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Future proof decentralised sludge recycling Elodry-pro®

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Abstract

At Linz-Unkel (Germany) sewage treatment plant the first full scale state-of-art EloDry-Pro® plant for sewage sludge has been constructed, consisting of the PYREG® reactor and the EloDry® belt dryer. The system is characterised by small footprint, flexibility, modular design and efficient energy management.

The sludge dried using an EloDry® belt dryer undergoes staged combustion using the PYREG® module at around 6,500°C. This reduces the sludge to a fraction of its original volume while disinfecting it and removing micro-pollutants such as pharmaceutical residues. The residual ash, which has a high percentage of plant-available phosphorus, is then supplied to the fertiliser industry as a recycled raw material.

The working principle of EloDry-Pro® installation, including heat flows of the system, is presented.

The paper describes Pyreg®'s advanced emission control systems, preventing NOx formation and removing harmful substances such as mercury and sulphur.

The EloDry-Pro® technology is an innovative and cost-effective approach to decentralised thermal recycling of sewage sludge. Both sewage sludge volumes and transportation costs are reduced by up to 90%, therefore making it a low carbon cost-effective alternative to the transportation of sludge and allowing local sludge processing at plants under 100 k population.

Key words: decentralised sludge treatment, gasification, nutrient recovery, thermal sludge conversion

INTRODUCTION

As land availability decreases and the volumes of sludge increase, sustainable thermal methods of sludge processing gain more significance. In Germany, the municipal water boards face further restrictions in the sludge disposal routes because, according to an upcoming regulation, they will be required to recover phosphate from the sludge.

At present, sludge disposal varies between different German states; however, on average approximately 50% undergoes thermal disposal (Weihman *et al.* 2013). This situation has many drawbacks for wastewater treatment plant (WWTP) operators, such as dependence on energy companies and sensitivity to gate fee changes, high transportation cost and loss of valuable materials such as phosphate.

Decentralised thermal treatment can provide a cost-effective and innovative solution whilst responding to environmental, regulatory and public pressures. The EloDry-Pro® process facilitates utilisation of the thermal energy and chemical resources in sewage sludge.

The Linz-Unkel WWTP (design capacity: 30,000 PE) is adjacent to the Rhine, located ca. 20 km south of Cologne, and is operated by the Linz-Unkel Joint Waste Management Association (Figure 1). The Linz-Unkel WWTP is the first full scale plant in Germany using the EloDry-Pro® process for sewage sludge utilisation. The technology uses low temperature drying and a process of staged combustion to reduce dried sewage sludge to around 40% of its volume, with simultaneous full conversion

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Figure 1 | Aerial view of Linz-Unkel WWTP.

to a high grade fertiliser material containing a high percentage of plant available phosphate. Additionally, in the process, removal of harmful substances (e.g. mercury, micro-plastics, and hormones) takes place.

The EloDry-Pro® installation at Linz-Unkel WWTP was commissioned in September 2015. Even though PYREG® technology has been used in the past for utilisation of biomass and organic waste materials, the Linz-Unkel project is the first where the Pyreg® 500 module is combined with a matching EloDry® low temperature belt dryer (by ELIQUO Stulz) in one innovative sewage sludge utilisation plant called EloDry-Pro® (Figure 2).

Figure 2 | EloDry® low temperature dryer – general view and installation at Linz-Unkel.

SLUDGE LINE OVERVIEW

The sludge line at Linz-Unkel WWTP processes 770 tonnes DS of sludge annually, of which approximately 23% is imported. Shortly before implementation of EloDry-Pro®, in 2013 and 2014, the sludge line at Linz-Unkel underwent a major upgrade:

- An old anaerobic tank was changed to a primary settlement tank.
- A two-step compact anaerobic mesophilic digestion system with 10 d + 10 d residence time was built.
- A microturbine with flue gas heat exchanger was installed for utilisation of the resulting biogas.

In the next step of the sludge line upgrade, the EloDry-Pro® installation, comprising an EloDry® low heat dryer and PYREG® installation, was designed using the following parameters:

- Digested sludge throughput 563 t DS/a
- Dry solids content of digested sludges 30% DS
- Organic solids content 54.6%oDS
- Biogas generation min. 22 Nm³/h (528 Nm³/d)
- Heat value: min. 6.0 kWh/Nm³

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ELODRY® TECHNOLOGY

The digested sewage sludge is first dewatered in a newly installed screw compactor, achieving high dry solids content of up to 31% using moderate amounts of polymer. Dewatering is carried out continuously and the dewatered sludge is fed directly to the EloDry® low-temperature belt dryer without intermediate storage. This avoids odours from intermediate sludge holding and ensures the sludge structure remains intact to aid drying.

The EloDry® was built off site and delivered pre-assembled. It is constructed in stainless steel and equipped with two stage polyester belts, specially designed to protect against electrostatic charges. The system is completely automated and equipped with several measurement and control loops to ensure safe operation. The dryer's waste air is cleaned to comply with appropriate standards, by applying acid gas scrubbing.

The EloDry® low temperature belt dryer dries the dewatered sludge to a dry solids content in excess of 84%. This percentage dry solids content is required to ensure exothermic operation of the PYREG® reactor.

The main design parameters of EloDry® sludge dryer at Linz-Unkel:

- Drying temperature 55–90 °C
- Drying output max 350 kg H_2O/h
- Specific heat requirement < 825 Wh/kg H_2O
- Electrical energy requirement < 40 Whel/kg H_2O

PYREG® TECHNOLOGY

The dried sewage sludge is continuously fed to the PYREG® reactor via a rotary gate valve. The PYREG® technology works using a staged combustion design. First the dried sewage sludge enters a gasification reactor equipped with an auger screw where it is heated up using off gases from the combustion chamber. As the material moves upwards, it undergoes gasification and then is carbonised and partially mineralised, which results in fully hygienised ash containing phosphorus.

In a second stage, the syngas developing in the reactor is completely combusted at about 1,250 °C in the combustion chamber (FLOX® burner). The generated heat is used for heating the PYREG® gasification reactor and for drying the digested sludge in the EloDry® dryer. Exhaust gas undergoes further treatment before being discharged to atmosphere. Figure 3 shows a schematic diagram of the PYREG® system.

The main design parameters for average digested sludge of Pyreg® module:

- Annual throughput 1,000 t DS
- Annual production 300 t P-ash
- Operating hours 7,500 h/a
- Min heating value 10 MJ/kg
- Particle size < 30 mm
- Fuel power 500 kW
- Useful waste heat up to 200 kW

PHOSPHORUS RECYCLING

The temperature of thermal treatment affects the chemical form of phosphorus in the final product. The phosphorus in the sewage sludge remains available to plants to a higher degree after the PYREG®

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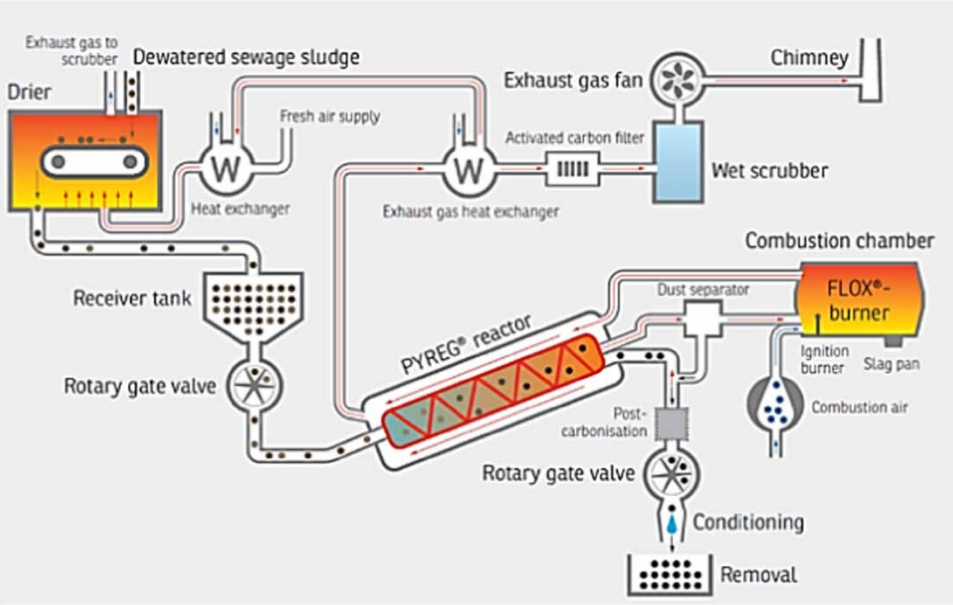

Figure 3 | EloDry-Pro® process schematic diagram.

process because the temperature of treatment is significantly lower than in conventional incineration. The sludge is also simultaneously fully sanitised and micro-contaminants such as pharmaceutical residues or micro-plastic are destroyed. Some heavy metals, mainly cadmium and mercury undergo volatilisation in the Pyreg® reactor (see Figure 4 and Figure 5), are transferred to the syngas and finally removed from off-gases by activated carbon filters.

Figure 4 | EloDry-PRO® installation, on the right the PYREG® module, in the building the EloDry-PRO® containers for P-fertiliser ash are visible on the left side.

The current European Union fertiliser regulation concerns mainly mineral fertilisers produced either from mined resources or by conventional chemical synthesis. The intention of the upcoming Fertilisers Regulation revision is to provide a regulatory framework for production and marketing of fertilisers from recovered organic materials. A strong drive behind the revision is the present dependence of the EU on import of the phosphate rock mined outside of the EU, while domestic waste,

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Figure 5 | Pyreg® module.

such as sewage sludge, could potentially cover about 20–30% of EU's demand for phosphate fertiliser (European Commission 2015). This regulation should have a positive effect on operators of waste water treatment plants, who will be able to access new markets for fertilisers originating from sewage sludge with a potential for bringing additional revenue.

Since at present the UK has not implemented laws regulating fertilisers produced from organic materials, nor specifies limit levels of heavy metals in fertilisers in general, the quality of P-mineral fertiliser ash was verified against German standards. The regulatory limits and the characteristics of the product are listed in Table 1.

The German regulations for fertiliser require a minimum level of 10% P_2O_5 and maximum threshold levels for metals like As, Pb, Cd, Cr, Ni, Hg, Cu, Zn. The P-ash resulting from the EloDry-Pro® installation at Linz-Unkel is a product fully compliant with the German regulations concerning both sewage sludge and fertilisers.

Table 1 | P-mineral fertiliser ash from EloDry-Pro® at Linz-Unkel –preliminary product characteristics

Content	Units	Limit according to sewage sludge ordinance 1992 (AbfKlärV 1992)	Limit according to fertiliser regulations 2012 (DüMV 2012)	Operational values from Linz-Unkel
Carbon content	% Dry mass			5
Phosphate P_2O_5	% Dry mass		>10	14
ACC-soluble phosphate	% Dry mass			Approx. 11
As	mg/kg DS		<40	4
Pb	mg/kg DS	<900	<150	31
Cd	mg/kg DS	<5	<1.5	0.95
Cr	mg/kg DS	<900		90
Cr^{VI}	mg/kg DS		<80	[a]
Cu	mg/kg DS	<800		404
Ni	mg/kg DS	<200	<80	21
Hg	mg/kg DS	<8	<1.0	<0.01
Zn	mg/kg DS	<2,000		998
Ti	mg/kg DS		<1.0	<0.05
Polychlorinated dibenzo(p) dioxin and furan (PCDD/F)	ng/kg Dry mass		<30	[a]

[a]Not determined.

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HEAT UTILISATION

The optimal utilisation of heat is an important factor guaranteeing the economic viability of the sewage sludge utilisation plant. At Linz-Unkel, the available heat is transferred between different stages of the process thanks to efficient heat recovery systems. Since different stages of the process demand heat at different temperature levels, the residual heat recovered after one step can be used in the next step at lower temperature. This is an important innovation in the utilisation of sewage works heat energy, avoiding the use of external fossil fuels. The existing micro-gas turbine on site and the waste heat of the PYREG® reactor produce enough heat to meet the requirements of the dryer and digester. The integration of EloDry-Pro® with the sludge line including mass balance and the heat flow, is presented in Figure 6.

The dewatered sludge still contains 70% water, which results in its calorific value being too low to sustain the PYREG® process. To dry the sludge to a suitable DS content, a large quantity of water needs to be removed, requiring a substantial amount of energy. The low temperature dryer is designed to use the waste heat available in the plant.

After the hot flue gas from the combustion chamber passes the PYREG® reactor, where it is used for gasification and carbonisation of sludge, its remaining usable heat is recovered in a heat exchanger downstream of the reactor. This heat is then combined with the waste heat of the microturbine and used for sludge drying in the EloDry® dryer.

The EloDry® belt dryer at Linz-Unkel WWTP includes waste air conditioning with heat recovery, a hot water installation with circulating pump and a waste air fan for waste air treatment. Heat recovered from the dryer waste air is used for heating the digestion tank and the operations building. The available heat is more than adequate to cover annual requirements.

GASEOUS EMISSIONS

The combustion of the gas generated in the PYREG® reactor takes place in the combustion chamber. This step is designed to minimise harmful emissions using less excess air combustion and flameless oxidation (FLOX®).

The combustion chamber is equipped with a FLOX® burner with internal flue gas recirculation. In this technology, the incoming fuel-gas and air are mixed with a strong recirculation flow of exhaust gas. The combustion takes place at lower temperature than in systems with a flame, at approximately 1,250 °C. Consequently, the thermal NOx formation is prevented and the carbon monoxide is oxidised.

Exhaust gas is cleaned in a two stage process. First, volatile sewage sludge components such as mercury are bound to an active charcoal filter where other heavy metals and dust are also filtered out. Next, an alkaline flue gas washer removes acid contaminants.

Of the emission control systems, the PYREG® flue gas emissions are compliant with the limits of the German 17th Federal Emission Protection Act (17th BImSchV), as presented in Table 2.

OTHER BENEFITS

The EloDry-Pro® can represent a beneficial solution in terms of reducing CO_2 emissions from sludge processing. The exact savings on the CO_2 emissions would clearly depend on the alternative process considered.

In the case of Linz-Unkel WWTP, a likely alternative to EloDry-Pro® would be drying of the sludge on site using energy from natural gas and then transportation to the nearest incineration plant where

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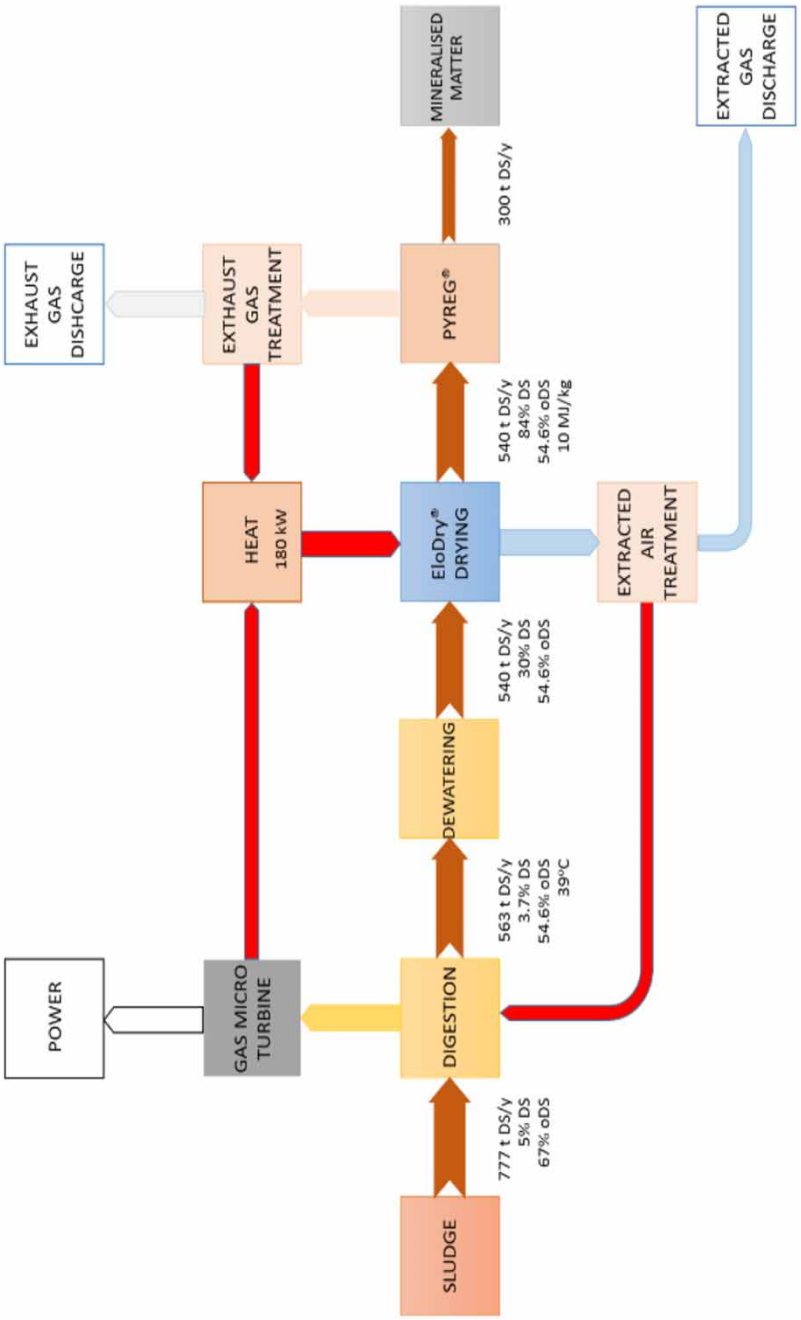

Figure 6 | Linz-Unkel WWTP – sludge line heat flows and mass balance.

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Table 2 | Flue gas emissions; the limits according to 17th Federal Emission Protection Act and Pyreg® module performance data

Component	Units	Limit	Operational values from Linz-Unkel
CO	mg/m^3	100	6
Dust	mg/m^3	20	<7
SO_2 and SO_3 as SO_2	mg/m^3	200	2.0
HCl	mg/m^3	60	1.3
HF	mg/m^3	4	0.5
NO and NO_2 as NO_2	mg/m^3	400	<200
Hg	mg/m^3	0.05	0.004
Cd, Ti	mg/m^3	0.05	0.027
Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V, Sn	mg/m^3	0.5	0.37
Dioxins and furans	ng/m^3	0.1	0.013

it would be combusted. Using the sludge data and the specific heat requirement of the sludge dryer given above, the amount of heat required by the process is approximately 1,100 MWh/a (assuming 95% boiler efficiency). Since EloDry-Pro® uses waste heat of the microturbine and from sludge combustion, the avoided emissions from natural gas combustion are in the order of 200 t CO_2/a (DECC/Defra 2012). Additionally a significant fraction of carbon from the sludge does not undergo combustion in the Pyreg® reactor, but is removed with the P-ash containing approximately 18% C. For the Linz-Unkel installation, this is an equivalent of 200 t CO_2/a.

CONCLUSIONS

The new EloDry-Pro® plant in Linz-Unkel represents an innovative, autonomic and full scale operational decentralised sewage sludge utilisation solution. It is fully integrated with the plant's sludge line, which is designed to treat approximately 18,000 m^3 sewage sludge (770 tons DS) per annum. Of this, ca. 300 tonnes per annum of phosphoric fertiliser ash remain after thermal treatment, which will be utilised by the fertiliser industry without any additional treatment. Main benefits for the Linz-Unkel Joint Waste Management Association include the following:

- Ability for long-term cost control in respect to sludge management, even in the light of more stringent P recovery regulations in Germany.
- Reduced requirements for sludge handling and storage as the system does not require any intermediate sludge storage.
- Ash product compliant with German sludge and fertiliser regulations.
- Guaranteed utilisation of ash; the ash is a source of plant-available phosphorus therefore it is used as a raw material for fertiliser production.
- Transportation by lorries reduced by up to 90%.
- Cutting edge emission control.
- Energy-efficient plant operation due to a multi-stage heat recovery concept.
- Potentially significant reduction in CO_2 emissions in comparison to other thermal sludge processing.

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