Phosphorus recycling by Mephrec®
– State of development –

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1 Introduction

Phosphor (P) is an essential raw material to human life. Phosphorus is absorbed by food and ultimately taken away from soils for agricultural crop production. About 30% respectively 150.000 t P of the German annual phosphorus need are applied in the form of mineral fertilizers. This fertilizer is produced from rock phosphate mining. Since the European Union has no significant deposits and the production of rock phosphate is concentrated in countries that either have a high personal use (China, USA) or are in politically unstable regions (e.g. Morocco), there is a dependence on imports of rock phosphates. In addition, the finite natural phosphates are increasingly polluted with heavy metals such as cadmium and uranium, which could endanger the soil and groundwater in agricultural use. Unlike crude oil, phosphorus cannot be replaced by any other material. Against this background, the recycling of phosphorus is becoming increasingly important. Therefore, waste with significant phosphorus contents such as sewage sludge, animal by-products and sewage sludge ashes are the focus of recycling.

Sewage sludge represents the pollutant sink during wastewater treatment and contains large amounts of phosphorus. In Germany, approximately 50% of sewage sludge is currently used as fertilizer in agriculture respectively for landscaping. The remaining part is disposed thermally [1]. Due to an increasing concern about potential health and environmental risks by the use of sewage sludge in agriculture, it is expected that this recycling method will continue to loose importance for the benefit of combustion. In Germany, this development is supported by a clear political will regarding phosphorus recycling. This is clearly reflected in the current coalition agreement “Shaping Germany’s future”. In Chapter “water and marine protection” it is said “We will end the sewage sludge as fertilizer and recover phosphorus and other nutrients…..” [2].

Today's mono- and co-incineration does not achieve this goal. The resulting ashes are entirely disposed and the phosphorus contained therein is permanently removed from the economic cycle.

The afore-mentioned facts clearly show the need for alternative sources of phosphorus and appropriate methods for phosphorus recovery.

Following this need, there have been developed a variety of methods within the last 10 years with the target to separate phosphorus (or phosphate) from waste water or sewage sludge and recover it for the use in agriculture. The below table shows the actual technique of phosphorus recovery processes from waste water, sewage sludge and meat and bone meal ash.

P-Recovery sewage sludge			
Process	**Location/Operator**	**Scale***	**Product**
AirPrex®	Waßmannsdorf (DE) BWB	full	MAP plant
AirPrex®	MG-Neuwerk (DE) Niersverband	full	MAP
AirPrex®	BS-Steinhof (DE) SE|BS/AVB	full	MAP in sludge
AirPrex®	Wieden-Echten (NL)	full	MAP
AirPrex®	Amsterdam (NL) In Vorbereitung	full	MAP
LYSOGEST®	Lingen (DE) SE Lingen	full	MAP
NuReSys®	Leuven (BE) Aquafin	full	MAP BIOSTRU®
PHOSPAQ	Olburgen (NL) Waterstromen	full	MAP
PHOSPAQ	Lomm (NL) Waterstromen	full	MAP
CRYSTALACTOR®	Geestmerambacht (NL)	full	CaP
Gifhornprocess	Gifhorn (DE) ASG	full	MAP
Fix-Phos	Hildesheim (DE) SEHi	full	CaP in sludge
Stuttgarter Verfahren	Offenburg (DE)	Pilot	MAP
BudenheimVerfahren	Mainz (DE)	Pilot	CaP
P-recovery process water			
Process	**Location/Operator**	**Scale***	**Product**
REPHOS®	Molkerei Altentreptow (DE) Remondis Aqua	full	MAP
PEARL® (PEARL 500)	Slough (UK) Thames Water	full	MAP Crystal Green™
NuReSys®	Molkerei (BE)	full	MAP BIOSTRU®
NuReSys®	Kartoffelverarbeitung (BE) Harelbeke	full	MAP BIOSTRU®
NuReSys®	Kartoffelverarbeitung (BE) Nieuwkerke	full	MAP BIOSTRU®

NuReSys®	Kartoffelverarbeitung (BE) Waasten	full	MAP BIOSTRU®
NuReSys®	Pharmaindustrie (BE) Geel	full	MAP BIOSTRU®
P-RoC	Neuburg (DE)	Pilot	CaP
PHOSTRIP	Brüssel Nord (BE) Aquiris (Veolia Eau)	Pilot	MAP or CaP
P-recovery during or after thermal treatment			
Process	**Location/Operator**	**Scale***	**Product**
MEPHREC®	Nürnberg (DE) SUN	full	P-slag
SUSAN	Königs Wusterhausen(DE) RETERRA	Full	P-fertilizer
ICL Düngemittelproduktion	Amsterdam (NL) Ludwigshafen (DE)	Full	P-fertilizer
LeachPhos	MSWI plant of Bern (CH)	Pilot	MAP or CaP
EcoPhos/SNB/HVC	EcoPhos (BE)	full	DCP

*Systems already in operation or under construction

Picture 1: Actual technique of phosphorus recovery processes from waste water, sewage sludge and meat and bone meal ash [3].

The present report concerns the Mephrec®-procedure what is a thermal P-recycling procedure. The state of development and further planned steps will be especially presented. After initial tests in an examination plant at the TU Freiberg, a pilot plant in semi-industrial scale is now built on the site of the wastewater treatment plant in Nuremberg.

The brand Mephrec® (Metallurgical Phosphorus Recycling) as well trade mark rights belonging to the Mephrec®-procedure have been registered by company ingitec Engineering GmbH We, company Baumgarte Boiler Systems GmbH, keep the global exclusive rights to distribute and to market the Mephrec®-method.

2 Mephrec®

In general, the Mephrec®-process or Mephrec®-reactor is a shaft furnace or cupola furnace. In long tradition, metals are melted in shaft furnaces. In 1794, John Wilkinson invented the cupola furnace to produce even small-scale cast iron.

Mephrec®-process means that during a metallurgical process, an oxygen melting gasification of P-containing materials such as sewage sludge (or sludge ash) is carried out. For this purpose, briquetted sewage sludge is gasified. Ash components are melted at about 2000°C. The phosphorus-rich liquid slag is separated from the iron metal alloy. After its solidification in a water bath it has a plant-available form. The fertilizer product is in conformity to the fertilizer ordinance.

2.1 Process description

In the current state of the art, material and energy recovery from sewage sludge and animal meal, i.e. fertilization vs. combustion, are mutually exclusive. The situation is different view the Mephrec® process. The Mephrec® method is a one-step method for the simultaneous material and energy utilization of sewage sludge. The dewatered and dried sewage sludge is briquetted in an upstream process step. The briquettes with a residual moisture content of less than 15% will be treated with the addition of coke and limestone inside the Mephrec® reactor.

The melt-gassing process produces:

- a liquid iron alloy
- a phosphorus-rich slag granulated in a water bath with a low heavy metal content and high plant-availability
- a fuel gas for energy use

2.1.1 Features

The process is characterized by the following specific features [4] [5]

- Simultaneous material and energy recovery from sewage sludge
  - Economical method for phosphorus recycling
  - Energetic use of raw gas in the existing incinerator (e.g. waste incineration plant)
  - In-process waste heat utilization for sludge drying
- High process flexibility
  - Use of briquettes from sewage sludge, sludge ash and other phosphorus-containing substances
  - Easy to combine and integrate into other processes
- High environmental compatibility
  - Products free of organic pollutants
  - Extremely low heavy metal content in produced slag (especially Cd, U and TI)
  - High plant-availability of the slag's phosphate (>90% P2O5-lemon soluble)
  - Good energy use
  - Exhaust air from sewage sludge drying is transferred to the combustion plant. Consequently, no need of external cleaning

2.1.2 Process components

2.1.2.1 Briquette loading

The dewatered sludge is dried to about 85% dry matter (DM) and then pressed by high pressure into briquettes without the addition of binders. After briquetting, the briquettes are ready for immediate use in the melting gasifier. The slag composition can be influenced by the addition of aggregates, but it is not mandatory.

The sewage sludge briquettes, coke and slag upon request (e.g. limestone) are batched via belt conveyor in a bucket and quasi-continuously supplied to the melting gasifier.

2.1.2.2 Shaft melt-gasification①

The below image shows the Mephrec®-reactor with offtake for the production of raw gas, granulated slag as well as iron ingots of a metal alloy.

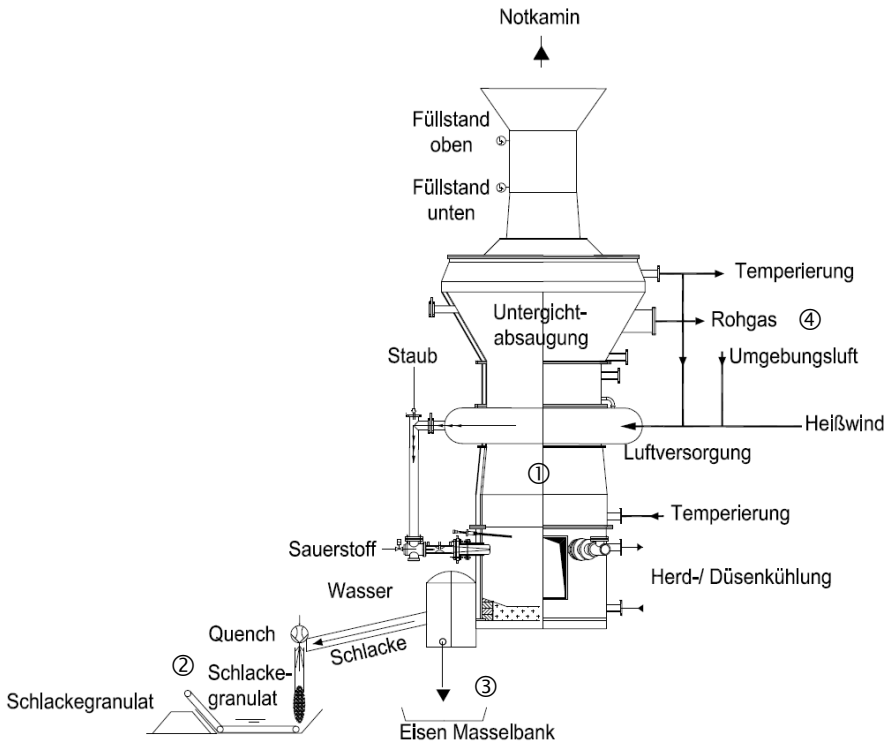

Figure 2: Schematic diagram of Mephrec®-reactor

The required air is firstly used for the temperature control of the double-walled furnace shaft. Via nozzles, it is then supplied to the melting gasification process. The heat is transferred to the material supplied from above in counter flow. The dust is supplied by a mechanical dosing into the vertical branch lines of wind power. Special injectors inside the nozzle head accelerate the dust as propellant by means of oxygen and blow it into the filling of high temperature zone with high flow velocity.

2.1.2.3 Slag granulation ②

The slag continuously flows from the siphon at the melting gasifier into a water bath. The scraper belt inside the water bath ensures a uniform granule and transports the material via a ramp into the bunker. To dry the still warm material, the bunker is ventilated. After drying the granules have a saleable form.

2.1.2.4 Iron separation ③

The reduced operation as well as the metallic content of raw materials, results in a iron-metallic melt. This is intermittently decanted into chill castings. These iron ingots could be in melting units in the iron and steel industry and/or foundries.

2.1.2.5 Raw gas ④

The produced raw gas is removed via a suction chamber (offtake) from the melting-gasifier. In the downstream cyclone dust is deposited. Depending on the location of the Mephrec®-reactor, the raw gas can be integrated either with or without cleaning into the power generation process. It can be used both latent and sensible heat of the raw gas.

3 Development stages

3.1 Test facility (Freiberg)

In 2008/2009, the testing of the Mephrec® process in laboratory scale was successfully performed at the TU Freiberg for the first time.

Mephrec® method was tested for the first time in 2008/09 in a pilot plant of the TU Freiberg under industrial conditions. This project was funded by the German Federal Environmental Foundation (DBU) under the project reference number 24557-23 AZ. A modified shaft furnace with a throughput of 300 kg / h of waste briquettes was used. The main furnace parameters as well as a picture of the small cupola furnace are specified in the table below.

Figure 3: Small cupola furnace: Charging unit, circuit gas pipe, injector and drainage channel, furnace paramater [4]

Furnace parameter	
Inside width furnace shaft	400 mm
Furnace shaft	
Furnace shaft	refractory
Height	approx. 2000 mm
Oxygen-injector	1 piece
SL1) Fe liquid	approx. 450 kg/h
SL1) Sewage sludge briquette	approx. 300 kg/h
Hot blast temperature	approx. 350 °C
Effective melting time	approx. 2 • 3 h
Operation of	
Slag melting	possible
Iron melting	possible
Operating modes	
Gas operation	possible
Oxygen	possible
Oxygen + air	possible
Air	possible
Dust injection	possible
Gas burner	Possible
1) Melting capacity	

Significant results from these experiments:

- Confirmed functionality of the Mephrec® method
- Mephrec® completely destroyed all organic pollutants contained in the sewage sludge and in the animal meal at temperatures up to 2000 ° C by the reducing melting
- Melting under reducing conditions leads to lower heavy metal contents of Mephrec slag than the sewage sludge in accordance with the applicable regulations (AbfKlärV) permissible levels,
- Phosphates in the generated product have a high plant availability [6]
- Granules is a primary product for phosphorus, nitrogen-phosphorus or nitrogen-phosphorus-potassium fertilizer
- Fine content of the granules can be directly used directly as P-fertilizer
- Mephrec® is very interesting for economic reasons

The final report [4] described in detail the technology and corresponding tests “Metallurgical phosphor recycling of sewage sludge and filter dust as a prerequisite for the economic production of a high-phosphorus fertilizer from phosphorus precipitation”.

The general suitability of this method and the quality of the products were demonstrated experimentally at the Foundry Institute of the Technical University of Freiberg in a small cupola furnace.

After these experiments, the city of Nuremberg has investigated 13 process concepts in the context of a European ideas competition in order to improve the future in the metropolitan area of ecological and economic criteria regarding the local economy, climate protection and the efficient use of resources, waste water and energy. As a result, the incineration of sewage sludge was selected with the Mephrec® method as the method with the greatest potential [7]. An investigation that was prepared on behalf of the Bavarian Ministry [8] also came to the conclusion that the project for the incineration of sewage sludge is not only for the Nuremberg Metropolitan Region, but in general the most promising model for implementing a nationwide phosphorus recovery.

3.2 Pilot plant (the project)

The findings from the studies in Freiberg and a feasibility study carried out on behalf of the City of Nuremberg were not sufficient to bring the risks of the construction and operation of such a large-scale technical solution to an acceptable level for the operator and/or installer. Therefore, a pilot plant at semi-industrial scale in the context of a research and development project should provide evidence that Mephrec® method is a reliable and economical solution.

The pilot plant respectively project is promoted by the German Federal Ministry for Education and Research in the ERWAS program under the title ERWAS - Collaborative project KRN-Mephrec: sewage sludge recycling region of Nuremberg - sewage sludge into energy, fertilizer and iron with metallurgical phosphorus recycling in one process step (Code: 02WER1313). The pilot plant will be built on the site of the sewage treatment plant 1 in Nuremberg and has a total volume of approx. € 5.7 million.

The alliance partners (see figure) are the city of Nuremberg as planning company and location donors, Baumgarte Boiler Systems GmbH as a private sector partner and process supplier, the company Innovatherm GmbH as the operator of a sewage sludge mono incineration plant and four renowned research institutes (see Figure 4)

Figure 4: Project partners KRN-Mephrec [9]

The project collaboration partners investigate and study the technical feasibility, economic viability and environmental sustainability of the metallurgical phosphorus recycling as an integrated, thermal process of sewage sludge gassing.

This pilot plant enables to test the Mephrec® method in its core components and develop the method for continuous industrial operation. Further evidence of technical feasibility, economic viability and environmental sustainability of the Mephrec® method is to be

provided. The process should be confirmed as a technological alternative to the use of sewage sludge to meet the domestic demand for high-quality phosphorus fertilizer according to energy and environmental aspects.

The research project is divided (focal points) in three areas:

- Regional sewage sludge utilization concept,
- Development of procedures and chain
- Analysis of product quality and marketing opportunities.

The topic "Regional sewage sludge recycling concept" concerns a concept of regional management is created with the purpose to combine the waste stream of wastewater treatment in the Nuremberg Metropolitan Region to enable a sustainable and economical management with maximum use of sewage sludge. The approach is ecologically reported. The effect of the concept is compared with the established sewage sludge recycling in Germany.

The topic "Development of the process chain" scientifically considers the issues of technology and their implementation on a large scale, taking into account the established procedure. In the first trial phase of the reactor is fed with dried, briquetted sludge. In another phase of the project sludge briquettes are replaced and tested by sewage sludge ash briquettes from the mono-incineration.

The third topic "Investigation of the product quality and marketability" examines the product's quality. In addition, the overall potential of the management system is explored. Its ecological and economic aspects in their importance for the wastewater sector of the Nuremberg region and the medium-term strategy of sludge and phosphorus recycling of the federal and state governments are determined as well.

The pilot plant has a capacity of 0.5 t/h sewage sludge (TS). The technical equipment of the pilot plant is reduced to the essential components of Mephrec®. The following flow diagram (P & ID) shows the system components of the pilot plant incl. flue gas cleaning. The flue gas cleaning is necessary as a use of the synthesis gas is not provided (internal post-combustion in the reactor). The synthesis gas will only be analyzed in the course of tests.

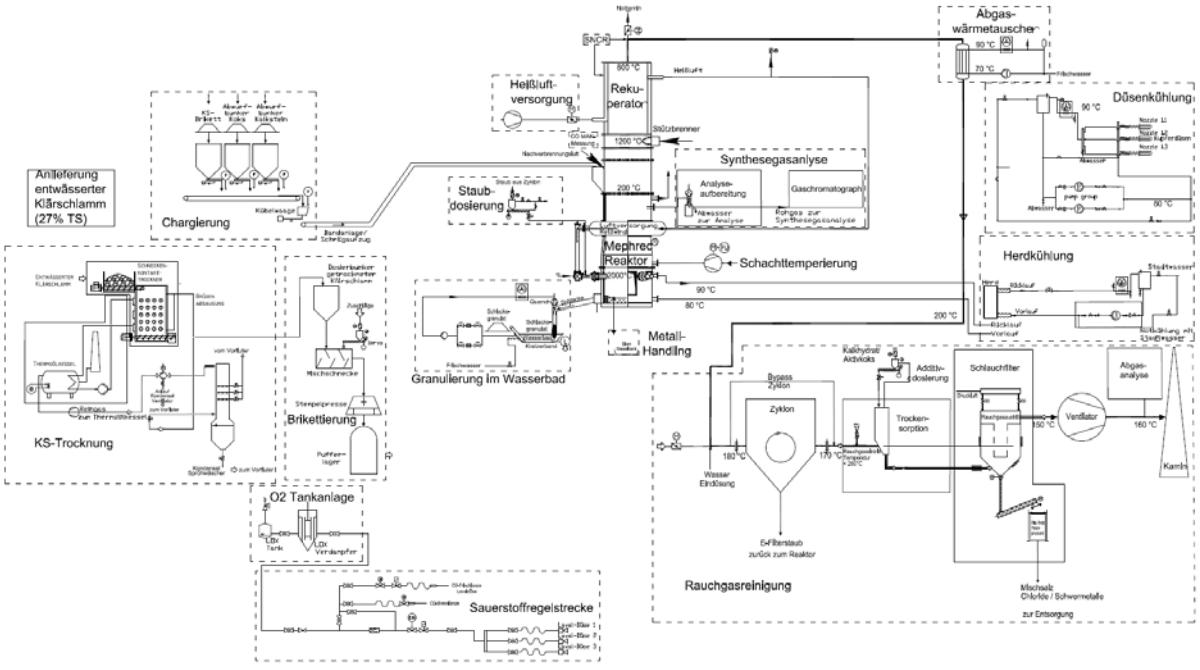

Figure 5: Flow diagram of pilot plant

End of October 2014, the project partners received the allocation decision. In November 2014 the project realization was launched. Figure 6 shows the coordinated schedule. The construction of the plant will be completed by autumn 2015. Thus, first test results will probably be available in the spring of 2016. The completion of the project is planned for the middle of 2017.

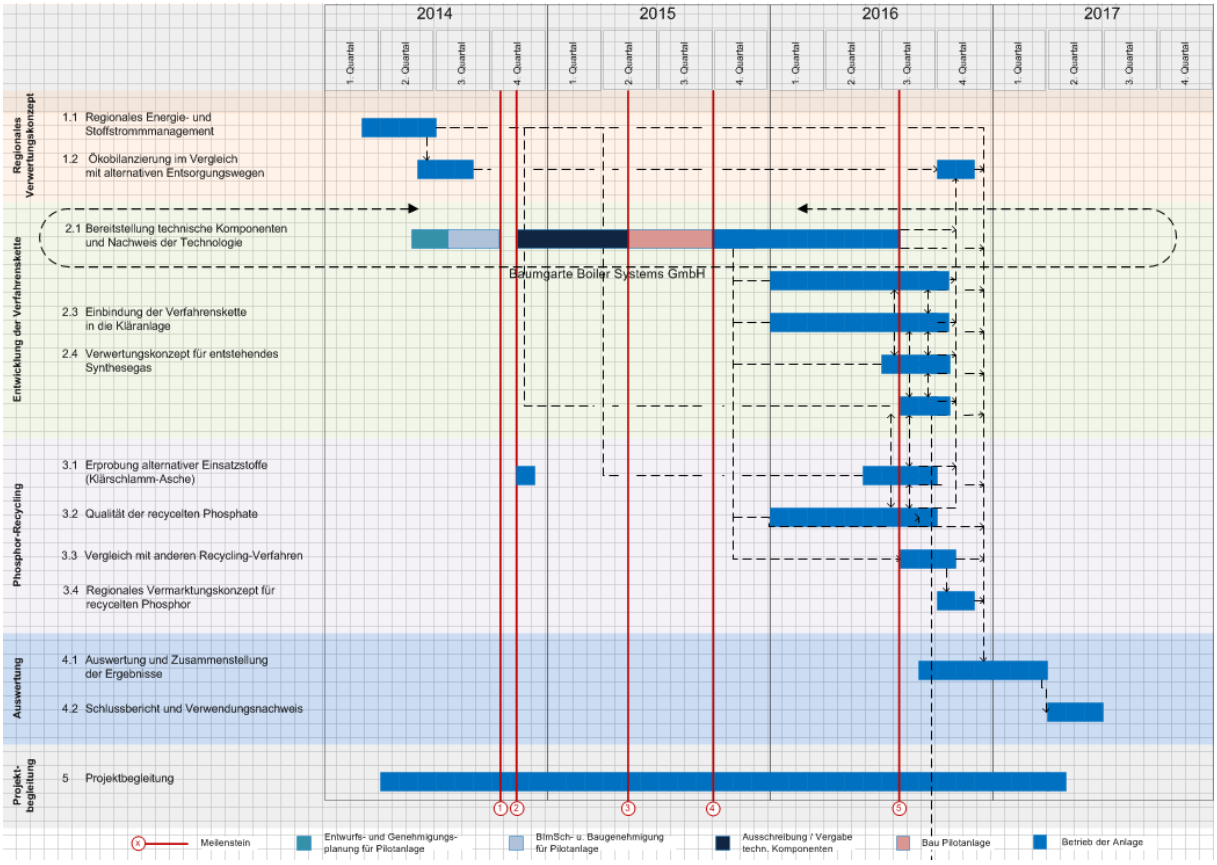

Figure 6: Schedule

Upon successful completion of this project, i.e. if the above project objectives have been achieved, the cities of Erlangen, Fürth, Nuremberg and Schwabach intend to recycle together the dewatered sewage sludge by using the Mephrec® method.

The sewage sludge Region Nürnberg GmbH (KSVN GmbH) then has the task to realize the design, construction and subsequent operation of a treatment facility for sewage sludge at the site of the WWTP 1 in Nuremberg for up to 70,000 tons (approx. 25% TS) dewatered sewage sludge. The throughput performance of the large-scale plant will be 2.5 t/h sludge TS.

4 Possible locations for Mephrec®

In addition to use on the area of wastewater treatment plants, where the sewage sludge is produced directly, the following alternative locations could be taken into consideration as well:

- behind a sewage sludge mono incineration plants
- before respectively inside waste incineration plants
- at sites with phosphorus-containing waste

In addition to the preferred location in sewage treatment plants, the Mephrec® method or a Mephrec® plant are particularly interesting for waste incineration. There are substantial synergies in systems engineering: e.g. sludge drying could be made or supported the by waste heat from the waste incineration plant. The produced fuel gas can be effectively used in the existing system without further treatment. A new flue gas cleaning is not necessary also since such systems are already equipped in accordance with 17th BImSchV.

For any location, individual observations are carried out under ecological and economic aspects for any location.

5 Summary

The increasing efforts to develop suitable methods for phosphorus recovery clearly show the increasing importance of this topic.

P-recycling attracts worldwide attention and the political will for the recovery of phosphorus and phosphate is clearly stated not only in Germany.
The presented Mephrec® method is characterized by the following specific features:

- simultaneous material and energy recovery from sewage sludge and other phosphorus-containing waste materials,
- high procedural flexibility
- high environmental compatibility.

The contradiction between material and energetic utilization of sewage sludge and animal meal, i.e. fertilization vs. combustion is no longer susceptible.

Through testing with the test facility at the Technical University of Freiberg, the suitability of the process and the quality of products has been approved. Studies [6] [7] certify that the Mephrec® method has a very large potential respectively the most promising method view economic and environmental aspects.
The ERWAS - Collaborative project KRN-Mephrec: sewage sludge Region of Nuremberg - sewage sludge to energy, fertilizer and iron metallurgical phosphorus recycling in one single process step now examines the technical feasibility, economic viability and environmental sustainability in the semi-industrial scale.

Preliminary results will be available in mid-2016. Upon a positive project development, we hope that this joint project and possible subsequent projects make a valuable contribution for the recovery phosphorus from phosphorus-containing waste (sewage sludge, animal by-products and sewage sludge ashes). Finally, we contribute to the reduction of pollutants in fertilizers for crop production as well.

6 Sources

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