewatered sludge in such treatment units has a dry substance content of approx. 28 – 30 %. This material will be kept in an intermediate storage (see also Figure 3) until final usage or disposal. For the following investigations samples have been taken directly after the sieve belt filter press (see also Figure 2; red arrow marks location of sample taking) and from the final storage bulks.

### 1.3. Analysis of the considered Manure

At each of the two considered production facilities 2 samples have been taken and afterwards analysed in a German laboratory. In general both sources show very similar characteristics – e.g. density, water content, ash content and total organics have almost been the same values.



Figure 3: Disposal site from where it will be transported to final disposal

As consequence we have more or less the same values for net calorific value as important indication for the behaviour in the incineration facility. More differences are observable for the analysis of the main components. The *A* type product has a higher level of Chlorine (~ 18 %), Sulphur (~ 60 %)(due to  $\text{FeSO}_4$  addition to manure treatment at *A*), Ni (~ 35 %) and K (~ 13 %) compared to the samples of *B*. On the other side the products of *B* have a higher content of F (~ 16 %), P (~ 11 %), Arsenic (~ 28 %), Cd (~ 15 %) and Cr (~ 15 %).

Referring their impact onto the incineration products, the manure samples show most values below the data of the reference sludge. Therefore the above mentioned variations can be considered as not significant and will add no additional effect on the pure sewage sludge feed, except for the high figures of Cl, F and S. The data for S is double of the sewage sludge content and the halogens Cl and F are even 3 times higher than the well known sewage sludge.

The only significant deviation of ash components to be mentioned here is the  $\text{Fe}_2\text{O}_3$  content of the ash. The *B* type has a content of 2.1 %, while the *A* type shows an almost 6 times higher level of 11.9 % caused by dosing  $\text{FeSO}_4$  before the dewatering process. This might have an effect on the processibility of the fly ash for phosphor recycling solutions.

Another critical data is the sintering temperature of 880 °C for the A product. This temperature level is very close to the operation temperature in the incinerator. This might be the start of agglomeration effects in the sand bed of the incinerator which could cause performance difficulties and a higher effort for the bed material treatment.

The phosphorus content in form of  $P_2O_5$  shows with 22 – 24 wt-% a relatively high value (common sewage might have 13 – 19 wt-%), which makes the fly ashes useful for further recycling procedures. Physical properties like flowability or adhesiveness will be not critical the granular particles of the product. The material has an almost dry surface and no difficulties referring transport or piling storage (see also Figure 3) is expected.

#### 1.4. Sensitivity of Manure Add-on in the Sewage Sludge Incineration

On basis of the manure analyses and the well-known characteristics of the sewage sludge a process calculation of various operation modes shall show the sensitivity of the feed to the main process and by-products. For this purpose a theoretical mixture of sludge and manure from 0 % up to 100 % is fed to a simulation program in order to estimate numerically its effect to the system.

The first operation mode describes the actual status of the pure sludge incineration. These values have been proven as harmless in day-to-day operations over a long period. The other 4 considered cases shall show which influence of co-incineration certain quantities of manure might have.

The following operation modes show an increasing input of Dry Substance (DS) into the dryer while keeping the throughput constant. The consequence would be a higher level of DS in the feed to the incinerator and subsequently an increase of temperature within the combustor. Due to the fact that we are already running the incineration at more than 900 °C we avoid a significant elevation of temperature by reduction of water evaporation in the dryer. This means we have to reduce the steam consumption in such a way that the output of sludge will keep the DS content below 36 %. Nevertheless the incineration temperature will increase due to the fact that the calorific value of the manure is higher compared to the sludge. According to this effect we will need for the complete thermal treatment of the feed more combustion air and will produce more flue gas respectively.

Table 1: Comparison of Calculation Results for 5 different operation Modes

Parameter	Unit	Operation Mode				
		100 % Sludge 0 % Manure	85 % Sludge 15 % Manure	70 % Sludge 30 % Manure	50 % Sludge 50 % Manure	0 % Sludge 100 % Manure
DS Content Dryer Inlet	%	23.4	24.0	24.7	25.6	28.3
DS Content Dryer Outlet	%	36.0	35.5	35.0	34.5	33.0
Combustion Air	Nm <sup>3</sup> /h	16,000	16,400	16,900	17,500	19,150
Temperature Incinerator Outlet	°C	910	913	911	912	910
Flue Gas Quantity	Nm <sup>3</sup> /h	24,200	24,700	25,600	26,400	28,600
SO <sub>2</sub> Concentration	mg/Nm <sup>3</sup>	1,030	1,060	1,100	1,140	1,230
HCl Concentration	mg/Nm <sup>3</sup>	200	280	350	430	620
Steam Production	kg/h	10,600	10,850	10,950	11,250	11,850
Steam Surplus	kg/h	3,950	4,750	5,400	6,400	8,850

The above described behavior will have an impact on the steam balance. The steam production in the boiler will increase due to the higher energy content of the feed mixture. On the other side the consumption in the dryer have to be reduced in order to control the temperature in the incinerator. By this we will get an additional surplus of steam compared to the initial or actual operation mode.

This energy benefit is an additional advantage of co-incineration of manure if the energy can be commercially used. This might be possible e.g. for utilization of waste heat in a district heating system internally or for export (low pressure steam provision) – alternatively for production of electricity (high pressure steam).

The concentration of HCl and SO<sub>2</sub> in the flue gas will be increased due to the higher S, Cl and F concentration in the manure. The existing flue gas treatment plant should be able to handle this. In general we expect higher consumption on chemicals (CaCO<sub>3</sub>, NaOH, etc.) and larger amount of ash and residues as result of shifting of the sludge/manure ratio to more manure.

### 1.5. Further Aspects of Viability

The viability of adding manure into the sludge feed touches various subjects in respect of proven normal operation conditions which have to be critically re-considered for this variation, like e.g.

- **Transport Behaviour:** The taken samples show a rather dry a non-sticky surface. Such quality let us expect a less complicated use when transported by crane or with screw conveyors than with the basic sludge feed. No critical sticky phase in dryers for manure observed.
- **Agglomeration/Blockages:** The analysis of the manure has shown a rather low sintering temperature. This might have the consequence of agglomeration effects in the sand bed. In such a case the sand bed might be treated more intensively by discharging, sieving and re-feeding.
- **Corrosion:** The significant high content of Cl and F (3 times higher than in sewage sludge) should be subject for additional considerations.
- **Abrasion:** Abrasion we only expect referring the sand content in the feed. The laboratory tests show lower data for the manure than measured for the sludge in the past.
- **Effect on Flue Gas Treatment:** Characteristics of manure similar to sludge. The actual flue gas cleaning system will be sufficient, but the consumption figures will vary according to the loads.
- **Effect on Emissions:** The emissions are limited by law and should be kept under all circumstances. Due to the similar characteristics of manure compared to sludge it is not very likely that we will endanger the legal limits at the stack.
- **Effect on future Phosphor Recycling:** The production of fertilizer on basis of the incineration ash according to the AshDec process is not restrained. The higher P<sub>2</sub>O<sub>5</sub> concentrations and even more so significantly higher K<sub>2</sub>O concentrations in the manure ash would improve economic viability.

## 2. Improved Usage of Waste Heat by New High Pressure Steam System

Some mono incineration plants operate with low pressure boiler or thermal oil systems for utilization of the heat coming from the incineration process. Due to better dewatering systems the dry substance content of the sludge is increasing and resulting in a surplus of energy which could be used for power generation. To do this the boiler system has to be replaced by a high pressure boiler and a turbine.

### 2.1. Technical Concept

The subject of a detailed conceptual study was an operating plant in Western Europe. In this plant the waste heat is actually used by low pressure boiler producing steam of 10.0 bar and 162.5 °C. This steam will primarily be used for drying of the sewage sludge before being fed to the incinerators. The surplus of the steam is forwarded to a steam motor unit in order to generate electricity. Additional surplus of energy is cooled down in cooling tower.

In order to optimize the boiler upgrade a parallel investigation of the incinerators should identify the quantity of unused spare thermal capacity and the possible increase of sludge throughput. By running the incinerator at its actual design limit it might be difficult to ensure the legal requested combustion time at peaks of feed.

As technical solution the first section of the old boiler will be modified such as to obtain a *post combustion chamber*. With this modification the time of combustion will be increased, allowing better control over the combustion process. By this modification of the incineration system we expect an increase of 10 % regarding the sludge throughput.

The new boilers are considered to be placed next to the old one. The works of local modifications and the installation of the new main equipment (HP boiler with 40 bar/450 °C, turbine-generator, etc.) as well as the auxiliary equipment (new demin water plant, HP feed water pumps, vacuum condenser and condensate pumps, adaptation of cooling system, etc.) shall be erected while the actual plant still operates in the usual modes. The main focus of the modification concept shall be to minimize the downtime of the plant, which is a non-productive period and means a loss of earnings.

### 2.2. Challenges of Realisation

In order to minimize the stoppage of the incineration line and to continue the disposal of delivered sludge feed, the installation works shall be done at its utmost period length without interfering the old facilities. The switch-over from the old to the new equipment and pipe work shall be done as short as possible. Therefore only one of the afflicted lines will then be shut down, when modification work for the *Post combustion chamber* and the connection from the LP boiler to the new HP boiler system has to be started. After finalisation of the work the line will be restarted and optimized.

The following challenges shall be taken into account when planning of the execution strategy and work sequences in detail:

- Early connection to common equipment (e.g. boiler water feed tank),
- Distance of erection crane arrangement,
- Limited space for equipment (e.g. compact design of new boiler due to local restrictions),



- Difficult (re-)routing of ducts, piping and cabling,
- On-the-job safety when installations work are executed while plant is still in operation.

The safety requirements for the installation works has a high significance due to the fact that parallel to the installation works the operation of the actual plant shall continue. But in this context safety has a double meaning – also the aspect of secured disposal of sludge (continuous incineration) has an important economic impact on the profitability of such a project.

### 2.3. Benefit of the Plant Modification

The above described technical extensions and modifications will result in improved performance data. The additional sludge throughput in our example should add up to more than 20,000 t per year sludge (etwa 23 % DS and 22,000 kJ/kg org.). This additional quantity of sludge increases the revenues for the operating company via gate fee. Due to the implementation of a more efficient HP-steam system might result in an electricity production of approx. 20,000 MWh per anno which can be used for the own consumption (Independence from future price increase for electrical power) or exported to a public grid.

The optimized thermal treatment of sludge touches 2 subjects of public interest which are getting more and more relevant – the sustainable disposal of an organic waste and the production of urgently needed electricity. Depending on the location of such a plant the operating company can expect additional financial support and economic incentives by the local political environment. In this context benefits might be getting relevant due to various commercial aspects like e.g. depreciation, tax savings, public grant application, substantial CO<sub>2</sub> reduction (certificates) or other subventions.

Taking all above mentioned information into account – including higher consumption of auxiliary media and maintenance costs – the return of investment should be feasible without any difficulty within a period of 10 years. The profitability might be even significantly better but depends on many project specific aspects which can only be considered by the investor in a detailed economic efficiency calculation.

## 3. Phosphate Recovery

Phosphorus is a vital component of every cell in all living organisms. No other element can replace phosphorus as a primary nutrient essential for plant growth and thus must be spread on cropland to compensate for phosphates taken up by crops.

Phosphate ores, the non-renewable, mainly sedimentary resource base for the production of phosphate fertilizers, call for sustainable management. Four countries – China, Morocco, USA and Russia – control 72 % of the global phosphate rock production, approximately 191 million metric tons in 2011 [7]. Drivers for a predicted average 2 – 3 % growth of phosphate consumption are available cropland, population growth, changing diets and bio-fuels [8].

Sewage sludge and biomass waste are secondary raw materials which can replace between 30 and 100 percent of imported phosphorus in countries with no primary resources. Due to a growing concern about nutrition safety, food manufacturers and policy makers prefer energy recovery from sewage sludge instead of its direct application on cropland. Additionally, landfill disposal of sludge is no longer a legal option in Europe.

In developed countries, a few hundred incinerators currently produce 3 million tonnes of ash annually with a phosphate concentration of up to 25 percent as  $P_2O_5$ . Left untreated, ash cannot be utilized as a fertilizer because of its high heavy metal concentration and limited plant availability.

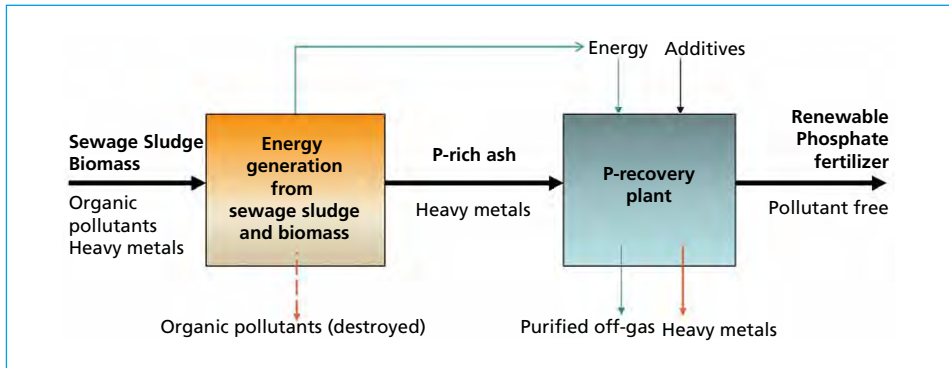


Figure 4: Phosphate recovery process flow

The technology is a thermo-chemical process which eliminates heavy metals from ash while making nutrients plant available.

### How the Process Works

Ash and additives are treated in a reactor at 900 – 1,000 °C. At these temperatures the toxic heavy metals become gaseous. Leaving the kiln with the process gas and being cooled they condense to solid particles and are retained in the form of dust in an air pollution control system. Meanwhile, solid alkaline compounds react with the ash-borne phosphates and yield a renewable phosphate semi-product that is accessible to crops and may be transformed into marketable phosphate and complex fertilizers [9].

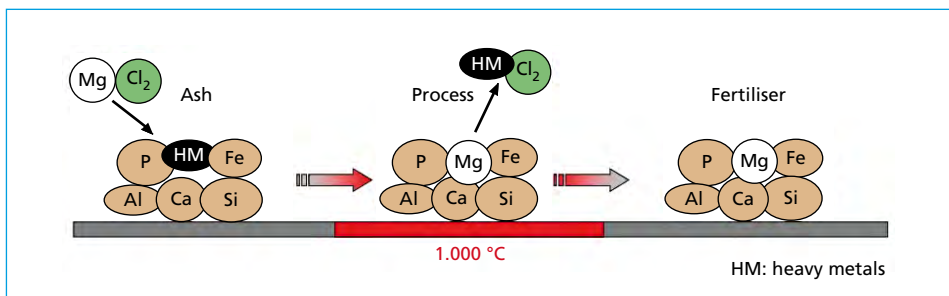


Figure 5: Chemical reactions during the AshDec Process

Source: Adam, C. et al.: Recovery of nutrients from sewage sludge – Results of the European research-project SUSAN. Berlin: Federal Institute for Materials Research and Testing (BAM), 2009, Research Report

Compared to other phosphate recovery technologies, processes which begin with ash as its main feedstock share the benefit of relatively low mass flows because the phosphate concentration in sludge ash is of the same order as in phosphate rock. With a P-recovery

rate of almost 100 % of the phosphorus eliminated at a wastewater treatment plant, the process is unrivalled in terms of P-recovery efficiency. The highly concentrated heavy metal dust – the only secondary waste from the process – does not exceed 3 % of the manufacturing plant inflow and may be used as a secondary resource for copper, zinc and other valuable metals in the future. Contrary to competitive technologies, ashes from all wastewater treatment processes qualify for the treatment with the process, regardless of their chemical characteristics.

The resulting ash based phosphate fertilizers meet the most stringent existing and foreseeable requirements of any fertilizer legislation in Europe. They contain 99 % less cadmium and 90 % less uranium than most phosphate rock based fertilizers and are equally effective in terms of yield and phosphate uptake by crops [11].

Leading soil and plant nutrition research institutes in Germany, Switzerland, The Netherlands and Austria have investigated and confirmed the fertilizing value of the product in numerous pot and field tests. Consequently, some European governments have licensed this type of renewable fertilizers for unlimited use on pasture and cropland.



Figure 6:

Complex fertilizer with ash-borne phosphorus

The process was tested and optimized in a 7-tonne-per-day pilot plant between June 2008 and May 2010. The plant has successfully produced almost 1,000 tons of complex fertilizers sold at market prices.

Three international patents protect the process and products and new patent applications will cover the process improvements currently in the pipeline. These include internal energy recovery systems which have reduced the specific heat energy consumption of the process to roughly 400 kWh per tonne of semi-product and significant savings for consumables. The specific energy consumption and the capital expenses could be further reduced if phosphate recovery becomes a fully integrated part of sewage sludge incineration and thus facilitates a shortcut for the hot ash from the fluidized bed combustion chamber of the incinerator to the rotary reactor of the phosphate recovery facility.

Outotec GmbH offers turnkey sludge-to-energy and fertilizer as well as ash-to-fertilizer production plants, manufacturing licenses and service & maintenance packages.

It is difficult to predict how many renewable phosphate fertilizer plants will be operational in the next decade. Much depends on the development of the global economy and commodity prices. In any event, the new technology can facilitate decentralized, non-integrated production of phosphate fertilizers independently from a manufacturer's access to primary resources.

## 4. Conclusion and Outlook

The above described ideas for technical upgrading of existing mono sludge incineration plants bear an economic potential, which is interesting for various operating companies. The continuous *evolution* of feed characteristic and also of business conditions is a daily challenge for the owner of such plants. Also in this business they have to face up to the competitive condition. The described upgrades might help to keep the cost effectiveness on high level and to firm up profitability for long periods.

The next step for these investigations is the implementation phase. There are clients interested in a realisation of such plant revisions or enlargements. They already started subsequent projects for more detailed engineering analysis (e.g. basic engineering) or even their real implementation. Outotec GmbH is able to execute such ambitious projects and to consult operators to keep their plants viable for the future.

## 5. References

- [1] Kratz, S.; Schnug, E.: Agronomische Bewertung von Phosphatdüngern. Schriftenreihe Landbau-forschung, Vol. Sonderheft, Braunschweig: s.n., 2008
- [2] Kratz, S.; Schnug, E.: Schwermetalle in P-Düngern. Special Issue, 286, Braunschweig: Federal Agricultural Research Centre, 2005, Recent Advance in Agricultural Chemistry
- [3] Milieujaarverslag Moerdijk: N.V. Sliberwerking Noord-Brabant, 2011
- [4] Jaarverslag Dordrecht : DRSH nv, 2009
- [5] Ott, C. ; Rechenberger, H. s. l.:The European Phosphorus Balance. Elsevier, 2012, Resources, Conservation and Recycling 60, pp. 159-172
- [6] Pascher, Mikroanalytisches Labor: Chemical & physical analysis of dewatered pig manure. Re-ragen: unpublished, 2012
- [7] U.S. Geological Survey: Minerals Information. U.S. Geological Survey, Mineral Commodity Summaries. Online 01 2012, Cited: 06 08 2012
- [8] World Phosphate Rock Flows, Losses and Uses. Prud'homme, M. Brussels: IFA, 2010. Procee-dings of the Phosphate 2010 Conference & Exhibition
- [9] Adam, C.; Kley, G.; Simon, F.-G.: Thermal Treatment of Municipal Sewage Sludge Aiming at Marketable P-Fertilizer. Material Transaction 12 (2007), Vol. 48, pp. 3056-3061
- [10] Adam, C. et al.: Recovery of nutrients from sewage sludge – Results of the European research-project SUSAN. Berlin: Federal Institute for Materials Research and Testing (BAM), 2009, Re-search Report
- [11] Nanzer, S. et al.: Development of a sewage sludge based fertilizer. International Cientific Centre of Fertilizers, 2009, More sustainability in Agriculture: New fertilizers and fertilization manage-ment