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First Author:	**Marieke Verbeke**
Co-author(s):	**Emilie Snauwaert**
Name of the responsible WP Leader:	**Emilie Snauwaert**
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https://systemicproject.eu/

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Scenario's and schemes of proven NRR techniques: first version

Marieke Verbeke, Emilie Snauwaert

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Content

Preface

This confidential report is a first version of the report that bundles knowledge and information regarding the efficiency of current nutrient recovery techniques for different types of digestate and also producing different end products.

In the report a list is provided with available full-scale proven and cost-effective nutrient recovery technologies and process approaches, which focus on the nutrient recovery efficiency rate.
A set of schemes with key techniques or technique cascades will put forward as starting point of discussion with the outreach locations when a business case with nutrient recovery is constructed for each specific case.

The report will be updated throughout the project and will be finalized in deliverable D3.2 to a public report with on January 31st 2020.

Summary

The information compiled in this report will be focussing on the recovery rate or efficiency of current full scale proven nutrient recycling and recovery (NRR) techniques.
In addition to the recovery rates, data will also be gathered on the different feedstocks, the composition of the digestate and end product quality.
If data on harmful components and heavy metals is available, it will also be included, as well as economic data (investment cost, maintenance cost, chemical cost, etc) gathered by WP2.

The information will be gathered by WP3 in scientific literature (publications, reports, press articles), outreach locations, associated plants. WP1 will provide data on the demo plants and all SYSTEMIC partners share their experiences and existing knowledge regarding NRR from other EU-projects and meetings.

The collected data will be summarized in the publicly available report on scenario's and schemes of proven NRR techniques (D3.2) which will be finalized on January 31st, 2020.
Meanwhile, the data will be stored in a non-limitative database which will be the foundation of the publicly available web-based tool, being developed during the SYSTEMIC project.
Together with the consortium, the outreach locations will the first to test the tool when in development and combine it with potential region-specific demands for recovered products and regional legislation to come to proposal(s) for specific business case(s) with NRR for each outreach location.

Key NRR technologies identified so far are:

- Liquid-solid separation techniques
- Ammonia stripping-scrubbing
- Drying and evaporation
- Phosphorus precipitation
- Biological treatment

These technologies are seen on full scale in configurations that by combining these technologies can ultimately lead to recovery of each nutrient or resource (N, P, K and other salts, organic matter, water) in separate end products.

1 Creating the database

1.1 Targeted information

The information compiled in this report will be focussing on the recovery rate or efficiency of current full scale proven nutrient recycling and recovery (NRR) techniques.
The recovery rate is defined as the percentage of the initial amount of organic matter, nutrients (N, P, K) or minerals that end up in the end product.
The same description is valid for the separation efficiency when a separation technique is used.

In addition to the recovery rates, data will also be gathered on the different feedstocks, the composition of the digestate and end product quality. Next to the technology itself, these parameters will have a large impact on the recovery rate.
Moreover, they will also determine the choice of the NRR technique (next to marketability of the end product or economic benefit).

Regarding information on the composition of feedstocks, digestate and end products, focus will be on the parameters in Table 1-1. If data on harmful components and heavy metals is available, it will also be included, as well as economic data (investment cost, maintenance cost, chemical cost, etc).

Table 1-1 Parameters focussed on in data collection

Parameter			
Density	Mineral N (ammonium + nitrate +nitrite)	Total P	Na
Viscosity	Ammonium N	Total P_2O_5	S
pH	Nitrite N	Organic phosphorus	Sulphates
Dry matter	Nitrate N	C:P	Electrical conductivity
Organic dry matter	Organic nitrogen	K-total	Cl
Total organic carbon	Kjeldahl-N (org N+ ammonium + nitrate)	Mg	F
Total N	C:N	Ca	

1.2 Information sources

The information will be gathered from:

- Scientific literature (publications, reports, press articles)
- experiences and existing knowledge of the consortium partners gained in other EU-projects and meetings
- Practical data on full scale NRR techniques from the participating biogas plants in SYSTEMIC
    - The demonstration plants
    - The outreach locations
    - The associated plants

Information from the demo plants is mainly collected by WP1 when setting up the mass balances for each one of them. A sampling period is planned during the project in order to fill in the missing gaps.

WP2 will analyse each demo plant's business case and will provide a summary on investment cost, maintenance cost, chemical cost and cost of recovery per kg N or P.
With this information we will be able to argument to the outreach locations if the business cases with NRR technologies theoretically are economically feasible and cost-effective.

WP3 as responsible for the outreach locations and associated plants, will coordinate the data collection from them and the assessment and development of NRR business cases. Analyses on digestate and end products of the outreach locations could be provided by the project to complete missing data.

1.3 Information output and dissemination

The collected data will be summarized in the **publicly available report** on scenario's and schemes of proven NRR techniques (D3.2) which will be finalized on January 31st, 2020.
In the report a list will provided with available full-scale proven and cost-effective nutrient recovery technologies and process approaches, which focus on the nutrient recovery efficiency rate.
It will also include a set of schemes with key techniques or technique cascades of current full-scale installations.

The data will be stored in a non-limitative database. The **database itself will not be published**, due to confidentiality of certain data from the Demo Plants, Outreach Locations and Associated Plants.
However, the database will be the foundation of the **publicly available web-based tool**, being developed during the SYSTEMIC project.
This quantitative tool will be used to support cost-benefit analysis (CBA) and help biogas plants in the selection of NRR technology combinations.
During the development of the tool, the outreach locations will get the chance to experiment with and feedback on it.
Together with the consortium, they will use and combine it with potential region-specific demands for recovered products and regional legislation to come to proposal(s) for specific business case(s) with NRR for each outreach location.

2 Collected data

This chapter gives a brief summary of the collected data after 12 months in the project (June 2017-June 2018).

2.1 Set-up of a database

The collected data were first compiled in an Excel-file®. A lot of time was spent on designing the database (cfr. Easy to input data and to look up data). In the last few months this has been improved by replacing the Excel-database by an Access-database®, which is more powerful in storing and finding the wanted data. A lot of time was invested in creating a user-friendly input form (Figure 2-1).

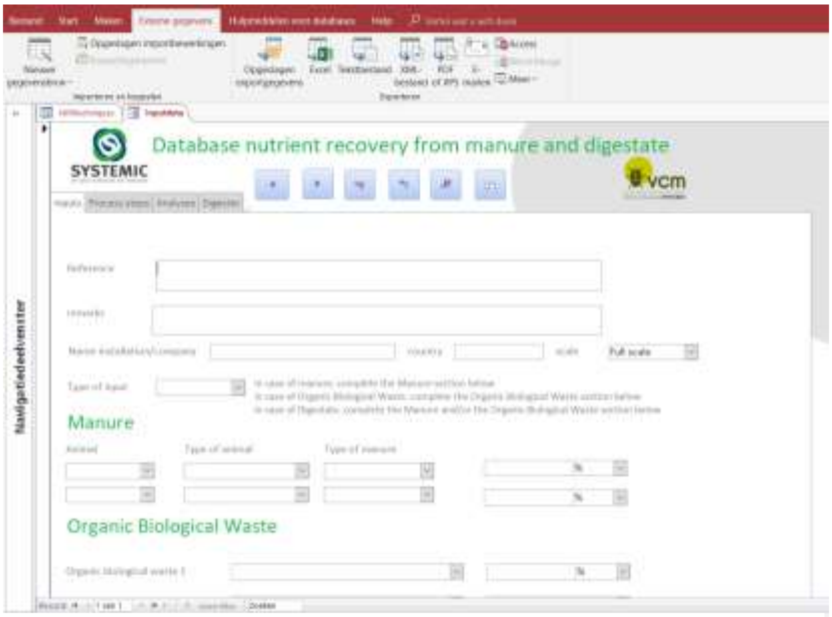


Figure 2-1 Screenshot of the input form of the Access-file®

2.2 Literature

The consulted literature consisted of scientific publications. Each record in the database gives information on a specific feedstock (mix), digestate or end product and contains analyses or average values, median, 10 percentiles, etc. of the recovery rate, the parameters described in Table 1-1. Each record also contains the technology cascade that was needed to come to this product. F.e. an analysis of N-total and P-total is given for the liquid fraction of digestate (from manure and organic biological waste), after separation by means of a centrifuge (Figure 2-2). .

Table 2-1 gives an overview of the amount of records collected in the database from each type of recovered end product.

Table 2-1 Number of records in the database (May 2018)

Type of records	Sample	Number of records
Scientific literature	Ammonium nitrate solution	28
	Ammonium sulphate solution	6
	Compost	2
	Mineral concentrate	3
	Dried digestate	5
	Digestate	46

	Dried solid fraction digestate	3
	Dried solid fraction manure	2
	Effluent biological treatment manure	3
	Liquid fraction digestate	9
	Liquid fraction manure	27
	Manure	32
	Permeate ultrafiltration	2
	Solid fraction digestate	15
	Solid fraction manure	26
	Total records	475
Digestate mono- digestion	Manure	26
Digestate bio-waste	Mix of different types bio-waste	7
Digestate from co-digestion	Manure and bio-waste	22
	Total records digestate streams (with feedstock info available)	55
Full scale plant data on end products		100
	Total records full scale plant data	128

2.3 Information from project partners

Data on recovery rates of the technology cascades from the Demo plants is already available (see D 1.2 "First annual updated report on mass and energy balances, products") and basic data is also collected from the twelve outreach locations (D 3.3 "Fact-sheets on outreach locations").

From several consortium partners, scientific publications were supplied, that still need to be processed and fed into the database (Drosg et al. 2015; Menkveld and Broeders 2017; Mykkänen and Paavola 2016; Schoumans et al. 2017).

In the coming years, the database will also be supplemented with economical information (investment cost, operational cost, transport cost, maintenance cost, chemicals cost, energy cost/benefit, etc) from the Demo Plants and outreach locations.

2.4 Strategy in further developing the database

Next to further extending the database content, obtaining the following types of data would make the dataset more robust:

- Full scale data instead of pilot scale or lab scale
- Data on the viscosity of digestate, since this appears to have a large impact on the separation of the digestate, which is usually the first step towards nutrient recovery
- Data on digestate and end products from feedstocks similar to those of the demo plants
- Data on digestate and end products rendered from similar technology cascades of the demo plants, outreach locations and associated plants
- Data from suppliers all over Europe on recovery rates of different NRR technologies on different types of digestates
- More data from or through the consortium partners and other projects.

3 Full scale proven NRR techniques

A combination of the current database and information from the demo plants, outreach locations and associated plants is used to create a first version of a list with full scale proven techniques or approaches for nutrient recovery.

3.1 Separation of digestate

The first step in nutrient recovery is usually the separation of digestate in a liquid and a solid fraction. Phosphorus, mostly bound to the organic matter will be concentrated in the solid fraction and the soluble compounds (N and K) stay in the liquid fraction.

Cascades with other NRR technologies
Separation technologies are:

- frequently the first step towards nutrient recovery (cfr. Liquid-solid separation of digestate)
- used to separate end products:
    - screw press to separate organic soil improver from P-poor liquid fraction (4.2.1) (Re-P-eat system at Groot Zevert Vergisting, The Netherlands) *building phase*
    - filter press to separate ammonium sulphate solution from calcium carbonate (Benas, GNS Halle, Germany)
    - screw press to separated digestate after ammonia stripping-scrubbing from Biogas-fibres®(Benas, GNS Halle, Germany)

3.1.1 Centrifuge

A frequently used technology to separate digestate is a (decanter) centrifuge. The centripetal force is used in a centrifuge to separate particles with a higher density from the liquid.

The separation efficiency is different for each type of digestate due to its texture and viscosity and composition, which are determined by the feedstock and the retention time in the digester.

When the digestate contains less fibrous material, separation can be difficult and addition of polymers or complexing agents (e.g. $FeCl_3$, $Fe_2(SO_4)_3$, etc.) can be necessary to improve the separation efficiency (GEA, personal communication, 2015).

The level of optimisation (e.g. a higher P recovery rate) is not automatically obtained by adding a higher concentration of polymer. Therefore, often consultants are relied upon to help choose the type of polymer (water- or oil based, powder polymer) and determine the concentration that should be added to the digestate (VCM 2018b). This is done on lab scale (so called jar-tests) and confirmed and finetuned in full scale on site.

The brands of decanter centrifuges currently appearing in the database are Pieralisi, Alfa Laval, GEA Westfalia and PaulMichl.

Figure 3-1 shows a summary of the most common technology cascade when using a centrifuge. The recovery rates mentioned are with and without polymer or the use of additives is not known. It shows that the mass separation (liquid-solid fraction) is quite predictable, but the recovery rates for phosphorus are quite variable.

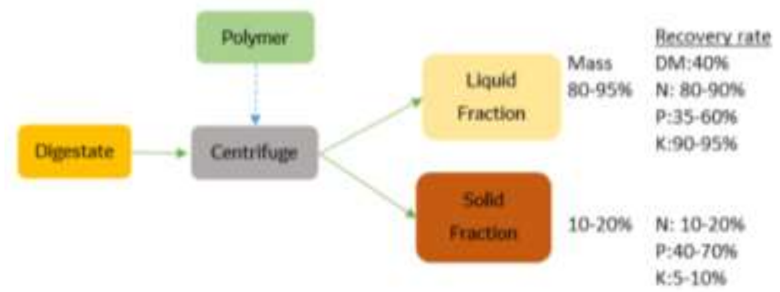
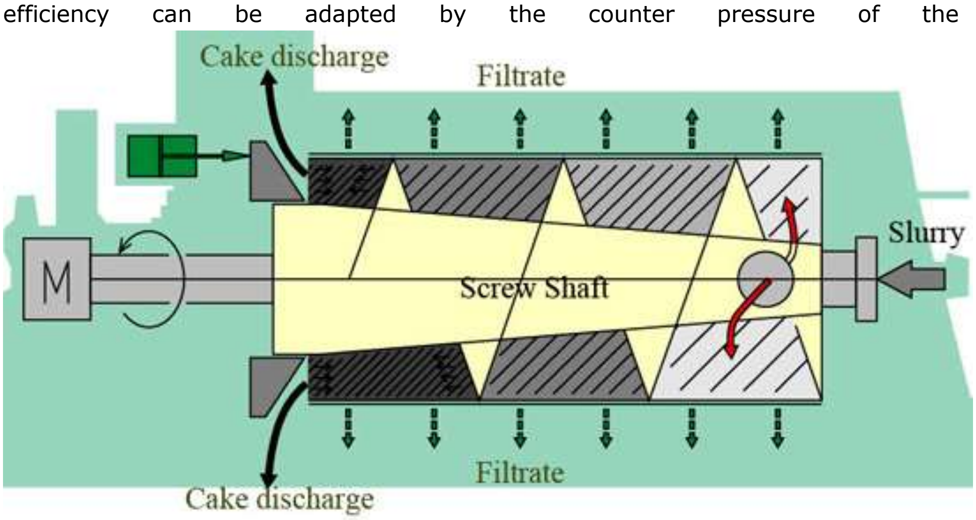


Figure 3-1 Scheme of separation of digestate with decanter centrifuge and recovery rates.

3.1.2 Screw press

A screw press consists out of a central screw housed in a cylindrical sieve cage with a screen. This separation is therefore based on particle size (filtration).The screw ensures a gradual increasing pressure and the solid fraction is retained by this screen and goes out through an outlet pipe. The separation efficiency can be adapted by the counter pressure of the outlet opening.



Figuur 3-1 Working principle of the screw press ("Ishigaki Company website: Filtration, Solid/Liquid Separation : ISGK Screw Press," 2018).

Digestate contains very little fibres compared to (cattle) manure which makes it hard to separate with a screw press. Nonetheless, in practice, separation of digestate from mono-digestion of cattle manure or co-digestion with bio-waste is also done with a screw press (VCM 2018b).

Besides the technology and the settings of the separator, the separation efficiency depends on the chemical characteristics of the digestate (DM-content, digester retention time, etc.). Again, the use of additives can improve the separation efficiency.

Separation by centrifuge obtains a higher P-separation efficiency (Figure 3-1), whereas with the screw press a higher DM-separation efficiency can be reached (Figure 3-2). Therefore it is mainly suitable for obtaining a high DM-content, instead of efficiently separating nutrients.

The brands of screw presses currently appearing in the database are FAN and Dorset.

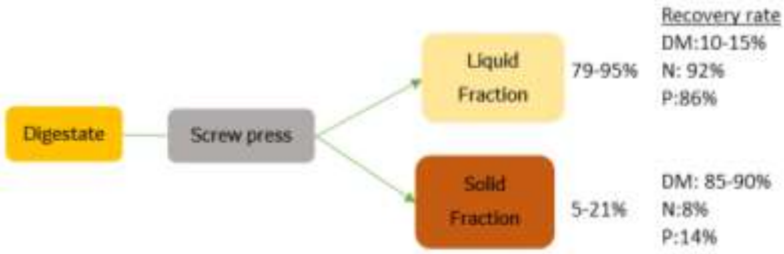


Figure 3-2 Scheme of separation of digestate with decanter screw press and recovery rates.

3.1.3 Dissolved air flotation (DAF)

A DAF is mainly used as an additional separation step, to remove suspended solids, oil, fats and grease and other apolar substances from liquid fraction.

Complexing agents like $FeCl_3$, $Fe_2(SO_4)_3$, organic coagulants, etc. are used to coagulate these unwanted substances. Polymer is added to flocculate the created complexes. By decompressing compressed air, very small air bubbles are created, which a released on the bottom of the tank.

The flocs attach to the bubbles and float to the surface where they form a crust, which can be scraped off (Lebuf et al. 2013).

Again, a balance has to be found in dosage of coagulant and polymer to become good flocs and not use to much of these additives. Therefore, often consultants are relied upon to help choose the type of polymer (water- or oil based, powder polymer) and determine the concentration that should be added to the digestate This is done on lab scale (so called jar-tests) and confirmed and finetuned in full scale on site.

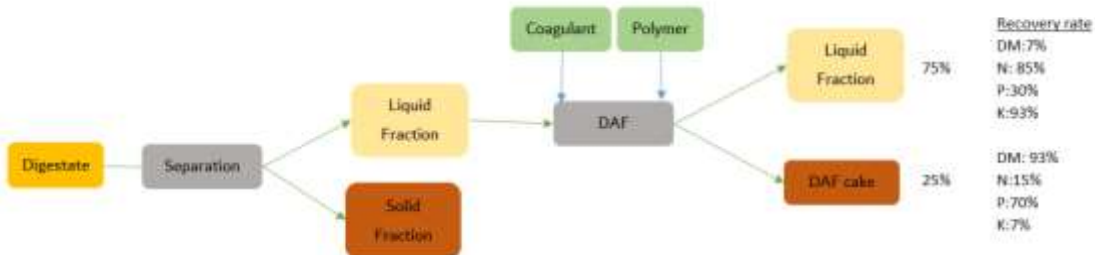


Figure 3-3 Scheme of separation of liquid fraction of digestate with DAF and recovery rates.

3.2 Ammonia stripping-scrubbing

The ammonia stripping and scrubbing technique can be applied on a nitrogen rich waste stream, such as (liquid fraction) of digestate, manure, waste water or air (only scrubbing).

As shown in **Fout! Verwijzingsbron niet gevonden.**, ammonia is removed (stripped) by blowing air or steam through the digestate in a tray or packed tower. The liquid stream enters on top of the system (on a packing material), while the air enters at the bottom. In this way ammonia is exchanged from the liquid to the gaseous phase in a counter current system. The stripping gas, charged with ammonia, is then captured and the ammonia is removed (scrubbed) by washing it with a strong acidic solution, such as sulphuric acid or nitric acid, in the scrubbing system. The stripping gas from which the ammonia is removed can be reused in the stripping tower.

Depending on the technology provider, it can be important that the input steam does not contain a lot of suspended solids or fibres, since this could cause clogging of the packing material.

To obtain optimal removal, the temperature increased to 70°C and the pH of the influent is often raised to 10 to shift the NH_4^+/NH_3 equilibrium towards free ammonia (Lemmens et al. 2007). The latter can be done with NaOH or $Ca(OH)_2$, or by stripping the influent from CO_2.

As stripping and scrubbing of ammonia occurs in a closed system, emissions will be low.

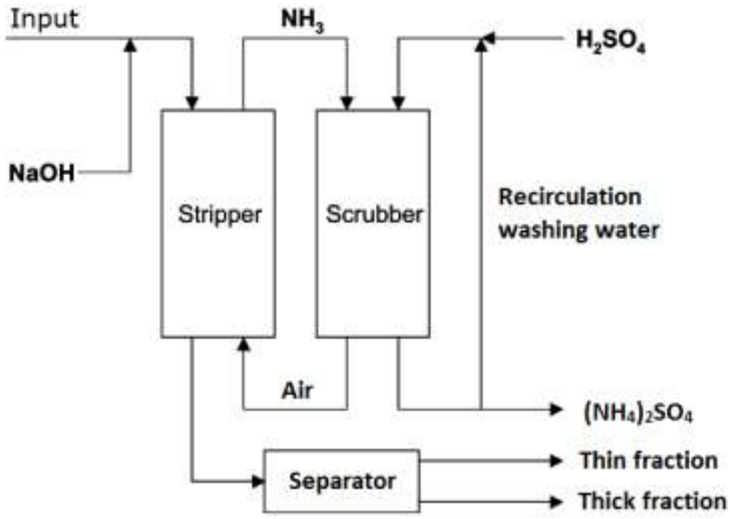


Figure 3-4 Schematic overview of the stripping and scrubbing technique to recover ammonia from manure. Source: modified from (Melse et al. 2004)

The acidic solution used to wash the ammonia (NH_3) from the air is usually sulphuric acid (H_2SO_4). A chemical reaction creates an ammonium sulphate ($(NH_4)_2SO_4$) solution.

Similar to synthetic produced mineral N fertilisers, ammonium sulphate contains Total N entirely in mineral form, as NH4-N. Since the product is obtained by means of sulphuric acid, ammonium sulphate is also an important source of sulphur (S). Depending on the amount of added acid, it is not only S concentration that will vary, but also the pH and EC. Low pH and high EC values should be taken into account during the product application process since it can cause the corrosion of machinery. But also produces limits N-emissions to the atmosphere during application in comparison with raw manure (SYSTEMIC et al. 2018).

Nitric acid (HNO_3) can also be used as scrubbing acid, which reaction with NH_3 would produce ammonium nitrate. The cost of nitric acid is higher, but the N-content of the end product is higher (up to 18 mass% N), and a neutral pH-value gives it a higher market potential (Digesmart 2016).

Table 3-1 gives a short list of some constructors/distributors of ammonia stripping scrubbing technologies on (liquid fraction of) digestate/manure.

Table 3-1 Overview of some constructors/distributors in the EU (non-exhaustive)

Name/type	Company	Remarks/More information
LGL stripper	Dorset Green Machines B.V. (NL)	http://www.dorset.nu/en/
/	Detricon (BE)	http://detricon.eu/
Amfer	Colsen (NL)	
Farmcubes	Circular Values (NL)	https://farmcubes.eu/
Digestate treatment System	GNS Halle (DE)	https://www.gns-halle.de/english.html
/	Biolectric (BE)	under development
Nijhuis Ammonia Recovery Unit	Nijhuis Water Technology (NL)	http://www.nijhuisindustries.com/
NITROstripp	BTS Biogas technology (DE)	http://www.bts-biogas.com/

Cascades with other NRR technologies

N-recovery technologies/cascades can be combined with

- with P recovery (N, mineral concentrates) from the solid fraction (RE-P-eat process, Wageningen University & Research, Groot Zevert Vergisting, The Netherlands; BioEcoSIM, Germany). *building phase*
- biological nitrification-denitrification of the liquid fraction (Waterleau New Energy, Belgium)
- air washing of exhaust air from drying installations (Biogas Bree, Belgium)

3.2.1 Air washers

In animal housing and manure or digestate processing facilities the N-rich air can be washed to prevent ammonia emissions to the atmosphere: via fans the air is drawn into an air scrubber where the ammonia is captured into water as dissolved ammonium by a low pH 'scrubber' solution. For air washing usually a sulphuric acid solution is used and ammonium sulphate is produced (SYSTEMIC et al. 2018).

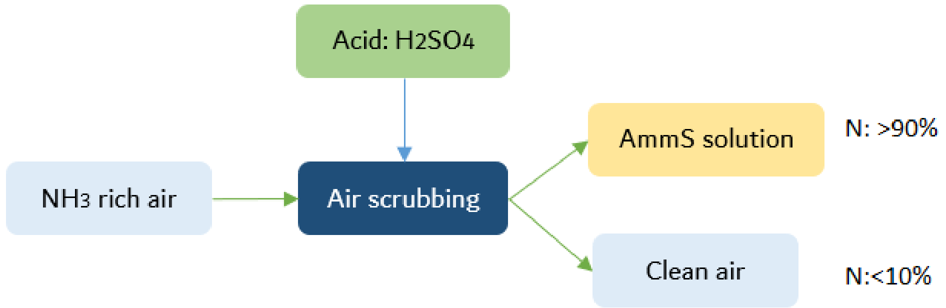


Figure 3-5 Scheme air scrubbing and recovery rates.

Table 3-2 Product characteristics of ammonium sulphate (air washing) in ranges based on average values reported in scientific studies (SYSTEMIC et al. 2018)

Parameter	**Ammonium sulphate**
Dry matter (%)	14-33
Electrical conductivity (mS/cm)	2,40-6,43
N total (g/kg)	30-86
NH4-N (g/kg)	30-86
S (g/kg)	30-114

3.2.2 Inline stripping

Some feedstocks (manure, proteins) contain a lot of molecules with a high nitrogen content, which cause high concentrations of ammonia to be released in the digester during anaerobic digestion. This can cause inhibition of the Archae and will lower the biogas production (Krakat et al. 2017; SYSTEMIC et al. 2018). Ammonia stripping scrubbing of part of the digestate and recirculating it back to the digester will have a diluting effect on the ammonia concentration and recovers nitrogen (Ghyselbrecht et al. 2017).

When stripping with air, the oxygen in the stripping gas can also lower the activity of the anaerobic bacteria and therefore stripping with biogas can lead to higher biogas production (Bousek et al. 2016; VCM 2018a).

Figure 3-6 show a wide range of N-recovery rate, since the recovery efficiency can be controlled by using higher temperatures and recirculating the wash solution until it contains a certain concentration of nitrogen.

Figure 3-6 Scheme inline ammonia stripping scrubbing from digestate and recovery rates

3.2.3 End of pipe stripping

Ammonia stripping scrubbing can also be useful as a polishing step (before or after biological treatment), when focussing on lowering and recovering the nitrogen from the digestate for marketing reasons (f.e. low N fertilizing application limits in nitrate vulnerable zones).
Figure 3-7 shows again a wide range of N-recovery rate, since the recovery efficiency can be controlled by using higher temperatures and recirculating the wash solution until it contains a certain concentration of nitrogen.

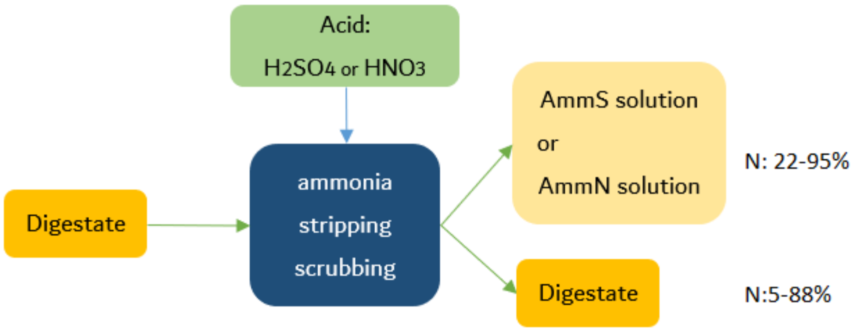


Figure 3-7 Scheme of ammonia stripping scrubbing from digestate and recovery rates

3.3 Membrane technologies

Membranes is mostly used on or pre-treated (liquid fraction of) digestate stream. Common technology cascades include reverse osmosis after microfiltration on condensate of the evaporator or on the liquid fraction of digestate after DAF.

Membranes can be made from different materials to have specific affinity for certain kinds of molecules (positively or negatively charged, apolar, etc.). The pore size of the membrane also determines which molecules go through and the pressure to be used. Microfiltration (MF) (pores > 0,1 µm, 0,1-3 bar), Ultrafiltration (UF)- (pores > nm, 2-10 bar) and Reversed Osmosis (RO) membranes (no pores, 10-100 bar).

A microfiltration membrane can retain suspended solids, while an UF membrane can also retain macromolecules.

Both can be put in series and thus serve as pre-treatment for reversed osmosis, preventing the blockage of the RO- membrane. Each membrane step produces a concentrate stream which has the suspended solids, macromolecules or ions, these are called "Mineral concentrates".

The permeate stream contains after reverse osmosis low concentrations of nutrients and can be discharged to sewer or surface water or re-used as process water (Hoeksma and De Buisonjé 2012; Hoeksma, de Buisonjé, and Aarnink 2012).

Therefore, membrane techniques are often used to reduce the volume of the digestate stream (Lebuf et al. 2013).

However, the RO membranes need to be regularly cleaned with chemicals to prevent fouling and scaling and need to be changed. The frequency of changing and the amount of cleaning depends on the efficiency of the pre-treatment steps .

Cascades with other NRR technologies

Membrane technologies can be a mineral concentrating step on

- The liquid fraction after centrifuge (Turbin at Arbio BVBA, Belgium) *building phase*
- The liquid fraction after ammonia stripping-scrubbing (3.2.3) ("GENIUS process"-Nijhuis Industries at Groot Zevert Vergisting, The Netherlands) *building phase*
- The liquid fraction after centrifuge and polishing by DAF (AMPower BVBA, Belgium)
- The condensate after evaporation of liquid fraction (own design at AMPower BVBA, Belgium) *building phase*

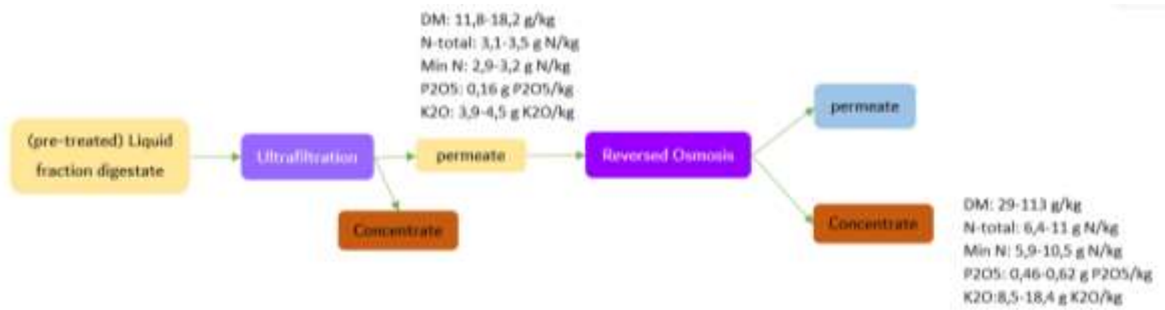


Figure 3-8 Scheme of membrane cascade (UF and RO) from (pre-treated liquid fraction of) digestate and characterisation of end products

3.4 Drying and evaporation

Cascades with other NRR technologies

Drying and evaporation of respectively solid fraction and liquid fraction/slurry of digestate combined with

- air washing (ammonia stripping) of the exhaust air from drying installations (Biogas Bree, Belgium) or an evaporator (Waterleau New Energy, Belgium)

3.4.1 Evaporators

Evaporation is a technique that is used frequently in the food industry and is used **on liquid streams**. Yet, it is also possible to evaporate pre-treated (liquid fraction of) digestate. Evaporation causes a large part of the water to be evaporated and volatile components to transfer to the gas phase. When cooling down, the water vapour condensates dissolving the volatile components (f.e. NH_3) in it creating a 'condensate'.

Meanwhile, solids, non-volatile components, salts, fats, etc. do not evaporate and are concentrated in the 'concentrate'(Gruwez 2012).

For example, ammonia/ammonium in a liquid stream will volatize and are concentrated in the condensate. The result is ammonium water (VCM 2018a).
The difference with ammonia stripping/scrubbing is that here, ammonia transfers from the liquid phase to the gas phase as NH_3 and in a second step, is captured in the liquid as a stable salt by means of a chemical reaction with acid solution.

The heat up the input stream for evaporation, steam is usually used (cfr. Heat exchanger).
The steam is produced with (RO permeate) water and heat preferably recovered from the digestion process or the condensed steam. Different configurations of the evaporator determine the amount of heat that can be re-used from the evaporation (Gruwez 2012).

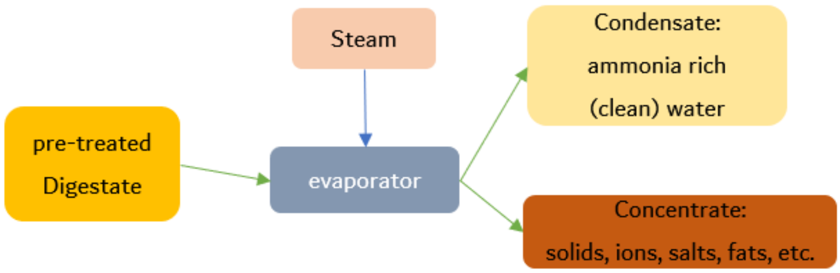


Figure 3-9 Process steps evaporator at Outreach locations Waterleau New Energy

3.4.2 Thermal drying

Thermal drying uses heated air, preferably by (recovered) heat from the anaerobic digestion process, to dry **slurries or solid input streams**, like (the solid fraction of) digestate.
Data on different types (drum dryer, disk dryer, band dryer, own designs, etc.) of dryers are available and the end products can contain up to 85% dry matter. The wide range in N and P content is due to the variability of the digestate feedstocks (bio-waste, manure, mix manure-bio-waste).

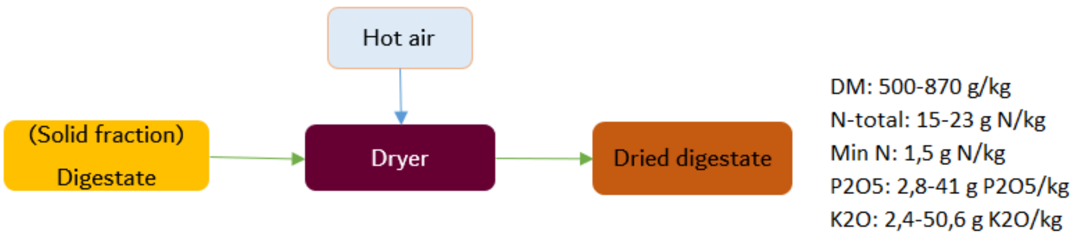


Figure 3-10 Scheme of thermal drying from (solid fraction of)digestate and characterisation of end product

3.5 Phosphorus precipitation

To recover the phosphorus, technologies that involve precipitation of phosphorus salts have proven efficient on full scale, mostly in waste water treatment. These technologies, like struvite precipitation are also transferable to other input streams, like digestate. Meanwhile, other technologies, exploring the precipitation of other phosphorus salts from digestate are almost ready for full scale (see chapter 4.2).

Cascades with other NRR technologies
Phosphorus precipitation technologies/cascades on can be combined with

- with nutrient recovery (N, mineral concentrates) from the liquid fraction (GENIUS process®,Nijhuis Industries, Groot Zevert Vergisting, The Netherlands; BioEcoSIM, Germany). *building phase*
- drying (e.g. concentrating) of the P-poor liquid fraction (Biogastur, Spain)
- drying of the P-poor solid fraction (BioEcoSIM, Germany; Re-P-eat, GZV, The Netherlands)
- dewatering of the P-poor digestate with a centrifuge (Waternet, The Netherlands)

3.5.1 Struvite

For phosphorus recovery from digestate, struvite ($MgNH_4PO_4.6\ H_2O$) precipitation, is already proven on full scale (VCM 2018b). Outreach location Waternet works with the Airprex® system (CNP) on raw digestate from WWT sludge and Biogastur recovers struvite with the ANPHOS® system (Colsen) on the liquid fraction of the digestate from co-digestion.
CO2 stripping by blowing air in the reactor shifts the pH to

$$Mg^{2+} + NH_4^{+} + PO_4^{3-} + 6\ H_2O \rightarrow MgNH_4PO_4.6\ H_2O \text{ (MAP or Struvite)}$$

Addition of $MgCl_2$ or $Mg(OH)_2$ is necessary because most digestates do not contain the right magnesium/ammonium/phosphate ratio's to create a controlled struvite precipitation in the reactor.

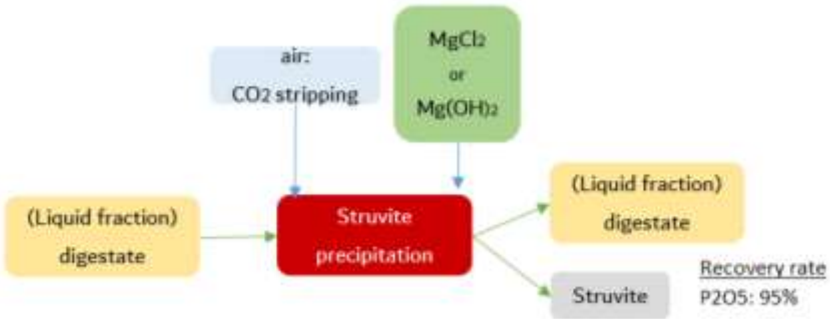


Figure 3-11 Scheme of struvite precipitation from (liquid fraction of) digestate and recovery rate

3.6 Biological treatment

In Flanders, Belgium, the most frequently used technique to process the surplus of nitrogen in (the liquid fraction of) pig and cattle slurry or digestate is biological nitrogen removal.
This is a system in which the bacteria in active sludge use oxygen to convert the ammonium in the manure to nitrate (nitrification). In low oxygen conditions they will convert the nitrate into (harmless) nitrogen gas (denitrification) that is released into the air as an inert gas.
After the treatment, the active sludge is separated from the liquid fraction (the effluent) by sedimentation. Part of the sludge can be reused in the tank in order to maintain sufficient bacteria for the biological process. The majority of sludge taken out and is used as organic fertilizer or is anaerobically digested.
Cascades with other NRR technologies
In the framework of nutrient recovery, biological treatment can be a polishing step after ammonia stripping-scrubbing (Waterleau New Energy, Belgium).
Effluent of biological treatment can be further purified to dischargeable water by:

- An active carbon filter
- Constructed wetlands

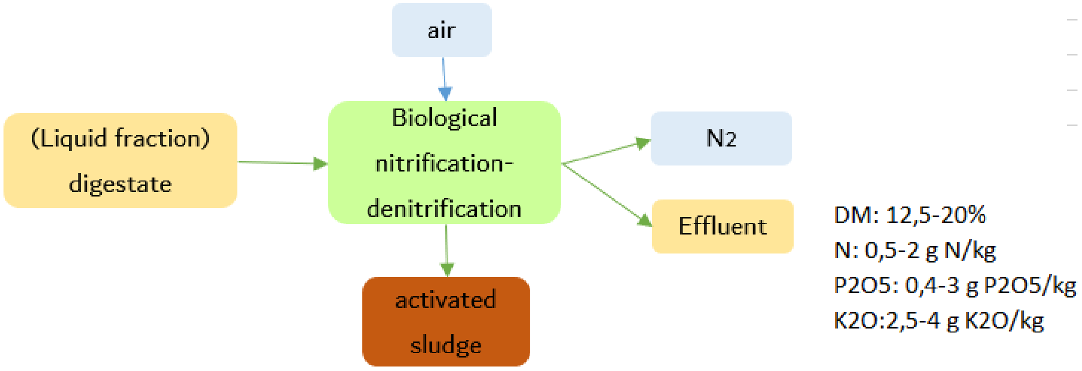


Figure 3-12 Scheme of biological treatment from (liquid fraction of) digestate and recovery rate

4 NRR techniques to be built in full scale

In the coming years of the project, the demo plants (and some outreach locations) will built NRR techniques in full scale that have proven themselves in pilot scale. **Data on recovery rates from these technologies will be available in the final version of this report.**

4.1 Evaporation

Demo Plant AMPower is building their own multiple effect, falling film evaporator. First part of the installation (2 steps of the 6 steps) will be ready in the end of 2018.
Ammonia/ammonium in the pre-treated digestate will volatize and concentrated in the condensate. The result is ammonium water (VCM 2018a) (Figure 4-1).

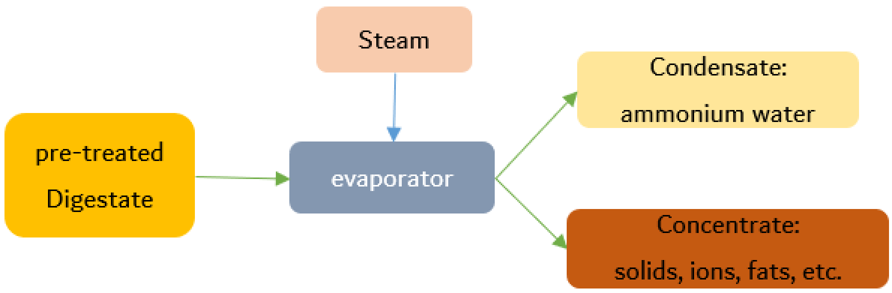


Figure 4-1 Process steps evaporator being built at Demo Plant AMPower

4.2 Phosphorus precipitation

4.2.1 Re-P-eat

The Re-P-eat (Recovery of P to eat) procedure, developed by Wageningen University and Research is and acid-alkaline approach, tested in pilot scale Demo Plant Groot Zevert Vergisting and being built in 2018.

The Re-P-eat system processes the solid fraction of digestate (3.1.1). By adding acid to it, the pH will drop, bringing P_2O_5 in the liquid phase. By a second liquid-solid separation (3.1.2) a P-poor organic soil improver and a P-rich liquid fraction are created. After adding Ca(OH)2 to the latter, phosphate salts can be recovered after sedimentation and drying.

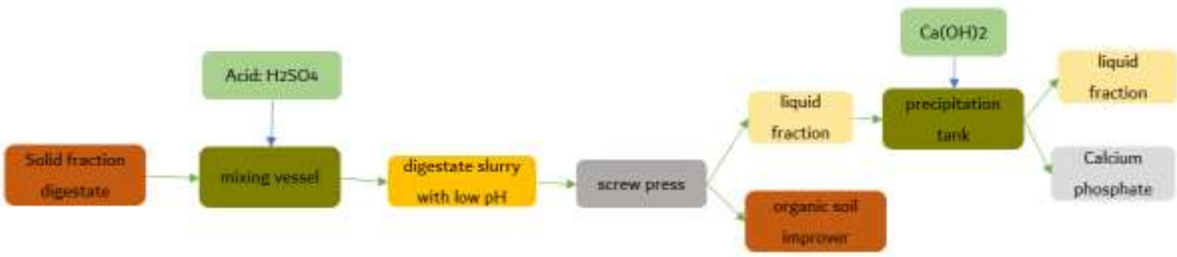


Figure 4-2 Process steps Re-P-eat system being built at Demo Plant Groot Zevert Vergisting

4.2.2 BioEcoSIM

In the framework of the BioEcoSIM project, the German research centre Frauenhofer IGB developed a similar technology cascade to recover phosphorus from manure and digestate.

The main difference with the Re-P-eat process is that BioEcoSIM acidifies the raw digestate to recover also phosphor from the liquid phase. This implies higher amounts of acid are used in comparison to Re-P-eat.

To precipitated phosphorus, BioEcoSIM does not add $Ca(OH)_2$ and phosphate salts are formed with the minerals (Ca^{2+}, Mg^{2+}, NH_4^+) present in the digestate.

A first full-scale plant implementing the BioEcoSim technique on manure is planned to be ready for use by the end of 2018 in Northern Germany. Meanwhile, the BioEcoSim technology was sold to Suez, a wastewater treatment and waste management giant, who will distribute the technology in Europe.

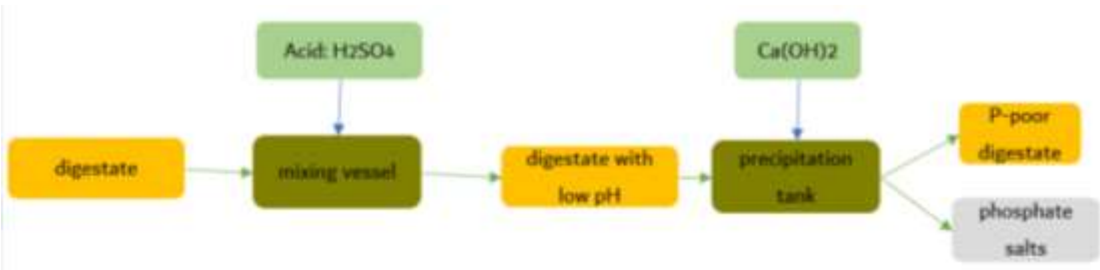


Figure 4-3 Process steps BioEcoSIM system being built in Northern Germany

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SYSTEMIC
Circular solutions for biowaste

Systemic large-scale eco-innovation to advance circular economy and mineral recovery from organic waste in Europe

Consortium

Wageningen University and Research (NL)
AM Power (BE)
Groot Zevert Vergisting B.V. (NL)
Acqua & Sole S.r.l. (IT)
RIKA Biofuels Development Ltd. (UK)
GNS Gesellschaft für Nachhaltige Stoffnutzung mbH (DE)
A-Farmers Ltd (FI)
ICL Europe (NL)
Nijhuis Water Technology (NL)
Proman Management GmbH (AU)
Ghent University (BE)
Milano University (IT)
Vlaams Coördinatiecentrum Mestverwerking (BE)
European Biogas Association (BE)
Rural Investment Support for Europe (BE)

Project coordinator

Oscar F. Schoumans
Oscar.Schoumans@wur.nl
Wageningen Environmental Research
The Netherlands

Project website: www.systemicproject.eu

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