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PhosFad

Production of mineral phosphate fertilizer from a secondary source with a filamentous bacterium

Motivation

- **phosphate is essential for** all **living** being[1]
- Europe has no primary phosphate sources[2] → local secondary sources demanded
- **aim:** production of **15 000 t a^{-1} phosphate** from secondary sources **in Germany**

Pig slurry as secondary source

- availability in **North Rhine-Westphalia** through **high density of pig farms**[3]
- provides a quantity of 30 600 000 t a^{-1} with a **potential of 85 680 t a^{-1} phosphate**[4]
- eutrophication due to **over-fertilization with raw slurry** can be **counteracted**[5]
- **ecologically beneficial** through **closed loop recycling** management

Press screw separator

- throughput: raw slurry 500 000 t a^{-1}
- separates in 90 % liquid and 10 % solid fraction[6]
- solvation of **87 % phosphate into liquid phase**[7]
- thick slurry processed in biogas plant

Sterile filtration

- retention of contaminating microorganisms
- **82 % remaining phosphate** of raw pig slurry for fermentation[8]
- pore size 0.2 µm

Phosphate separation by *Beggiatoa leptomitoformis*

Microscopic image of the strain *B. leptomitoformis* sp. nov. D-402T; Scale bar size: 10 µm[9]

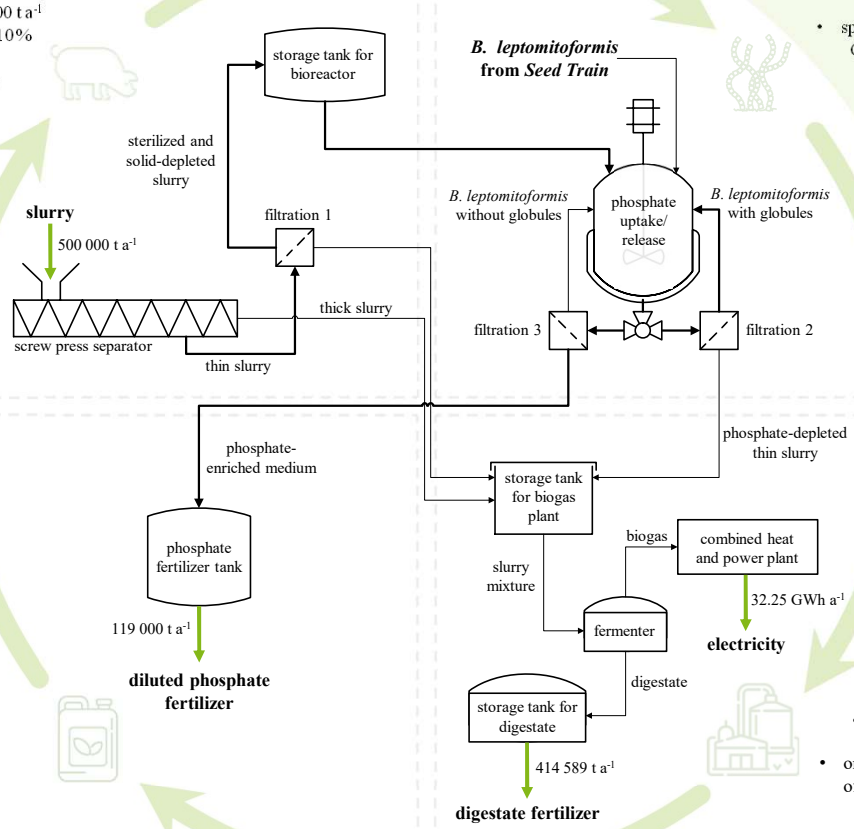
I **phosphate uptake** from sterilized thin slurry by *B. leptomitoformis*
T = 28 °C, t = 72 h, Y = 75 $g_{phosphate}$ $kg^{-1}_{bacteria}$

2 **separation** of phosphate-depleted thin slurry from **bacteria** with **phosphate globules**

II filling up the tank medium and heat to **48 °C**, hold for **4 h;** polyphosphate globules are **released** back into the medium as phosphate

3 **separation** of phosphate-enriched medium from bacteria **without globules**

phosphate-enriched medium refills container in step II for phosphate accumulation until 6 wt.-%



Beggiatoa leptomitoformis:

- species name *leptomitoformis* means in Greek "shaped like a narrow **filament** (deutsch: 'Faden')", from which the concept name **Phos*Fad*** is derived[10]
- mixotrophic freshwater sulfur bacterium[2]
- **incorporation** of polyphosphate globules[11]
- **re-release** of the globules in case of **heat**[11]
- cultivation takes place separately in *Seed Train*

Product quality

- **790 t a^{-1}** per plant of liquid fertilizer
- achieving a mass fraction of **6 wt.-%** by recirculation the product stream
- product price **9 € l^{-1}**

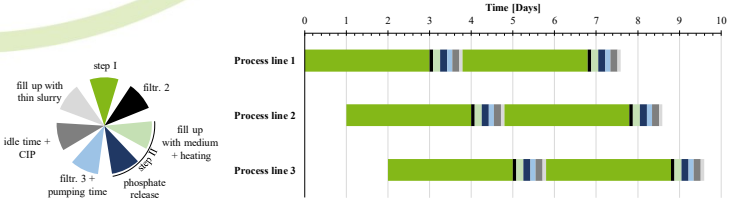
CO_2 – Balance in total

Logistics
- slurry transport by truck
- **586 t CO_2-EQ per year**

Biogas plant
- **161 t CO_2-EQ per year**

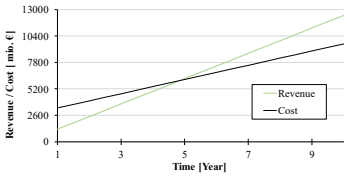
Gantt-Chart for phosphate separation

- three process lines operate parallel with 24 h offset in every plant (20 plants in total)
- three bioreactors per process line
- each bioreactor has a volume of 500 m³
- 22 charges per year and plant
- one charge every 15 days with overall product of 5 400 m³ phosphate fertilizer



Break-Even analysis

- plant amortises after **5 years**
- target quantity is reached by **20 plants**
- cost **for 20 plants**[13]
  - Investment costs: **2 640 mio. €**
  - Variable costs : **600 mio. € a^{-1}**



Source	Revenue [€ a^{-1}]
Phosphate fertilizer	1 307 mio.
Digestate fertilizer	98 mio.
Electricity	77 mio.
Σ	**1 482 mio.**

ReSults

- ✓ **15 000 t a^{-1} pure phosphate**
- ✓ **119 000 m³ phosphate fertilizer**
- ✓ **yield of 56.5 %**
- ✓ **local resource in Germany**

Biogas plant

- processes **waste stream of 423 000 t a^{-1}**
- CH_4 12.9 mio m³ biogas with 60 % methane
- generates **32.25 GWh a^{-1}**
  → supply of whole plant
  → excess fed into power grid
- wet fermentation (solid fraction is under 10 %)[12]
- fermentation sludge used as **digestate fertilizer**
- **Phos*Fad*-plant operates CO_2-neutral**

[1] Killiches, F., Gebauer, H.-P., Franken, G., Röhling, S., Schulz, P. u. Müller, H.: Phosphat: Mineralischer Rohstoff und unverzichtbarer Nährstoff für die Ernährungssicherheit weltweit. 2013 [2] Bundesanstalt für Geowissenschaften und Rohstoffe: Phosphat. Rohstoffwirtschaftliche Steckbriefe. Hg. v. Bundesanstalt für Geowissenschaften und Rohstoffe, 2014. www.bgr.bund.dew [3] Bestand an Schweinen in Deutschland nach Bundesländern im Jahr 2022. https://de.statista.com/statistik/daten/studie/28795/umfrage/schweinebestand-in-deutschland/, abgerufen am: 06.09.2022 [4] Statistisches Bundesamt: Die Hälfte der Landwirte düngt mit Gülle. https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Landwirtschaft-Forstwirtschaft-Fischerei/Produktionsmethoden/aktuell-duengen.html, abgerufen am: 20.05.2022 [5] Indikator: Eutrophierung von Flüssen durch Phosphor. https://www.umweltbundesamt.de/daten/umweltindikatoren/indikator-eutrophierung-von-fluessen-durch-phosphor#welche-bedeutung-hat-der-indikator, abgerufen am: 06.09.2022 [6] Stallkamp: Gülle separieren. https://www.stallkamp.de/produkte/separatoren/guelle-separieren, abgerufen am: 14.07.2022 [7] Landwirtschaftkammer: Nährstoffabscheidegrade und Gaserträge der Feststoffe bei verschiedenen Separationsverfahren. https://www.landwirtschaftskammer.de/duesse/znr/pdfs/2013/2013-10-31-gaerreste-04.pdf, abgerufen am: 16.07.2022 [8] Landwirtschaftskammer NRW: Aufbereitung von Gülle und Gärsubstraten - verschiedene Verfahren und deren Einsatzbereiche: https://www.am.rlp.de/Internet/global/themen.nsf/0/801cad4d9f5a6165c125834800227f65/$FILE/G%C3%BClle%20Celejewski%20DLR2019-pdf.pdf, abgerufen am: 15.05.2022 [9] Dubinina, G., Savvichev, A., Orlova, M., Gavrish, E., Verburg, S. u. Grabovich, M.: Beggiatoa leptomitoformis sp. nov., the first freshwater member of the genus capable of chemolithoautotrophic growth. International journal of systematic and evolutionary microbiology 67 (2017) 2, S. 197–204 [10] Grabovich, M. Y. u. Dubinina, G. A.: Mixotrophic and Lithoheterotrophic Growth of the Freshwater Filamentous Sulfur Bacterium Beggiatoa leptomitoformis D-402. Mikrobiologiya 67 (1998) 4, S. 464–470 [11] Sandra Havemeyer: Polyphosphate storage in the family Beggiatoaceae with a focus on the species Beggiatoa alba, Universität Bremen Dissertation. Bremen 2013 [12] Fachagentur Nachwachsender Rohstoffe e.V.: Leitfaden Biogas - Von der Gewinnung zur Nutzung. https://www.fnr.de/fileadmin/allgemein/pdf/broschueren/Leitfaden_Biogas_web_V01.pdf, abgerufen am: 16.07.2022 [13] Woods, D. R.: Rules of thumb in engineering practice. Weinheim, Chichester: Wiley-VCH 2010