



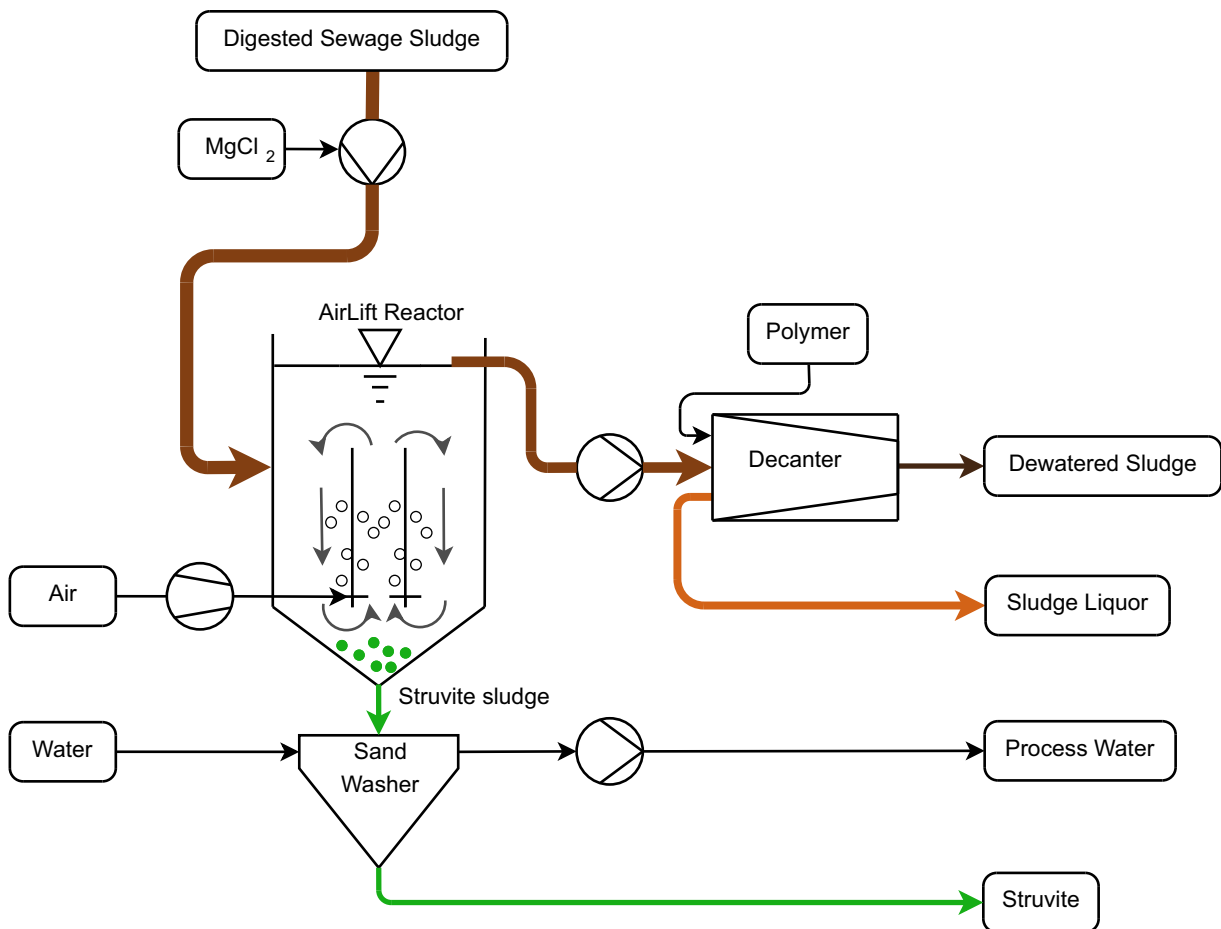
AirPrex[®] *Struvite crystallization in sludge*

Short description

The AirPrex[®] process was developed to prevent unwanted struvite incrustation after digestion in EBPR WWTP. It is currently operated at several WWTP in Germany and the Netherlands, installed directly after the digesters and prior to sludge dewatering. In the AirPrex[®] process pH increase is achieved by CO₂ stripping with intensive aeration. Additional Mg is added as MgCl₂ solution. Sedimented

struvite crystals are harvested at the bottom of the reactor. The struvite product is crystallised within the wet sludge and can therefore show some organic and inorganic impurities. Washing and gentle drying of struvite improves the quality and provides a marketable fertilizer product. "Berliner Pflanze" is the first product of AirPrex[®] with official fertilizer approval and REACH registration.

Process scheme



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General Data

Type of Process	crystallisation
Type of Plant	airlift reactor
Input Material	sewage sludge after digestion
Product	struvite
P-concentration	21 % P ₂ O ₅ of DM
P recovery performance ¹	7 % of P in sludge input

Supply

Average total electricity demand ¹	10.3 [kWh/kg P _{recovered}]
Average chemical demand ¹ (as 100% concentrate)	14.5 [kg MgCl ₂ /kg P _{recovered}] 4.7 [molar ratio Mg:P _{recovered}] 2.1 [molar ratio Mg:P _{dissolved}]

Advantages

- Improvement of sludge dewatering (+2 to 5% DM)
- Savings of polymer in dewatering (up to 25%)
- Prevention of down-stream struvite precipitation (pipe clogging, damage of centrifuge)
- WWTP retrofit possible by implementation after digestion
- Proportional reduction of phosphorus and nitrogen return load from sludge liquor

Remarks

- Process is limited to WWTP with enhanced biological P removal and concentrations of more than 50 mg/L PO₄-P in sludge liquor
- Product yield can be enhanced by thermal or chemical hydrolysis prior to digestion (increase of PO₄-P concentration in liquor)

Patents and Licenses

Patent held by	Berliner Wasserbetriebe (BWB)
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References

Berlin Wassmannsdorf

(BWB, andreas.lengemann@bwb.de)

Start of operation	2009
Annual struvite capacity	~ 600 - 1,000 tons

Mönchengladbach Neuwerk (Niersverband)

Start of operation	2009
Annual struvite capacity	~ 600 tons

Waternet, NL, RWZI Amsterdam-West

Start of operation	2014
Annual struvite capacity	~ 1,500 tons (projected)

¹Process data related to reference sludge line defined in P-REX (digested sludge of wastewater treatment plant for 1 Mio inhabitant equivalents, dry matter (DM) content: 3%, P content: 4.2% of DM, PO₄-P in liquor: 200 mg/L (EBPR) or 10 mg/L (ChemP), Fe content: 2% (EBPR) or 6.6% (ChemP)). More information on modelling can be found in P-REX LCA report.



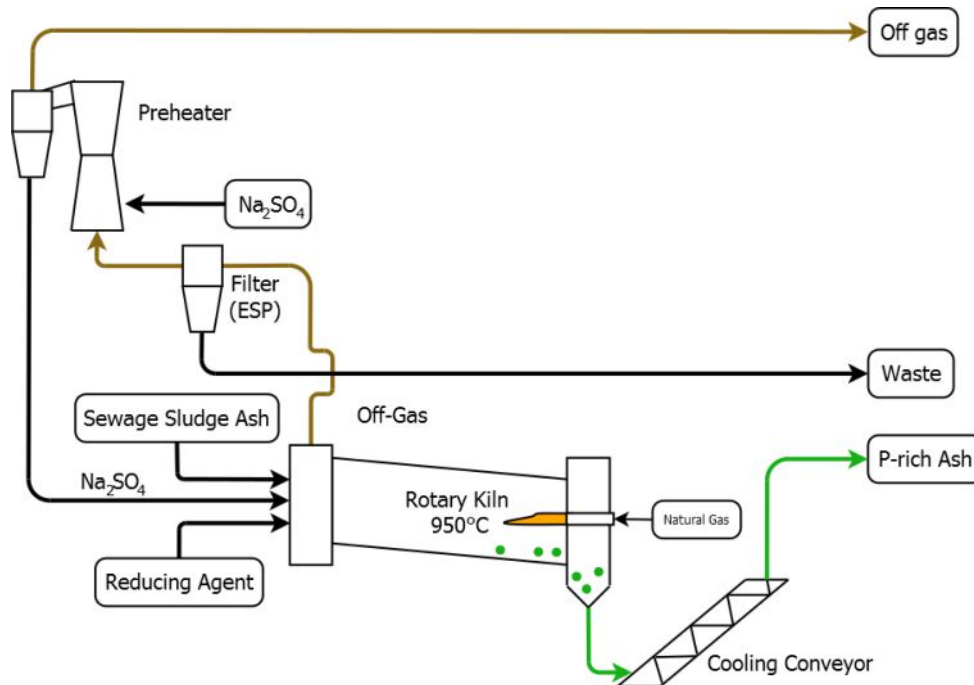
Ashdec[®] Thermo-chemical ash treatment

Short description

The ASH DEC process thermochemically treats sewage sludge ash (SSA) in a rotary kiln and has been jointly developed by Outotec and BAM Federal Institute for Materials Research and Testing. The phosphate phases present in SSA are transformed into bio-available NaCaPO_4 by reaction with Na_2SO_4 at 900 - 1000 °C with a minimum retention time of 20 min. Dry sewage sludge is used as a reducing agent in this process. Volatile heavy metals (As, Cd, Hg, Pb, Zn) evaporate and are removed via gas phase. The hot kiln off gas could be used to heat ash, Na_2SO_4 and kiln air

for energetic process optimization. An alternative ASH DEC process is the treatment with MgCl_2 . In this process heavy metals are removed via gas phase in form of the respective chlorides and oxichlorides and phosphorus is transformed into calcium-magnesium phosphates. Heavy metal removal via the chloride pathway is generally superior compared to the process under reducing conditions, but the bioavailability of the output material of the MgCl_2 -process is limited to acidic soils ($\text{pH} < 7$).

Process scheme



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General Data

Type of Process	thermochemical
Type of Plant	rotary kiln
Input Material	sewage sludge ash
Output Material	calcined ash with CaNaPO_4 phase
P-concentration	15 - 25 % P_2O_5
P recovery performance ¹	98% of P in sewage sludge ash

Supply

Average total electricity demand ¹	0.8 - 0.9 [kWh/kg $\text{P}_{\text{recovered}}$]
Average total natural gas demand ¹	5.2 [kWh/kg $\text{P}_{\text{recovered}}$] (stand alone) 3.5 [kWh/kg $\text{P}_{\text{recovered}}$] (integrated)
Average chemical demand ¹ (as 100% concentrate)	3.3 [kg Na_2SO_4 /kg $\text{P}_{\text{recovered}}$] 1.3 [kg dried sludge/kg $\text{P}_{\text{recovered}}$] 0.1 [kg $\text{Ca}(\text{OH})_2$ /kg $\text{P}_{\text{recovered}}$] 0.1 [kg NaOH /kg $\text{P}_{\text{recovered}}$]

Advantages

- Process applicable for ashes of WWTP with enhanced biological and chemical P removal
- Production of highly plant available phosphate (CaNaPO_4) with Na_2SO_4 addition
- Removal of As and heavy metals (Cd, Hg, Pb, Tl, Zn) in ash
- Low amounts of waste for disposal (2 - 3 % of ash)

Remarks

- ASH DEC reactor requires natural gas as fuel
- Energy consumption based on simulation
- Integration of ASH DEC into existing mono-incineration decreases demand for natural gas (transfer of hot ash into rotary kiln) and for electricity because of sharing off-gas cleaning
- Successful demonstration trial with new process based on Na_2SO_4
- The process is particularly cost efficient for P-rich and Si-poor ash

Patents and Licenses

Patent held by	Outotec
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Patent held by	BAM
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References

Pilot plant for ASH DEC
with MgCl_2 process 2008-2010

Two weeks demonstration and production (2 t) trial for ASH DEC
with Na_2SO_4 process in cooperation with external company IBU-tec advanced materials AG, Weimar/Germany in 2014.

¹Process data related to reference sludge line defined in P-REX (ash of wastewater treatment plant for 1 Mio inhabitant equivalents), ash composition (% DM): 10.7% P, 5% Fe (EBPR ash) or 15% Fe (ChemPash). More information on modelling can be found in fact sheet "reference model" and P-REX LCA report.



Gifhorn *Sludge leaching*

Short description

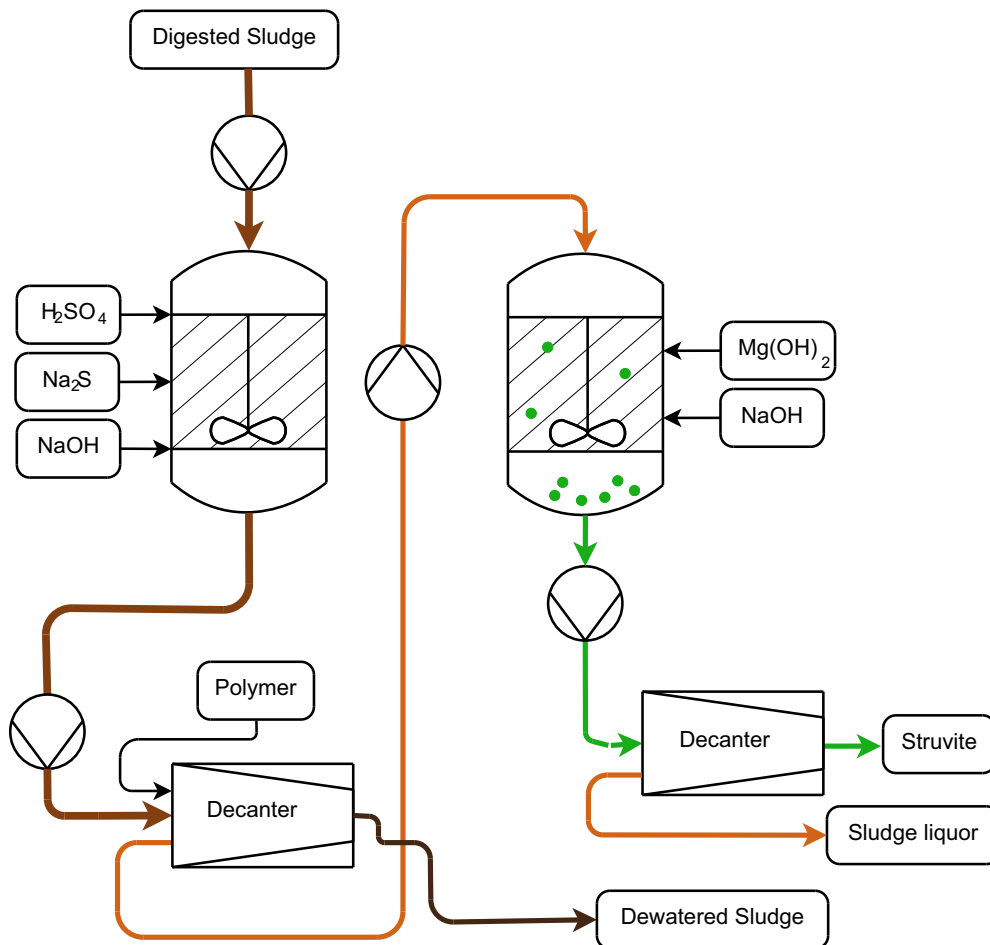
The basic concept of this process was originally developed in 2000 by Seaborne Environmental Laboratory AG (Germany) in order to recover nutrients from liquid manure. Since then, the Seaborne process was modified, optimized and implemented in full scale at WWTP Gifhorn, which gave the current name of this process ("Gifhorn process").

The phosphorus bound in the biomass is extracted at low pH = 4.5 from the solid phase of digested sewage sludge by addition of sulphuric acid (H_2SO_4). In a second step, the dissolved heavy metals are precipitated as sulfides (dosing of Na_2S) at pH 5.6 which is adjusted with NaOH. After

solid/liquid separation with a decanter, dosing of $Mg(OH)_2$ initiates precipitation of phosphorus as mix of struvite/calcium phosphate at high pH = 9 (adjusted with NaOH). Mg is dosed below stoichiometric ratio to provoke complete calcium precipitation. This prevents scaling in the stripping reactor but produces a major fraction of hydroxylapatite next to struvite.

The P product is harvested by a second solid/liquid separation. The Gifhorn process can also be extended by an optional nitrogen recovery step (air stripping at pH = 10.5, recovery of NH_3 in sulfuric acid as diammonium sulfate).

Process scheme



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General Data

Type of Process	acidic dissolution and precipitation
Type of Plant	precipitation reactor
Input Material	sewage sludge
Product	mix of struvite and hydroxylapatite
P-concentration	28 % P ₂ O ₅ of DM
P recovery performance ¹	49 % of P in sludge input

Supply

Average total electricity demand ¹	6.9 [kWh/kg P _{recovered}]
Average chemical demand ¹ (as 100% concentrate)	8.2 [kg H ₂ SO ₄ /kg P _{recovered}] 2.9 [kg NaOH/kg P _{recovered}] 0.2 [kg Mg(OH) ₂ /kg P _{recovered}] 0.1 [molar ratio Mg:P _{recovered}] 0.1 [molar ratio Mg:P _{dissolved}] 0.8 [kg Na ₂ S/kg P _{recovered}]

Advantages

- Process can be applied with EBPR or Chem-P sludge (acid demand calculated with 4% Fe)
- Separate heavy metal precipitation as sulfides
- Proportional reduction of phosphorus and nitrogen return load from sludge liquor
- Downstream recovery of nitrogen possible (air stripping) in the form of diammonium sulfate

Remarks

- Al coagulants in WWTP reduce P recovery rate. Higher rates of P recovery are possible at pH < 4.5, but with reduced dewaterability and increased chemical consumption. High Fe content in sludge leads to an increase in Na₂S dosing (FeS precipitation).
- Product contains small fractions of iron phosphate and larger fractions of hydroxylapatite.

Patents and Licenses

Patent held by	Seaborne EPM AG
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References

Owschlag (pilot)

Start of operation	2000
Scale	10.000 p.e., 50 kg struvite/d

Gifhorn (full scale)

Start of operation	2007
Scale	50.000 p.e., 270 kg struvite/d (currently limited performance due to economic reasons)

¹Process data related to reference sludge line defined in P-REX (digested sludge of wastewater treatment plant for 1 Mio inhabitant equivalents, dry matter (DM) content: 3%, P content: 4.2% of DM, PO₄-P in liquor: 200 mg/L (EBPR) or 10 mg/L (ChemP), Fe content: 2% (EBPR) or 6.6% (ChemP)). More information on modelling can be found in P-REX LCA report.



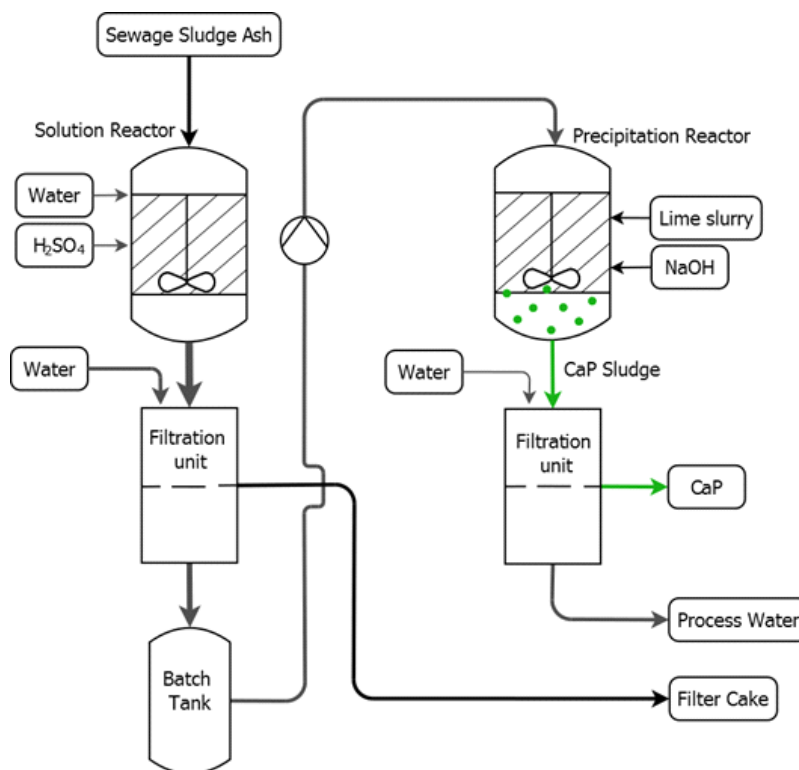
Leachphos[®] Ash leaching

Short description

LeachPhos was developed by BSH Umweltservice GmbH. Phosphorus (P) is extracted from sewage sludge ash (SSA) by addition of diluted sulfuric acid. 80-95 % of P is transferred into the leachate. The pH is subsequently increased by addition of sodium hydroxide or lime until target P_{recovery} is achieved. Heavy metals such as cadmium, copper, and zinc are only partially dissolved and precipitated, leading to acceptable mass fractions in the output material. A

mixture of aluminum-, ferric- and calciumphosphate is separated by filtration. The remaining heavy metals in the filtrate are quantitatively precipitated at $\text{pH} > 9$ with a precipitating agent and are separated for disposal. Calcium phosphates or magnesium ammonium phosphate (struvite) are targeted output materials for future industrial-scale plants.

Process scheme



General Data

Type of Process	wet chemical
Type of Plant	leaching and crystallisation reactors
Input Material	sewage sludge ash
Product	CaP or struvite (wet)
P-concentration	20 - 40 % P ₂ O ₅ of DM
P recovery performance ¹	70% of P in sewage sludge ash

Supply

Average total electricity demand ¹	1.6 [kWh/kg P _{recovered}]
Average chemical demand ¹ (as 100% concentrate)	5.6 [kg H ₂ SO ₄ /kg P _{recovered}] 0.6 [kg NaOH/kg P _{recovered}] 3.9 [kg Ca(OH) ₂ /kg P _{recovered}]

Advantages

- Output material comparable to dicalcium phosphate
- High P content of output material
- Reduction of heavy metal content
- High process flexibility

Remarks

- Wet residual filter cake (60% DM) requires disposal (1.7 kg wet waste/kg ash) or additional treatment.
- Process data does not include a potential finishing (e.g. drying, granulation) of the wet LeachPhos output material (40-50 % DM).
- Higher recovery rates can be reached depending on ash composition and output quality requirements

Patents and Licenses

Patent held by	BSH Umweltservice AG
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References

Pilot study BSH 2012/2013

Amount	40 t sewage sludge ash
Throughput	2 t ash/h

Pilot plant at FHNW

Batch process with 50 kg ash

¹Process data related to reference sludge line defined in P-REX (ash of wastewater treatment plant for 1 Mio inhabitant equivalents), ash composition (% DM): 10.7% P, 5% Fe (EBPR ash) or 15% Fe (ChemP ash). More information on modelling can be found in fact sheet "reference model" and P-REX LCA report.



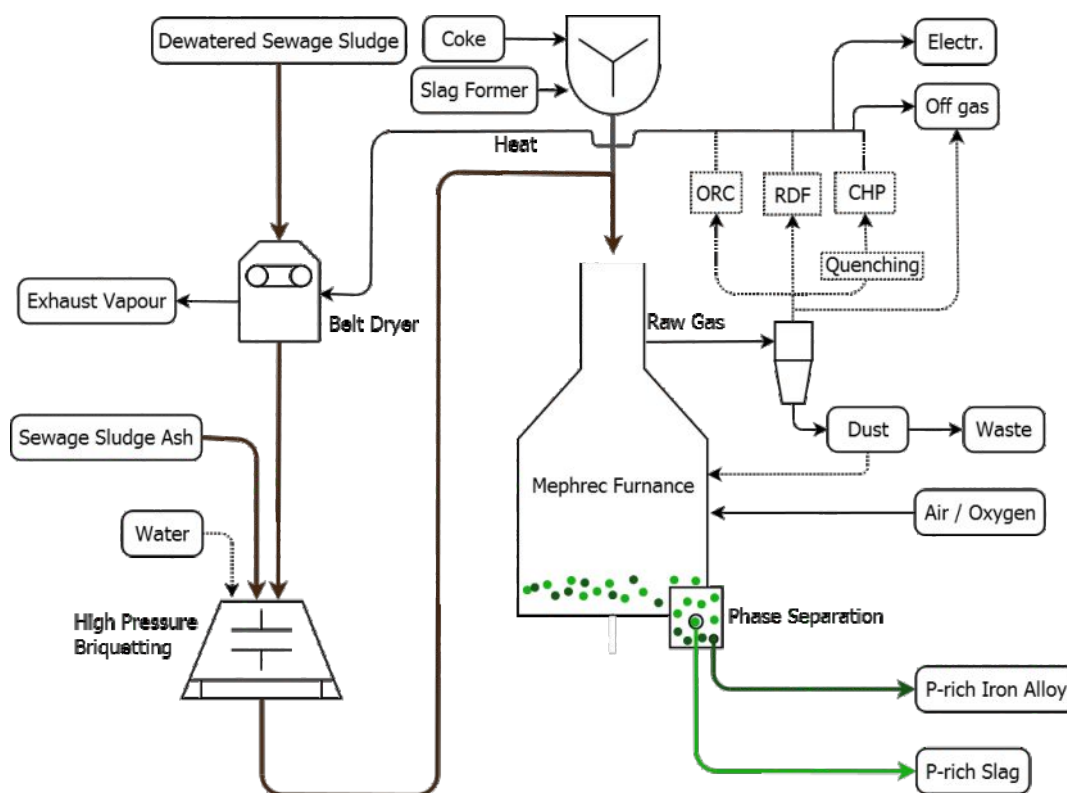
Mephrec[®] Metallurgical sludge or ash treatment

Short description

The Mephrec process was developed by the German company Ingitec for recovery of phosphorus from sewage sludge and/or ash. Dewatered sewage sludge (>25 % dry matter (DM)) is dried to 80 % DM and pressed into briquettes. The briquettes of sludge and/or ash are thermally treated (gasification) in a shaft furnace at temperatures above 1450 °C. Heavy metal compounds are reduced under these conditions into their elemental form. Volatile metals (Cd, Hg, Pb, Zn) are evaporated and separated via gas phase whereas non-volatile heavy metals are separated from the

slag in form of a liquid metal phase. The phosphates present in sewage sludge are transformed into silico-phosphates (comparable to “thomas phosphate”). The Mephrec process with sludge as raw material also produces electricity and heat with the highly calorific raw gas. The raw gas can be directly injected into an Organic Rankine Cycle (ORC) process or municipal waste incineration plant, or refined in multiple steps to feed a combined heat and power (CHP) plant.

Process scheme



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General Data

Type of process	reducing shaft melting gasification
Type of plant	coke fired oxygen shaft melting gasifier
Input material	sewage sludge and/or ash
Output material	slag
P concentration in slag	10 - 25 % P ₂ O ₅
P recovery performance in slag ¹	81% of P in input sludge/ash
P in iron alloy ¹	> 5 % of P in input sludge/ash
Energy recovery potential in off-gas ¹	55 kWh/kg P _{recovered} (for sludge as input)

Supply

Estimated electricity demand (ash) ¹	1.2 [kWh/kg P _{recovered}]
Estimated electricity demand (sludge) ¹	12 [kWh/kg P _{recovered}] (incl. drying)
Estimated heat demand (sludge) ¹	68 [kWh/kg P _{recovered}] (for drying)
Estimated chemical demand ¹ (100% concentration)	2.3 - 2.7 [kg coke/kg P _{recovered}] 0.4 - 0.8 [kg O ₂ /kg P _{recovered}] 1.3 [kg dolomite/kg P _{recovered}] 0.1 [kg Ca(OH) ₂ /kg P _{recovered}]

Advantages

- P recovery process for sludge and/or ash as input material
- Process applicable for P rich waste, sludge and ashes of WWTP with enhanced biological or chemical P removal
- Energetic and material recycling in single process step (for sludge as input)
- Main output is slag (enriched with P, depleted in heavy metals)
- By-product: iron alloy with P content
- By-product (sludge as input): raw gas with high calorific value

Remarks

- Pilot plant in Nuremberg in planning, production will start in 2015
- Validation of process parameters intended in pilot plant
- Slag has a P solubility in citric acid comparable to “thomas phosphate”

Patents and Licenses

Patent held by	ingitec
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References

Test trials

with a metallurgical shaft furnace (modified small cupola) at Bergakademie Freiberg (2008)

¹Process data related to reference sludge line defined in P-REX (dewatered sludge or ash of wastewater treatment plant for 1 Mio inhabitant equivalents), sludge composition (25% DM): 54% VS, 4% P, 7% Fe in DM, ash composition (% DM): 9.5% P, 15% Fe. More information on modelling can be found in fact sheet “reference model” and P-REX LCA report.



Pearl[®] *Struvite crystallisation in sludge liquor*

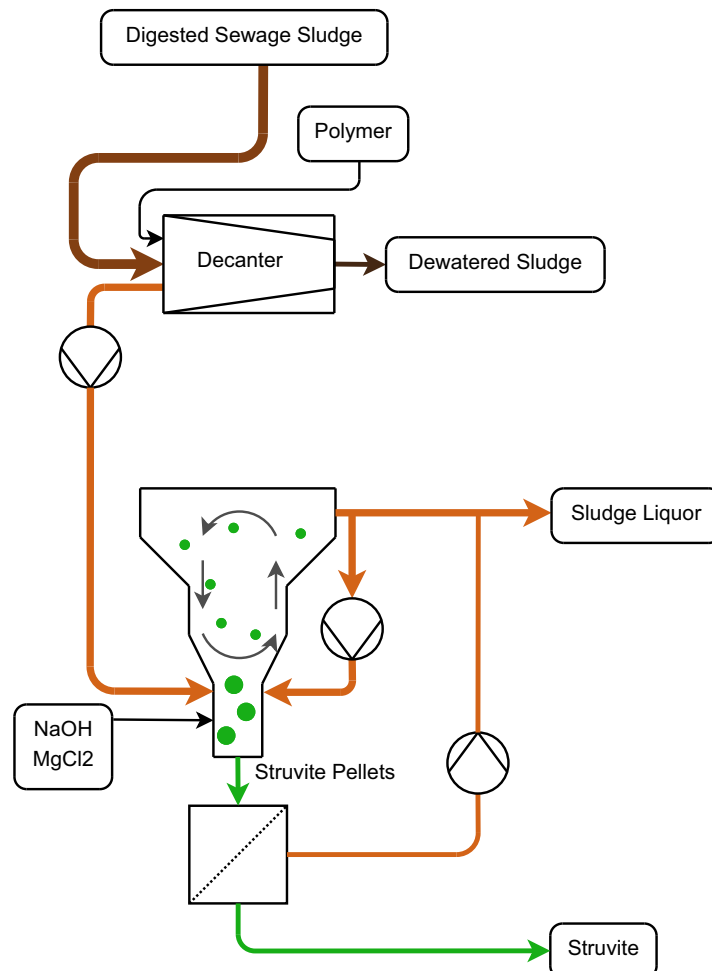
Short description

The Pearl[®] process is developed and commercialized and licenced by OSTARA Nutrient Recovery Technologies Inc. (Vancouver, Canada) which specializes in nutrient recovery from municipal and industrial wastewaters. Pearl[®] is designed to prevent unwanted struvite incrustation after sludge dewatering in EBPR WWTPs. It is currently operated at several WWTPs in Canada, the US and the UK.

The crystallization reactor is installed directly after the dewatering unit and treats the sludge liquor. Struvite is

precipitated by dosing MgCl₂ and increasing pH with NaOH dosing. Internal recirculation in the PEARL[®] reactor assures proper mixing and good crystal growth, while the specially designed reactor shape guarantees uniform crystal size and optimum hydraulic conditions. Crystalline pellets reaching the desired size sink to the bottom of the reactor where they are harvested. The extracted struvite prills are dried in a fluidized bed dryer. The product (Crystal Green[®]) is very uniform and highly pure.

Process scheme



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General Data

Type of Process	crystallisation
Type of Plant	crystallization reactor
Input Material	sewage sludge liquor
Product	struvite
P-concentration	28 % P ₂ O ₅ of DM
P recovery performance ¹	12 % of P in sludge input

Supply

Average total electricity demand ¹	2.2 [kWh/kg P _{recovered}]
Average total heat demand ¹	1.8 [kWh/kg P _{recovered}]
Average chemical demand ¹ (as 100% concentrate)	3.1 [kg MgCl ₂ /kg P _{recovered}] 1.0 [molar ratio MG:P _{recovered}] 0.8 [molar ratio Mg:P _{dissolved}] 0.2 [kg NaOH/kg P _{recovered}]

Advantages

- WWTP retrofit possible by implementation after centrifuge
- Prevention of struvite incrustations after centrifuge
- High purity of struvite product and defined prill size
- Proportional reduction of phosphorus and nitrogen return load from sludge liquor

Remarks

- The process is limited to WWTP with enhanced biological P removal and more than 50 mg/L PO₄-P in sludge liquor
- Product yield can be enhanced by thermal or chemical hydrolysis (increase of PO₄-P in sludge liquor)
- In combination with WASSTRIP® process for P release prior to digestion, P recovery can be significantly increased while improving sludge dewaterability and digester capacity

Patents and Licenses

Patent held by	Ostara Nutrient Recovery Technology Inc.
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Website	www.ostara.com

References

Hillsboro (Oregon)

Start of operation	2012
Scale	930 t struvite/a

London (Slough)

Start of operation	2013
Scale	150 t struvite/a

¹Process data related to reference sludge line defined in P-REX (digested sludge of wastewater treatment plant for 1 Mio inhabitant equivalents, dry matter (DM) content: 3%, P content: 4.2% of DM, PO₄-P in liquor: 200 mg/L (EBPR) or 10 mg/L (ChemP), Fe content: 2% (EBPR) or 6.6% (ChemP)). More information on modelling can be found in P-REX LCA report.



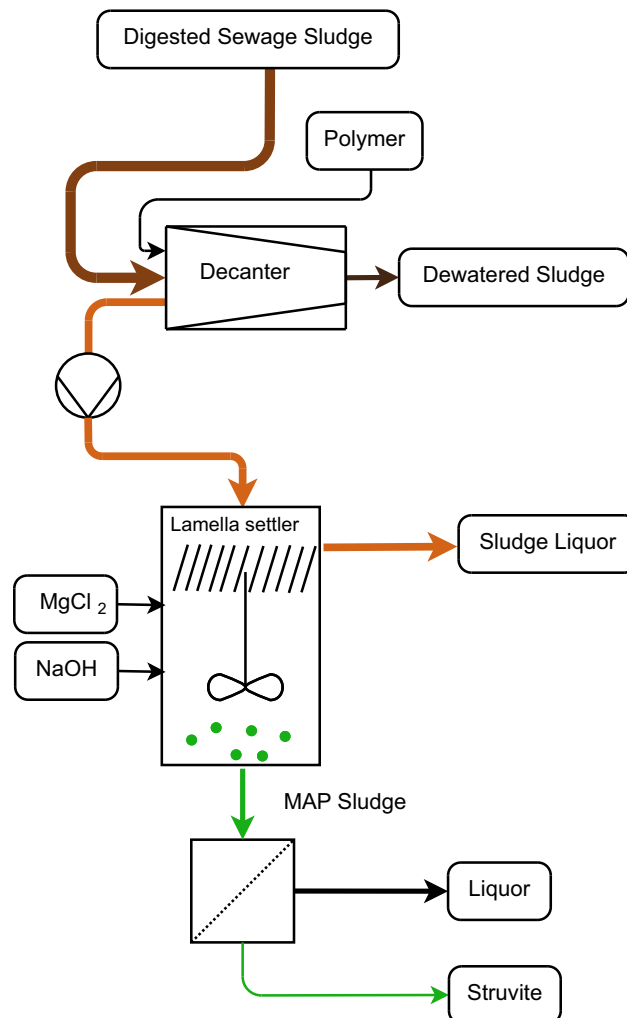
Struvia™ *Struvite crystallisation in sludge liquor*

Short description

The STRUVIA™ process is a modification of the phosphorus recovery technology Phostrip, originally developed by the Japanese company Showo Kankyo Systems K.K. (SKS). Since 2011, SKS is owned by Veolia Water which has developed the process into the current state and renamed the process to STRUVIA™.

For recovering struvite from sludge liquor, a continuous stirred tank reactor (CSTR) combined with a lamella settler on top are installed after the dewatering unit of a WWTP with enhanced biological P removal. Rapid mixing in the CSTR is enabled by a special mixing technology (Turbomix®). After dosing of $MgCl_2$ and $NaOH$ for pH adjustment to 8-9, struvite is precipitated and can be harvested as a clean powder at the bottom of the reactor. Struvite can be dried at low temp (40-50°C) before storage.

Process scheme



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General Data

Type of Process	crystallisation
Type of Plant	crystallization reactor
Input Material	sludge liquor
Product	struvite
P-concentration	29 % P ₂ O ₅ of DM
P recovery performance ¹	11 % of P in sludge input

Supply

Average total electricity demand ¹	1.3 [kWh/kg P _{recovered}]
Average total heat demand (optional)	0.9 [kWh/kg P _{recovered}]
Average chemical demand ¹ (as 100% concentrate)	3.2 [kg MgCl ₂ /kg P _{recovered}] 1.0 [molar ratio MG:P _{recovered}] 0.8 [molar ratio Mg:P _{dissolved}] 0.2 [kg NaOH/kg P _{recovered}]

Advantages

- WWTP retrofit possible by implementation after centrifuge
- Prevention of struvite incrustations after centrifuge
- High purity of struvite product
- Proportional reduction of phosphorus and nitrogen return load from sludge liquor

Remarks

- Process is limited to WWTP with enhanced biological P removal and more than 50 mg/L PO₄-P in sludge liquor
- Two process configurations: separated reactor and struvite settler (Turbomix® configuration) and integrated reactor and settler (Turboflo™ configuration)
- On demand the process is also capable of recovering P as calcium phosphate

Patents and Licenses

Patent held by	Veolia Environment
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References

Pilot plant on WWTP Brussels North (2013-2014)

Veolia subsidiary SKS

is successfully operating three reference WWTPs with hydroxylapatite or struvite production in Japan

- Urabandai plant: hydroxylapatite
- Hakusyu distillery: struvite
- Kyoto distillery: struvite

¹Process data related to reference sludge line defined in P-REX (digested sludge of wastewater treatment plant for 1 Mio inhabitant equivalents, dry matter (DM) content: 3%, P content: 4.2% of DM, PO₄-P in liquor: 200 mg/L (EBPR) or 10 mg/L (ChemP), Fe content: 2% (EBPR) or 6.6% (ChemP)). More information on modelling can be found in P-REX LCA report.



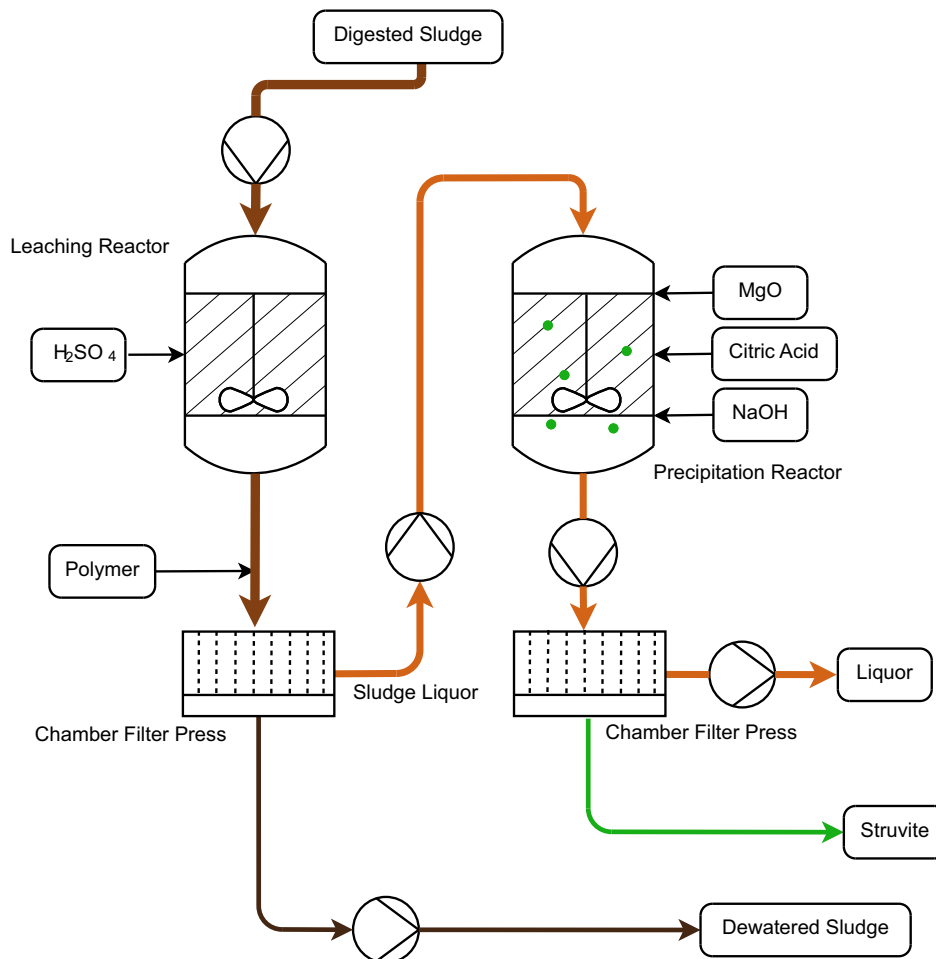
Stuttgart *Sludge leaching*

Short description

The STUTTART process for P recovery from digested sludge of chemical P removal WWTPs was developed at University of Stuttgart by the Institute for Sanitary Engineering (ISWA). The process is based on acidic extraction of P from digested sludge at pH 4 with addition of H_2SO_4 . After solid/liquid separation, dissolved Fe and heavy metals in

liquor are masked by citric acid to prevent their transfer into the P product. Struvite precipitation is initiated by dosing of MgO and raising pH to 8, adjusted with NaOH. Finally, struvite is harvested as a powder by solid/liquid separation and dewatering/drying.

Process scheme



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General Data

Type of Process	acidic dissolution and precipitation
Type of Plant	extraction and precipitation reactors
Input Material	sewage sludge
Product	struvite
P-concentration	27 % P ₂ O ₅ of DM
P recovery performance ¹	45 % of P in sludge input

Supply

Average total electricity demand ¹	4.8 [kWh/kg P _{recovered}]
Average chemical demand ¹ (as 100% concentrate)	11.9 [kg H ₂ SO ₄ /kg P _{recovered}] 1.5 [kg MgO/kg P _{recovered}] 1.2 [molar ratio Mg:P _{recovered}] 1.0 [molar ratio Mg:P _{dissolved}] 2.7 [kg NaOH/kg P _{recovered}] 3.9 [kg C ₆ H ₈ O ₇ /kg P _{recovered}]

Advantages

- Process applicable for WWTP sludge from enhanced biological or chemical P removal
- Complexation of Fe and heavy metals with citric acid
- Proportional reduction of phosphorus and nitrogen return load from sludge liquor

Remarks

- Higher rates of P recovery are possible at a pH lower than 4, but with reduced dewaterability and increased chemicals consumption
- Citric acid consumption depends on metal concentration (Fe) in input sludge

Patents and Licenses

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References

<i>Offenburg (Pilot plant)</i>	
Start of operation	2011
Scale	8.000 PE
P yield	50 kg struvite/d

¹Process data related to reference sludge line defined in P-REX (digested sludge of wastewater treatment plant for 1 Mio inhabitant equivalents, dry matter (DM) content: 3%, P content: 4.2% of DM, PO₄-P in liquor: 200 mg/L (EBPR) or 10 mg/L (ChemP), Fe content: 2% (EBPR) or 6.6% (ChemP)). More information on modelling can be found in P-REX LCA report.