Baltic Forum for Innovative Technologies for Sustainable Manure Management

KNOWLEDGE REPORT

Examples of Implementing Manure Processing Technology at Farm Level

By Erik Sindhöj and Lena Rodhe (Editors)

- WP3 Innovative Technologies for Manure Handling
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The project is partly financed by the European Union - European Regional Development Fund

PREFACE

Baltic Manure (The Baltic Forum for Innovative Technologies for Sustainable Manure Management) is a Flagship Project in the Action Plan of the EU Strategy for the Baltic Sea Region (BSR), which is co-funded by the Baltic Sea Region Programme of the European Union. The work described in this report was performed within Work Package 3 (WP3) "*Innovative technology for animal feeding and housing, processing, storage and spreading of manure*" within Baltic Manure.

The overall aim of WP3 is to identify innovative and economically viable technologies for handling and processing manure in an environmentally friendly and user-friendly way on large-scale livestock farms in the BSR.

This report presents a selection of manure processing technologies currently available in the BSR and, more importantly, describes examples of implementation of these technologies on farms. The examples were chosen to demonstrate the use of innovative technology to improve farm manure management in an environmentally sound and economically viable manner, but in many cases adequate data for environmental assessment were lacking.

The researchers responsible for the studies were Kalvi Tamm at the Estonian Research Institute of Agriculture (ERIA) in Estonia, Ilkka Sipilä at MTT Research Finland, and Erik Sindhöj and Lena Rodhe at the Swedish Institute of Agricultural and Environmental Engineering (JTI) in Sweden. Contributions were also made by Anni Alitalo, Pellervo Kässi and Sari Luostarinen, all from MTT, and Raivo Vettik (ERIA) and Knud Tybirk at Agro Business Park A/S. Appendix 1 contains contact information for the main authors. The other chapters were written by Erik Sindhöj and Lena Rodhe, who also edited the report.

The authors would like to thank all the farmers who opened up their farms to us and generously contributed valuable time and assistance to complete these descriptions.

Erik Sindhöj and Lena Rodhe
April, 2013

CONTENT

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1 Summary

Manure from intensive livestock production in the Baltic Sea Region (BSR) is contributing to eutrophication of the Baltic Sea. Manure is used as a fertiliser resource for crop production, but there could be bottlenecks that prevent this fertiliser being applied at the right time, at the right place (field) and at the right rate. Low concentrations of nutrients in manure make handling costly per kg nutrient (NPK) compared with mineral fertilisers and the costs of storing, transporting and spreading manure could easily exceed the economic value of the macronutrient content. Soil could also become saturated with nutrients such as phosphorus, which would create a need to export manure off-farm. Common processing technologies for sewage sludge from wastewater treatment plants could potentially be used for manure, but farm conditions would most likely require modifications and adaptions when introducing new manure processing technology.

The main objective of this report was to present case-study examples of manure processing technologies that have been implemented and used on livestock farms in the BSR. Farm conditions and the technologies are described and information such as capacity, motive for use and the economics of use are summarised for the different technologies.

The report includes descriptions of technologies for nutrient concentration, slurry acidification, drum composting, mechanical separation and slurry cooling in manure channels and also a brief description of aspects of anaerobic digestion relating to nutrient management. The technologies implemented are mainly for processing slurry, and only one is for processing solid manure. The processing technologies presented have a capacity ranging from 1200 to 20 000 m^3 slurry per year.

The motives for using manure processing technologies were many, including decreasing the volume of liquid manure to handle, lowering the viscosity of liquid manure, reducing ammonia emissions and thereby complying with legislative requirements, improving air quality in livestock houses, recovering heat energy by cooling, and producing different qualities of fertilisers with higher nutrient concentrations for different applications. Other reasons were producing commercial soil and fertiliser products from manure (mainly solids but also liquids) and obtaining income from selling those products on market, and getting tipping fees for organic products.

Information on nutrient flows and balances was generally unavailable for the processing technologies under varying conditions. Such information is needed in order to analyse whether these manure processing technologies are actually reducing the environmental impact of livestock production. The technology for concentrating nutrients in manure is not yet commercially viable for farm use, while the other processing technologies are on the market, like mechanical separation and acidification.

The estimated processing costs were 1-7 EUR per m^3 slurry and year. The profitability of the investment depends very much on the income derived from selling fertiliser products, so an accurate and realistic farm-specific business plan for investment is strongly recommended, as external income could be the driver of good financial returns. It is also important to consider the whole handling chain, so that all components are resolved (e.g. how to spread new fertiliser products, plant availability, etc.) before investment.

1.1 Svensk sammanfattning

Hantering av stallgödsel bidrar till diffusa utsläpp av växtnäring och därmed över-gödning av Östersjön. Stallgödseln används i första hand som ett gödselmedel i växtodlingen men det är inte alltid möjligt att använda den på bästa sätt, t.ex. att tillföra näringen vid rätt tid, på mest lämpliga fält, och i rätt giva. Växtnärings-koncentrationerna i stallgödsel är låga jämfört med mineralgödsel och därmed är hanteringskostnaden per kg växtnäring (kväve, fosfor och kalium) hög jämfört med mineralgödsel. Kostnaderna för lagring, transportering och spridning över-stiger ofta värdet av makronäringsämnena i stallgödsel. Marken kan också ha god status av P och K varför denna växtnäring skulle göra bättre nytta utanför djur-gården, t.ex. på en växtodlingsgård. Det finns därför behov av att förädla stall-gödseln så att den blir en attraktiv handelsvara. På reningsverk finns viss teknik för att extrahera P ur slam, men tekniken har ännu inte anpassats för stallgödsel.

Målet med detta arbete var att visa exempel från gårdar kring Östersjön, på vilka man använder ny teknik för att förädla stallgödseln. I rapporten beskrivs förut¬sätt-ningarna på gårdarna och i tabellform summeras motiv för investering i ny teknik samt data för teknikerna såsom kapacitet och ekonomi. Huvuddelen av teknikerna är för flytgödsel och endast en teknik är för fastgödsel. Kapaciteten hos de pre-senterade teknikerna var mellan 1200 och 20000 m3 flytgödsel per år. De använda förädlingsteknikerna syftar till att ta fram koncentrat med växtnäring, för¬hindra ammoniakavgång genom försurning eller kylning av flytgödsel, mekanisk sepa¬rering av flytgödsel i fast och flytande fraktion samt kompostering av fastgödsel i trumma.

Motiven för att processa gödseln varierade. Till exempel var det för att minska mängden gödsel att hantera, göra flytgödseln mer lättflytande, minska ammoniak-avgången för att uppfylla lagkrav, förbättra luften i stallarna, återvinna energi från värmen i gödsel, och för att ta fram gödselprodukter med högre näringskoncentra-tioner än den ursprungliga för den egna gårdens bruk. I andra fall var produktion och försäljning av kommersiella gödselprodukter eller jordförbättringsmedel en viktig inkomstkälla, likaså att ta emot organiska produkter som t.ex. häst¬gödsel eller grönsaks¬rester mot betalning.

Data kring växtnäringsflöden och -balanser för utrustningarna under olika drifts-förhållanden saknades oftast, vilket gör det svårt att bedöma om förädlingen verkligen minskar de diffusa växtnäringsutsläppen från stallgödsel. Teknikerna för att ta fram växtnäringskoncentrat från stallgödsel var inte så välbeprövade med stallgödsel, medan andra tekniker fungerade väl med stallgödsel. Till exempel är mekanisk separering av flytgödsel i en fast och en flytande fraktion en välkänd teknik, som har funnits på marknaden i årtionden. Även försurning av flytgödsel i stall, lager eller vid spridning tillämpas i ökad omfattning i Danmark under senare år.

Årskostnaden för att behandla gödseln med de olika teknikerna uppskattades till 9 – 65 kr per m3. Gödselbehandlingens lönsamhet beror mycket på om det är möjligt att få externa intäkter, t.ex. inkomst från tippningsavgifter eller genom försäljning av gödselprodukter. Innan beslut om investering i utrustning tas är det därför viktigt att göra en detaljerad affärsplan anpassad efter gårdens förutsätt-ningar och att undersöka marknadens efterfråga av produkter, eftersom externa inkomster kan vara det som ger lönsamhet i gödselförädlingen. Det är också viktigt att ha vetskap om hur nya gödselprodukter ska hanteras i efterföljande led, t.ex. hur man ska sprida dessa jämnt i önskad giva och att växtnäringen blir tillgänglig och väl utnyttjad av grödorna.

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2 Introduction

Erik Sindhöj, JTI

Livestock production and crop production were historically tightly integrated, but the availability of mineral fertilisers eventually decoupled the dependence on manure for fertiliser. For the most part manure continued to be spread on arable land, but it was considered more a "disposal" option, and little consideration was given to reducing nutrient losses, since they were easily compensated for with mineral substitutes. Poor manure handling techniques for collecting, storing and spreading manure can have significant negative impacts on air, soil and water quality. Livestock production is the greatest source of ammonia emissions in BSR countries and is a major non-point source of nutrient pollution to the Baltic Sea (Bartnicki et al., 2011).

During recent decades, the negative environmental impacts of livestock production and manure handling have been controlled by stricter regulations for manure storage and spreading. However, the intensification of livestock production has led to larger herds on fewer farms and industrial-scale operations that produce large quantities of manure at centralised locations. Furthermore, many farmers tend to specialise in either crop production or livestock production, and in some cases pig and poultry producers do not engage in crop production at all. As intensive livestock farming is being placed under increasing pressure to minimise the environmental impact of its operations, there is a growing interest in innovative processing technologies that can improve the economic competitiveness of manure handling while at the same time improving utilisation of the nutrient resources.

There are a number of reasons for processing manure and there are a wide range of different processing techniques available. Some of the reasons for processing manure are to:

- Reduce the volume
- Increase the fertiliser value
- Recover/utilise energy
- Reduce greenhouse gas and ammonia emissions
- Improve hygiene
- Reduce odours
- Improve the handling properties
- Decrease nutrient losses

At present, less than 8% of the estimated livestock manure amount produced in Europe is processed, with large variations between regions (Foged et al., 2011). Manure processing is still relatively uncommon in the BSR, possibly with the exception of anaerobic digestion. While many recent reports list best available technologies for manure processing (Forbes et al., 2005; Schoumans et al., 2010; Foged et al., 2011; Frandsen et al., 2011), little information is available about how these technologies are actually used on farms. This report is not an all-inclusive inventory of available manure processing technologies. For that we recommend the comprehensive Agro Technology Atlas (http://www.agro-technology-atlas.eu), which is continually updated with new technologies, data and information. The main objective of this report was to provide case study examples of manure processing technologies that are implemented on animal farms in the BSR. The farm conditions and the technologies are described and information on e.g. capacity, motive for use and the economics of use of the technologies is summarised.

3 Nutrient concentration technologies

Erik Sindhöj and Lena Rodhe, JTI

Systems for liquid manure (slurry) handling have both advantages and disadvantages over solid manure handling systems but are generally preferred, because slurry systems are less energy- and labour-intensive and offer better potential for conserving nitrogen (N) during storage and land application (Burton and Turner, 2003). The main disadvantage with slurry in general is that it consists of 85-95% water, meaning low concentrations of nutrients per kg, especially compared with mineral fertilisers. This results in high costs for storage, transportation and spreading per kg N and kg phosphorus (P). In addition, there are risks of major environmental impacts during storage and from application of manure, for example in the form of ammonia and greenhouse gas emissions, bad odours, nutrient leaching and soil compaction by heavy vehicles.

The most ideal processing technology for manure would be to reduce the volume and produce a nutrient concentrate that is more similar to mineral nutrients. Such concentration technologies could drastically minimise the costs of handling manure. The aim of concentration technologies is often two-fold: 1) to produce a nutrient concentrate with a high fertiliser value (high nutrient concentration levels and high percentage of plant-available nutrients), and 2) remove the water so that it is clean enough to be safely discharged into the environment.

Slurry contains nutrients in both particulate and dissolved form. Concentration techniques are most often designed around multiple processes, where the first step is to remove the particulate matter by separating the slurry into solid and liquid fractions. For the purpose described here, the solid fraction should contain as much of the total dry matter as possible. Many different types of equipment can be used for separation of the solid phase from the liquid phase with varying separation efficiency and investment and operating costs (Hjorth et al., 2009). Chapter 5 gives more details on some separation technologies. Separation techniques that can effectively separate even small particulate matter from the liquid fraction can also in a sense concentrate nutrients such as P, which is mostly associated with particulate matter, into the solid fraction. Several separation technologies are often used in series to remove enough of the particulate matter for further processing, and in some cases filtration or precipitation techniques may be necessary to adequately clarify the liquid fraction.

The second step is to accumulate the dissolved nutrients into a concentrate, leaving water that is ideally clean enough to discharge without a negative environmental impact or is filtered in beds or wetlands before being released to surface waters. There are also several processing technologies to achieve this nutrient concentration and in many cases multiple techniques are used in series to achieve adequate results. Examples include: ammonia stripping followed by re-adsorption, struvite precipitation, evaporation-condensation, ion exchange and the use of membrane techniques such as reverse osmosis and nano-filtration, to name a few. Biological processes also exist that break down the organic N through mineralisation followed by nitrification and denitrification, but if scrubbers or stripping towers are not used in conjunction with these methods, the N is lost. Precipitation and adsorption techniques can also effectively remove dissolved nutrients such as P but, depending on the chemicals used, the recovered nutrients may not be suitable for use as fertiliser.

There is growing interest in nutrient concentration technology in the BSR, especially among large-scale livestock producers who are looking for ways to decrease the costs of transporting and spreading large quantities of manure. In the Netherlands, where manure disposal costs are high due to a surplus of manure in relation to available arable land for spreading, a number of farmers have built their own nutrient concentration plants to reduce the volume of manure needing to be spread. These plants are all based on reverse osmosis techniques (Hoeksma et al., 2011), which have high investment and maintenance costs but are profitable in Holland due to the otherwise high cost of manure disposal (de Hoop et al., 2011).

Despite the great interest in this technology, there are currently no commercially available solutions for processing slurry into nutrient concentrate and relatively clean water. However, two companies in the BSR have developed prototype concentration equipment, based on different technologies, that they hope will soon be available on the market. Brief descriptions of these prototypes follow, as well as a description of one of the homemade reverse osmosis solutions in Holland.

3.1 Nutrient concentration of dairy slurry using Split-Box®

Erik Sindhöj, JTI

The Split-Box system was developed by Biotain AB of Sweden (www.biotain.se) and a prototype was tested on a dairy farm in Sweden during 2012. The farm has 500 milking cows and produces on average 9000 ECM kg certified organic milk per cow and year. Approximately 20 000 m^3 of slurry are generated per year. As of May 2013, Split-Box is not commercially available.

Figure 1. Split-Box Agri installed outside the main cow house on the trial farm.

3.1.1 Description of Split-Box processing technology

Split-Box is pre-installed in two easily transportable containers, which were placed outside one of the cow sheds on the trial farm (Figure 1).

The Split-Box technology consists of several processing steps (Figure 2) involving coarse (200 µm) and fine filtration (50 and 10 µm) to separate the solid particulate matter from the liquid fraction. The first separation process is achieved using a rotating square sieve (200 µm) method developed and patented by Biotain (Figure 3). The rotating sieve uses filtrate from the 50 µm filter to wash out the solid material onto screens. As the screens become saturated with solids, the square is rotated and the solid material falls onto a screw conveyor, which transports it to a roller press. The solid fraction separated with these three filters has a dry matter content of approximately 35% without coagulants and the filtering process generally consumes less energy than typical mechanical separation techniques (P. Ewers, personal communication 2012). Because water is used to separate the solids, there is no frictional wear from mechanical scrapers on the screens, which should keep the maintenance costs moderate.

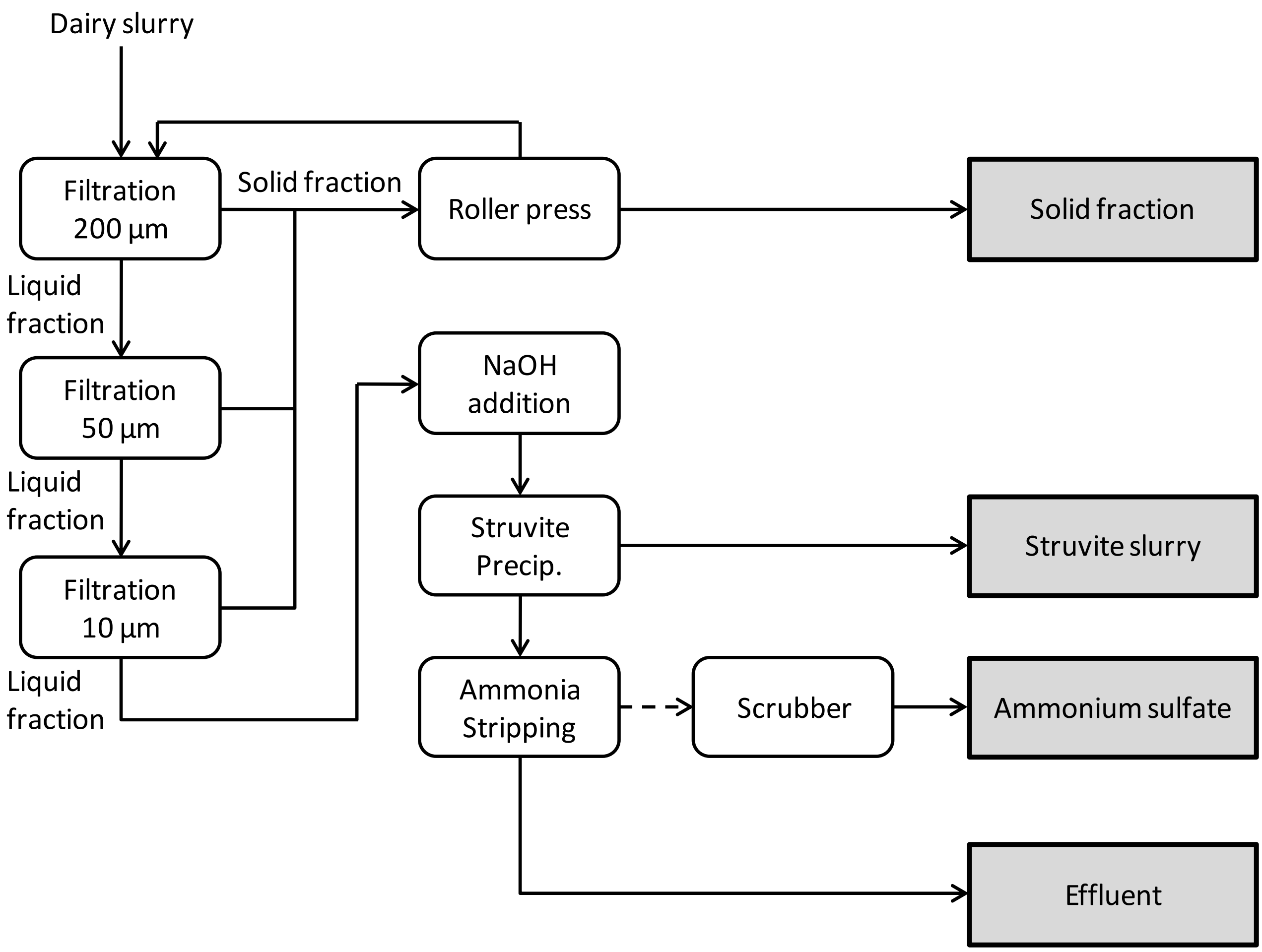

Figure 2. Process diagram for Split-Box® Agri by Biotain AB of Sweden. Coarse and fine filtration steps are carried out using proprietary technologies with patents pending. NaOH addition is to raise pH and improve subsequent precipitation and stripping steps. The struvite precipitation step includes the addition of $MgSO_4$. The scrubber uses sulphuric acid (H_2SO_4). Solid lines represent solid and liquid flow and the dashed line is gas flow.

The fine filtration process also uses proprietary Biotain technology to remove the remaining suspended fine particulate matter from the liquid fraction without the need for chemical coagulants. This process is actually a series of similar filtration steps, with each step having a smaller mesh pore size (50 and 10 µm). The filters are self-cleaning using filtrate from the actual filtering step, so maintenance is minimal.

After filtration, the liquid fraction is mixed with 25% sodium hydroxide (NaOH) solution (2.85 litres per m^3) to raise the pH, Epsom salts (49% $MgSO_4$) (0.75 kg per m^3) to react with phosphate (P) and either ammonium (NH_4^+) or potassium (K) to precipitate struvite slurry ($MgNH_4PO_4$ and $KMgPO_4$, respectively). Potassium ammonium phosphate ($K_2NH_4PO_4$) precipitation can also occur. After adequate retention time in the precipitation tank, which has a conical base, the struvite sediment is drained and collected as a NPK concentrated slurry in tanks underneath. The struvite slurry can be further dried to produce struvite crystals, but this would require considerable energy inputs. The liquid fraction continues to the stripping columns to remove the remaining ammonium, which is then recaptured in the scrubbing process using sulphuric acid (H_2SO_4).

The effluent water from Split-Box is intended to be clean enough for discharge into, for example, the sand and gravel infiltration field originally constructed behind the cattle houses on the trial farm for stormwater collected from hard standings around the yard. Split-Box operates continuously, although many individual processes operate in batch mode, such as the struvite precipitation step. Slurry processing capacity is approximately 15 000 m^3 per year (Table 1).

Figure 3. a) Coarse 200 µm filter (rotating square sieve) for incoming slurry, with filtrate collection tanks underneath, b) drum press for solid fraction, c) parallel fine mesh filters at 50 µm with filtrate collection tanks underneath, d) parallel struvite precipitation tanks, e) ammonia strippers, and f) acid scrubber unit.

Table 1. Approximate volumes of incoming slurry and outgoing fractions from Split-Box provided by Biotain.

Material	Mass (tonnes/yr)
IN: Raw manure	15 000
OUT: Solid fraction	2 700
OUT: NPK concentrate (struvite slurry)	1 200
OUT: Ammonium sulphate	25
OUT: Effluent water	11 850

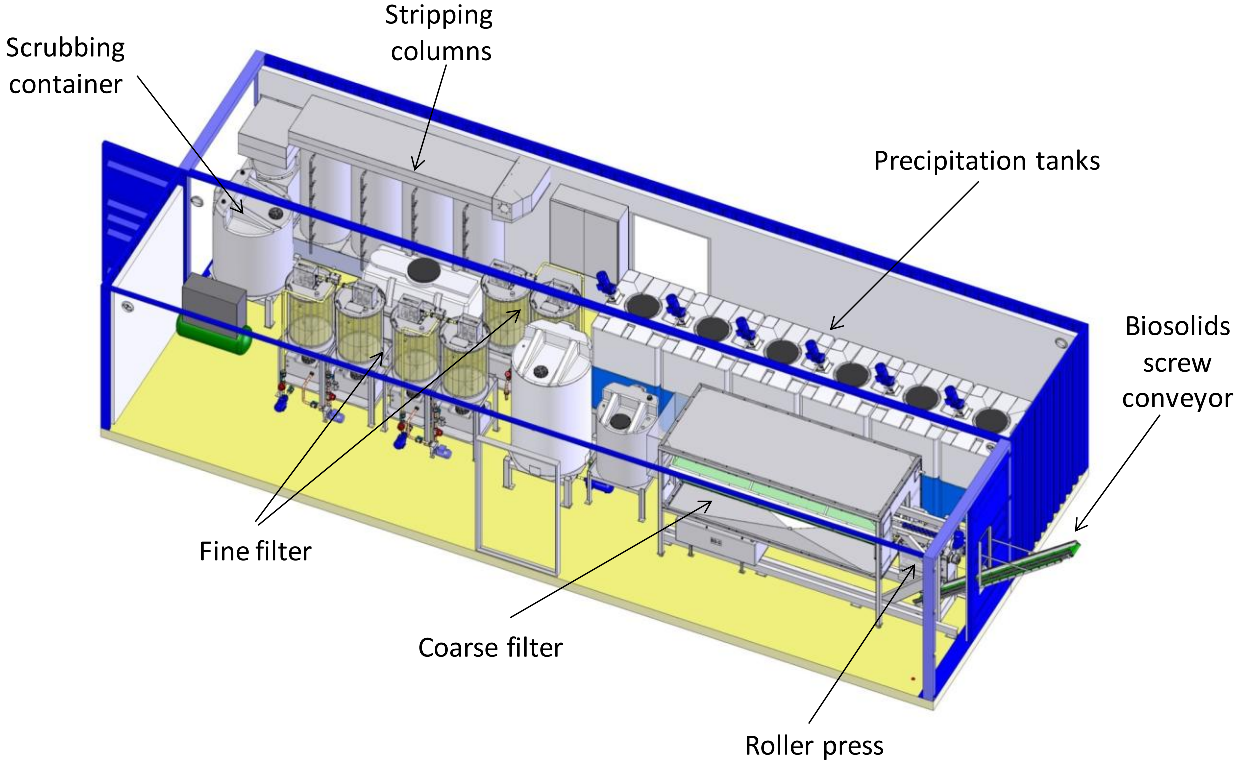

Figure 4. Configuration of the various components inside the two Split-Box containers sitting side by side (diagram by Biotain). In Figure 1 the two boxes are placed end to end.

3.1.2 End product use

The solid manure fraction is stored on a solid manure pad and disposed of together with the other solid manure produced on the farm. The farmer is considering using this fraction as bedding material for the cows.

During the testing period, the struvite slurry and the ammonium sulphate were added to the existing slurry storage tanks used to store the slurry not treated by Split-Box. It has not yet been determined how best to apply these liquids or the appropriate dosage to meet plant needs. Adding the struvite slurry and ammonia sulphate back to the slurry would in a sense increase the nutrient concentration of the slurry, meaning lower application rates, but rates within the range of a slurry spreader (minimum dosage ~10 tonnes ha^{-1}) should be possible.

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The effluent water from Split-Box is intended to be released to an infiltration area or constructed wetland.

3.1.3 Investment and operating costs versus income

The costs of the manure processing plant are divided into fixed and variable costs plus costs for the disposal of end products. Biotain estimated investment cost of Split-Box to be 300 000 EUR. Fixed yearly costs include depreciation and interest costs on Split-Box, plus extra constructions and equipment necessary for installing the plant.

Variable costs include the cost of additives, energy, maintenance (service contract with Biotain AB) and labour. Chemical additions, electricity, and the maintenance contract were estimated to cost 35 000 EUR per year.

Income would be counted as savings on building an additional 5 300 m^3 of storage for slurry, plus savings on the cost of slurry transport and spreading on fields.

3.2 Slurry separation and nutrient concentration on a pig farm with Pellon

Anni Alitalo, MTT

The Pellon system is newly developed and currently in its first implementation/validation phase on a pig farm in Finland. The farm produces finished pigs and generates about 6 m^3 slurry manure per day or about 2 200 m^3 annually.

3.2.1 Pellon manure treatment system

The Pellon manure treatment system is based on a combination of mechanical separation, biological treatment and ammonia stripping (Figures 5-7).

Solid-liquid separation

In the first treatment stage, the slurry is separated into solid and liquid fractions using a series of mechanical and chemical processes. This separation occurs in a closed building to minimise odour and emissions to the surroundings. Raw slurry is pumped from a temporary storage tank onto a belt press separator, which removes 1-2% of the dry matter content. The liquid fraction is treated with chemical polymers to increase flocculation and sedimentation of the remaining dry matter. The sediment from flocculation and the solids from the belt press are then further separated, using a screw press, into a solid fibre fraction that contains most of the P from the raw slurry (see Table 2). The liquid fraction leaving this treatment stage has a dry matter content of about 1% (Table 3).

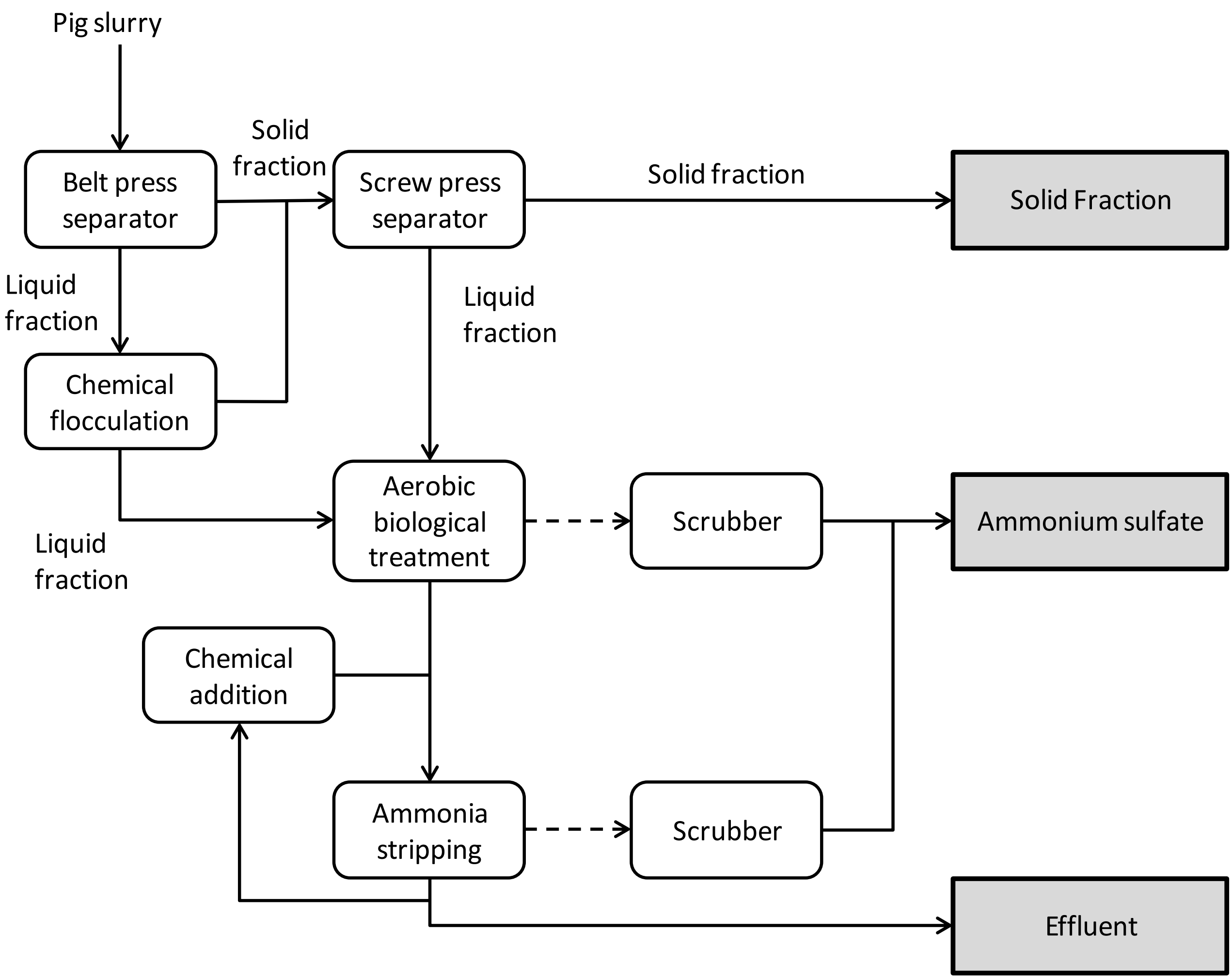

Figure 5. Process diagram for the Pellon manure treatment system. The chemical addition step includes both NaOH and MgO addition. The scrubbers use sulphuric acid. Solid lines represent solid and liquid flow and the dashed line is gas flow.

Aerobic biological treatment

The next stage is an aerobic biological treatment to separate N from the liquid fraction. The liquid fraction is drawn through a pipe to an insulated container (2 m x 2 m x 11.8 m, outside dimensions) consisting of six 4 m^3 tanks connected in series (Figures 6 and 7). Rotameters are used to regulate aeration in each tank using high pressure blowers through membrane diffusers for fine bubble aeration. Feedback effluent from the last tank is used to inoculate the first tank. Gases released during the aerobic biological activity are collected and led to a sulphuric acid air scrubber.

Ammonia stripping

After biological treatment, air stripping is carried out by conducting a series of repeated stripping cycles. First, the biologically treated liquid fraction is air-stripped as it is. Then chemicals are added (MgO, $Ca(OH)_2$ or $NaOH$) can be used to raise the pH of the liquid fraction before a second stripping. Further stripping cycles are continued, incrementally increasing the pH, until the desired ammonia level in the liquid fraction is obtained. Air from the stripping tower is led to a sulphuric acid scrubber, which is independent of the scrubber for the biological treatment described above.

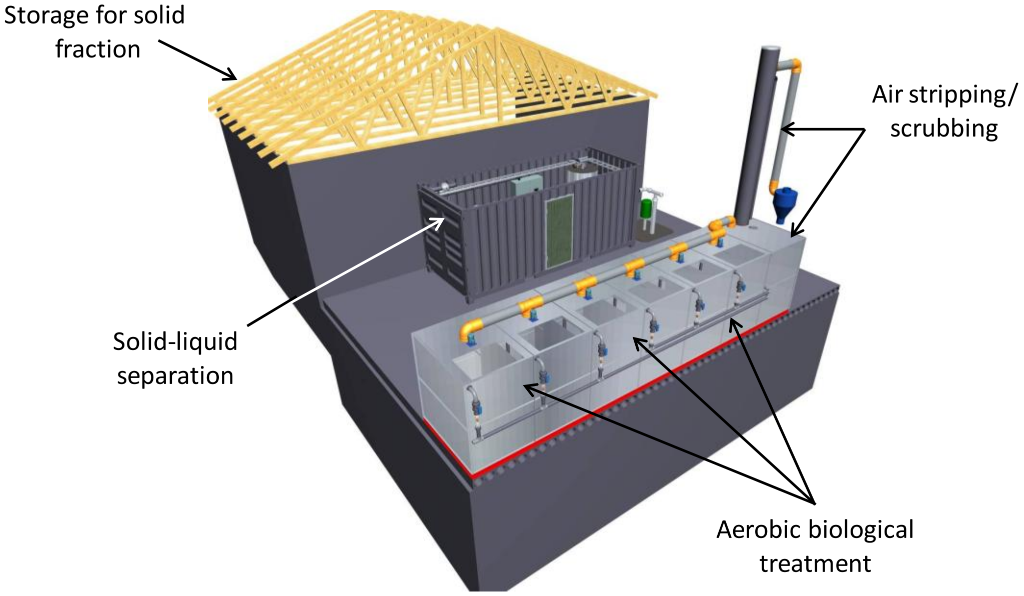

Figure 6. Diagram of a Pellon total treatment system including separation and biological treatment.

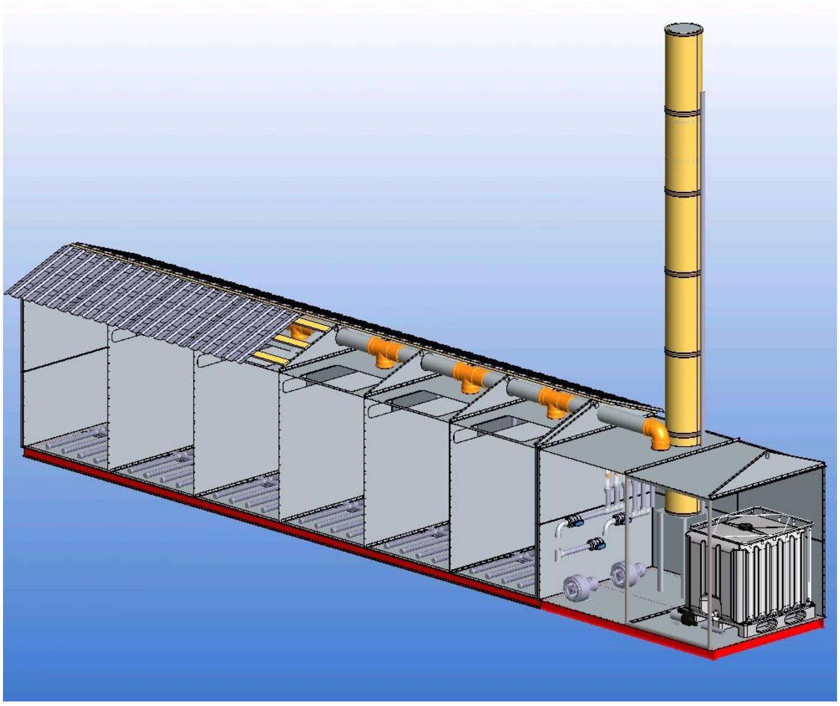

Figure 7. Aerobic biological treatment and the air stripping tower.

Table 2. General characteristics of the incoming slurry and products after the separation processes, including flocculation. DM = dry matter content, TN = total nitrogen, TP = total phosphorus, TK = total potassium

Material	Volume or mass (m^3/day)	DM (%)	TN (kg/tonne)	TP (kg/tonne)	TK (kg/tonne)
IN: Raw slurry	6.0	5.0	3.78	1.1	1.4
OUT: Solid fraction	0.9	30	8.6	7.9	1.2
OUT: Liquid fraction	5.1	1.0	1.8	0.1	1.0

Table 3. General characteristics of the slurry and stripped products. DM = dry matter content, NH_4-N = ammonia nitrogen, TN = total nitrogen

Material	DM (%)	pH	NH_4-N (kg/tonnes)	TN (kg/tonnes)
IN: Aerobically treated liquid fraction	0.99	8.78	1.6	1.9
OUT: After 1st stripping	0.88	8.45	1.3	1.5
OUT: After 2nd stripping	1.11	8.52	1.0	1.2
OUT: After 3rd stripping	0.75	8.77	0.5	0.6

Depending on the desired level of treatment for the effluent, it is possible to further treat the liquid fraction with Fe and Al salts for precipitating any remaining soluble P from the effluent. Phosphorus precipitation is not normally included in the Pellon system, however.

3.2.2 End product use

The high P content of the solid fraction makes it suitable as a P fertiliser, which can be spread with an ordinary solid manure broadcaster. The treated effluent can be either spread with conventional techniques on the nearby fields, used as irrigation water, or discharged into soil treatment systems, depending on the level of treatment applied. The ammonium sulphate concentrate can be applied as a liquid fertiliser. Application rates depend on legislation, local soil fertility conditions and plant requirements.

3.2.3 Costs versus savings

Fixed costs comprise investments for the separation process, including solid separator belt, flocculation and screw press, which are estimated to cost about 80 000 EUR. This includes the container for the separator treatment, but not the cost of the building for storage of the solid fraction. The complete aerated biological treatment and air stripping systems cost about 50 000 EUR.

Variable costs include the electricity and labour necessary for normal operation and maintenance, plus the cost of additives including polymers for flocculation and other chemicals used. Estimates of these costs are approximately 1 € per m^3 according to Pellon.

Benefits of the Pellon system

Most of the P is separated into a solid fraction, which reduces logistical transportation costs per kg of P and handling distances for recycling the P. The final effluent from the system has a hygiene status, with no odour problems. The effluent is very homogeneous and easy to spread and the hygiene quality has a positive effect on silage hygiene and on yield.

3.3 Nutrient concentration of pig slurry with reverse osmosis techniques

Erik Sindhöj, JTI

This case study of reverse osmosis nutrient concentration is on an integrated pig farm in the south-east Netherlands, 30 km from the border with Germany. The sow and piglet production unit is housed on the original family farm and the newer fattening pig facility is approximately 15 km away. The 1 050 sows produce approximately 29 000 piglets annually and they are grown to 25 kg live weight before being transferred to the fattening facility, where they are finished at 120-122 kg live weight.

All feed is purchased as individual components and is milled and mixed on the farm. Dry feeding is used for all pigs and diets are composed of wheat, soybean, beet pulp, rapeseed cake, maize and between 1-1.5% mineral mix. The small piglets are fed primarily local dairy by-products. Specific diets are mixed for mating sows, gestating sows, farrowing sows and dry sows. The growing pigs receive six specific phase diets, for 8-10 kg, 10-16 kg, 16-25 kg, 25-42 kg, 42-75 kg, and 75 kg to finishing weight.

The housing systems meet current standards for the Netherlands and are closed and insulated with forced ventilation. Heating in the winter is required only for the small piglets. Pens have 40% solid concrete floors and the remaining area is covered with either concrete or plastic slats. Small amounts of bedding are used for the piglets. Except for this, no bedding materials are used in either the sow or fattener facilities. Manure is stored in deep-storage pits underneath the slatted floors and storage capacity is 12 months in both the sow and fattening housing facilities. However, the separation and concentration processes work best with relatively fresh manure, so the manure storage is not fully utilised.

Average manure production for fattening pigs with dry feeding systems in the Netherlands is about 1.2 m^3 per place and year (F.E. de Buisionjé, personal communication 2012). The case study farm takes several steps to reduce water addition to the liquid manure, and has reduced annual manure production on the farm to around 1.0 m^3 per pig place and year for the fatteners. For instance, it has developed its own cleaning technology for the fattening pig barn, which consists of stationary sprinkler heads in each section that are used just before high-pressure cleaning. The sprinklers are programmed to run for 2 minutes every hour for two days, after which the section is clean. Groba and Verba drinking systems (www.groba.nl and www.verba.nl) are also installed in the feeding troughs and, to further reduce spills during drinking, the water pressure in the pipes is reduced to 0.4 bar.

3.3.1 Description of manure processing facility

The reverse osmosis plant is based on a series of processing steps and technologies (Figure 8).

A reverse osmosis manure processing facility was built in 2008 (Figures 9 and 10), and has been in operation since then. The plant was built in an existing machine shed at the end of the sow housing facility (Figure 9a). The storage and mixing tank (150 m^3) for receiving the liquid manure before processing is underneath the concrete floor of the shed. Manure is pumped into the storage tank from the deep-storage pits under the sow housing facility. In addition, a lorry-drawn tanker (25 m^3) owned by the farm is used to transport manure from the fattening facility to the storage tank every 2-3 days.

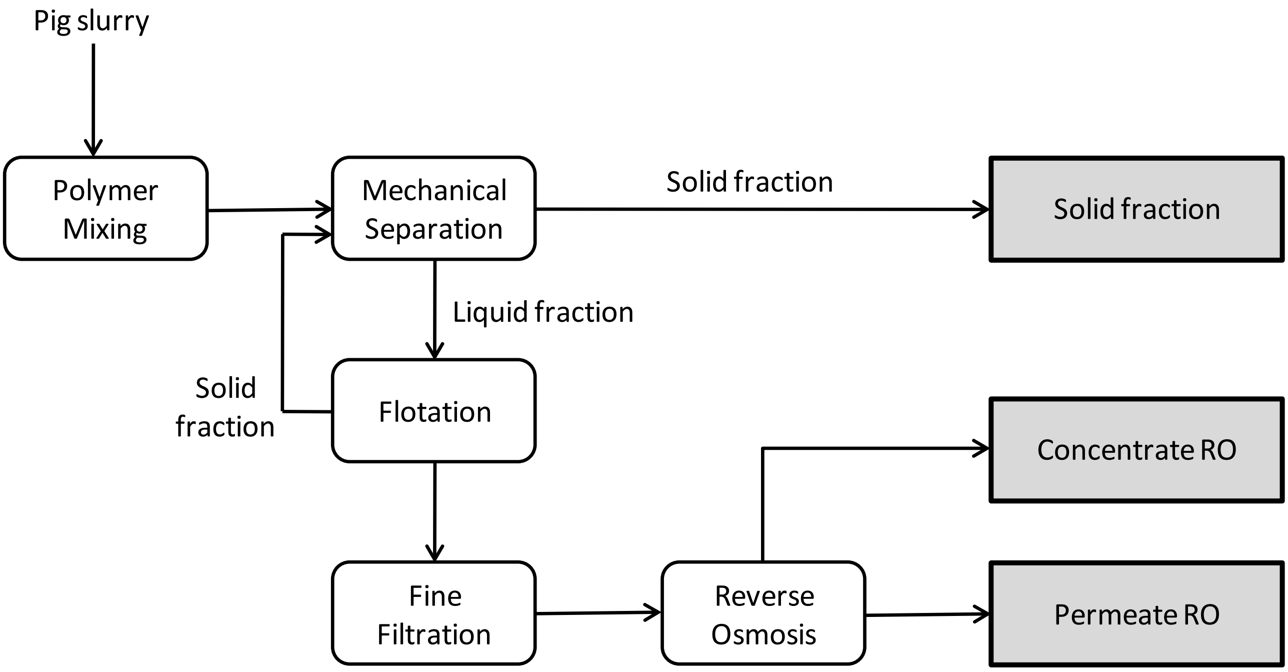

Figure 8. Treatment process of the reverse osmosis (RO) plant for pig slurry. Mechanical separation is accomplished with a screw press. Organic material accumulated on the surface of the flotation process is scraped from the surface. Fine filtration uses a 10 µm paper filter.

Figure 9. a) Manure processing shed, b) polymer mixing tank on far left in front of large flotation tank, c) screw press separator with conveyor for transport of solid fraction to (d) covered storage.

Manure in the storage tank is mixed for 1 minute every hour prior to pumping into the processing facility. The manure is first mixed with Nalco CE 45031 polymers (0.3-0.45 kg per tonne slurry) (Figure 9b) and then retained in a buffer tank for about 45 minutes to allow activation of the polymer with the organic material, after which a screw press separates the slurry into solid and liquid fractions (Figure 9c). The solid fraction is deposited onto an angled conveyor belt, which transports it to the storage area inside the shed (Figure 9d). The liquid fraction goes to the flotation separator (Figure 9b), which uses tiny bubbles to lift the remaining organic material to the surface, where they are scraped off and led back to the screw press. After flotation, the liquid fraction passes through a simple fine filtration device which consists of a paper filter on the bottom of a small tub (Figure 10a). The filter paper is on a large roll and as the level of the water in the tub rises to a certain height, new filter paper is automatically rolled out. The filter paper has a pore size of 10 µm, but in general it is not needed and is mainly a safety step to protect the reverse osmosis membranes in the event of imbalance in the separation steps. About one roll, or 100 m of filter paper, is used per year. After filtration, the liquid is retained in another buffer tank for 3-4 hours to allow the remaining polymer to de-activate, which by experience has been shown to produce better results in the reverse osmosis process (Table 4).

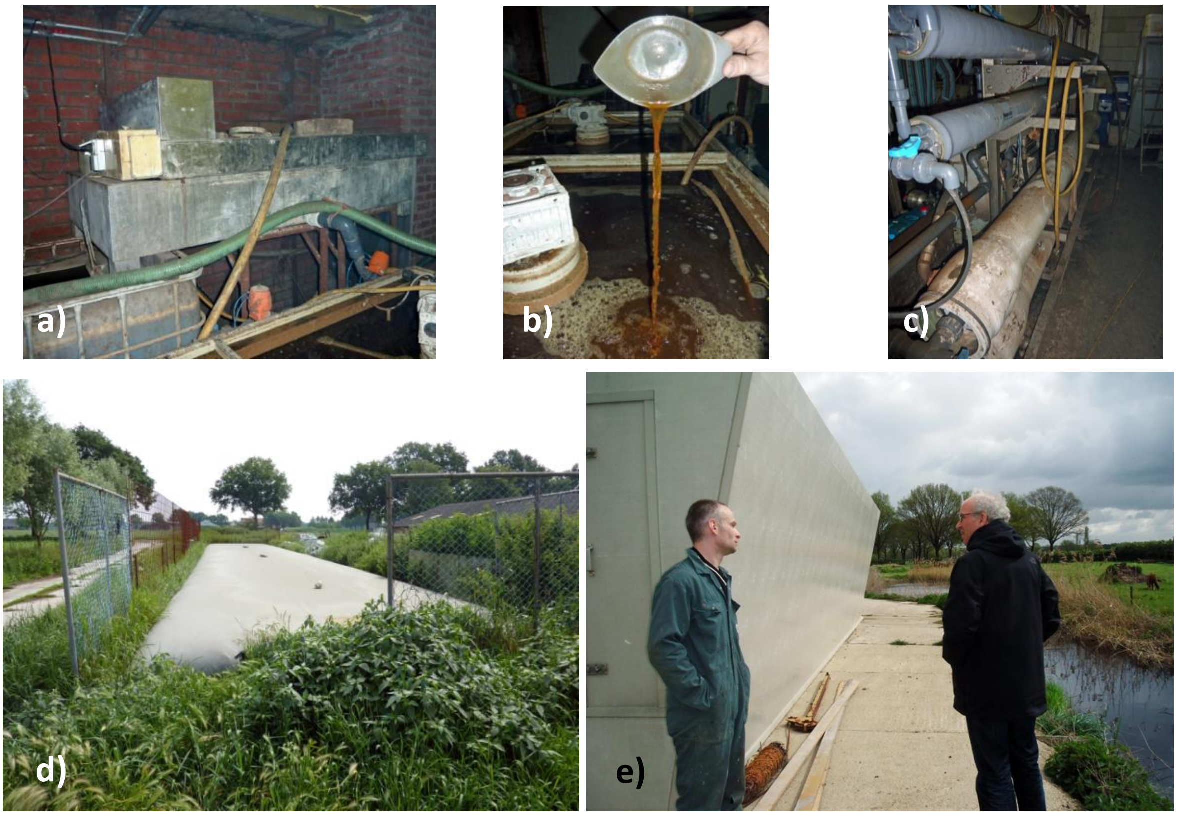

Figure 10. a) Fine filtration tank, b) stabilisation tanks and example of pre- reverse osmosis liquid, c) reverse osmosis membrane cartridges, d) reverse osmosis concentrate storage bag (300 m^3), and e) stormwater pond that receives reverse osmosis permeate (metal structure on left is acid air scrubber for the sow housing facility.

The reverse osmosis equipment uses six Hydranautics SWC 4+ membrane units (pore space 0.1-1 nm), which have a total surface area of 216 m^2 (Figure 10c). The capacity of the plant is 2 m^3 per hour when operating at a pressure of 50 bars. Electrical conductivity is measured in the concentrate to determine when the reverse osmosis process has reached the desired result, after which a small amount of permeate is used to back-flush the filter. The reverse osmosis membranes are cleaned once daily using hydrochloric acid and sodium hydroxide.

The reverse osmosis concentrate is then stored in a 300 m^3 bag outside the processing shed (Figure 10d). The reverse osmosis permeate is released into a stormwater collection pond behind the animal housing facilities, which then empties into an infiltration field (Figure 10e).

The reverse osmosis plant operates continuously throughout the year, although many of the processes operate in batch mode, such as the actual reverse osmosis process.

Table 4. Average characteristics of the incoming liquid manure and the outgoing fractions at the reverse osmosis processing plant. DM = dry matter content, NH_4-N = ammonia nitrogen, TN = total nitrogen, TP = total phosphorus, TK = total potassium

Material	Mass (tonnes/yr)	DM (%)	TN (kg/tonne)	NH_4-N (kg/tonne)	TP (kg/tonne)	TK (kg/tonne)
IN: Raw manure	10 000	3.7	3.3	2.2	0.9	2.7
OUT: Solid fraction	1 500	24	10.9	4.3	7.0	2.8
OUT: Concentrate RO	4 000	2.6	5.2	4.7	0.1	6.8
OUT: Permeate RO	4 500	>0.03	0.1	0.1	0.01	0.06

Data from Hoeksma et al. (2011) and chemical values are mean of 14-19 separate samples taken over 2 years.

3.3.2 End product use

Roughly two-thirds of the manure from the sows and fatteners is processed in the reverse osmosis plant. A small amount of the unprocessed slurry is spread (25 tonnes per ha) on 12 hectares of arable land for cultivating maize. The rest of the unprocessed slurry is handled by a local contractor specialising in manure transport and distribution to farms in the Netherlands and Germany.

The entire solid manure fraction is delivered to a company with a large drum composter. They compost pig manure solids together with solid poultry manure to produce a soil amendment which they sell commercially.

All the reverse osmosis concentrate is exported off-farm, either given away or sold to surrounding farmers, depending on the time of year and need for fertiliser. Kumac (www.kumac.nl) has modified a trailing shoe slurry spreader in order to cope with the lower application rates needed for the reverse osmosis concentrate (Figure 11). However, most of the farmers who receive the concentrate mix it with unprocessed slurry to allow spreading with conventional equipment.

Figure 11. A RoGator slurry spreader with a boom with trailing shoes. The spreader was modified by Kumac specifically for spreading reverse osmosis concentrate.

3.3.3 Investment and operating costs versus income

Costs for construction and operation of the reverse osmosis plant are divided into three categories: fixed costs, variable costs and disposal costs (or profits) for the end products. During the spring and summer the reverse osmosis concentrate is largely sold as a NK fertiliser, but the sales price is much less per kg N and K than for mineral fertilisers. During the rest of the year the farmer pays for transportation of the concentrate to farms willing to accept it, or in some cases has to pay them to accept it.

Fixed costs include interest and depreciation on total construction, installations and equipment necessary for the plant, and have been estimated to be 2.3 EUR per tonne processed manure (de Hoop et al., 2011). Variable costs include the cost of additives, energy, maintenance (filters and cleaners) and labour, which the farmer provides himself and does not include in the calculation. Variable costs were estimated to be 3.9 EUR per tonne processed manure (de Hoop et al., 2011). Fixed and variable costs for the processing technology are 6.2 EUR per tonne processed manure.

Disposal costs for end products include transportation and possible tipping fees paid to farmers and the composting company to receive the end products, which varies during the year. Total costs for the reverse osmosis processing plant amount to 9 EUR per tonne of processed manure (de Hoop et al., 2011).

Since the farm has limited arable land, a local contractor takes most of the liquid manure produced by the pigs on the farm, at a cost of just over 12 EUR per m^3. Thus savings on this cost are considered income, which is 3 EUR per m^3 of manure treated.

3.3.4 Future plans for processing

The farmer plans to increase the capacity of the reverse osmosis plant to process all manure produced on the farm. He is also considering investing in larger storage capacity for the reverse osmosis concentrate, so that a larger proportion is available when there is interest in purchasing the concentrate.

4 Slurry acidification

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Erik Sindhöj, JTI
Knud Tybirk, Agro Business Park A/S

Livestock manure is responsible for a large proportion of anthropogenic ammonia emissions (Hutchings et al., 2001; Webb and Misselbrook, 2004; SCB, 2007). Back in 1993, HELCOM adopted recommendations for reducing ammonia volatilisation from animal housing in the BSR. Ammonia emissions affect the environment through N deposition, which leads to eutrophication and acidification. Ammonia emissions also affect human health by the formation of fine aerosol particles in the atmosphere, which are major components of smog. In addition to this, ammonia losses during manure handling on the farm represent direct losses of valuable N fertiliser in crop production.

Ammonia emissions can occur during all phases of the manure handling chain on a farm: during manure collection and removal within the housing systems, storage and land application. In general, ammonia volatilisation takes place from the open surface of manure and therefore techniques for reducing emissions often include reducing the surface area from which ammonia can be emitted and controlling environmental conditions (wind and temperature) around the surface area, in housing and storage and during land application. Reducing levels of dietary crude protein in feed has also been shown to significantly reduce ammonia emissions from housing and during storage (Li et al., 2009).

In liquid manure, ammonia (NH_3) and ammonium (NH_4^+) are in chemical equilibrium, where the balance of each is largely dependent on pH. As pH increases, a larger proportion of ammonium occurs as ammonia, which can be lost as a gas. Lowering the pH shifts the equilibrium towards ammonium, which is water soluble and does not evaporate, decreasing the risk of emissions. Around a pH of 4.5 there is almost no measurable free ammonia. Acidification of slurry can therefore be considered a viable technique for reducing ammonia emissions from manure during various points in the handling chain.

Sulphuric acid (H_2SO_4) is highly effective for lowering the pH of slurry and is currently considered the most economically viable additive for acidification (Ndegwa et al., 2008). Slurry acidified with sulphuric acid has been shown to significantly reduce ammonia emissions in animal housing systems, during storage, and after band spreading with trailing hoses (Kai et al., 2008). Acidification of slurry with sulphuric acid has also been shown to reduce methane (CH_4) emissions from storage of slurry (Petersen et al., 2012)

Sulphuric acid has a very low pH and is a dangerous product. Strict safety precautions, protective clothing and working routines should always be observed when handling sulphuric acid.

4.1 In-house slurry acidification on a pig farm

This case study is of a farm in Denmark which has 600 hectares of arable land and produces approximately 6 500 fattening pigs annually. The pigs generate about 3 250 tonnes of manure per year, which is stored in manure channels under slatted floors in the pig housing units and in an outdoor storage tank.

In 2002, the farm expanded its pig production to the current levels and, as a condition of planning permission, the local authority demanded the implementation of technologies to reduce ammonia emissions. Therefore, the InFarm slurry acidification technology was incorporated into the expansion designs. The Danish Agricultural Advisory Services made regular pH measurements in the processing tank, the in-house manure channels and the storage tank and found that InFarm reduced slurry pH satisfactorily to between 5.5 and 6.0. Acidification of slurry with this method reduces ammonia emissions from animal houses, from storage tanks (MTK, 2011), and later from field-applied slurry.

4.1.1 Description of InFarm A/S technology

InFarm uses sulphuric acid for slurry acidification, at a dosing rate of approximately 5 kg sulphuric acid per tonne slurry. The goal is to reduce the pH value of the slurry from over 7 to about 5.5. The addition of sulphuric acid to slurry generates large amounts of CO_2, which causes a great deal of foaming, and therefore the mixing process must take place in a well-aerated area outside the animal house. This is done in the InFarm processing tank (Figure 12).

Slurry must first be pumped from the manure channels in the pig shed to the InFarm processing tank outside, in which sulphuric acid is added. The pH is continuously measured and sulphuric acid addition adjusted accordingly. Alarms for hydrogen sulphide levels are also integrated. Part of the slurry is then pumped back into the manure channels in the animal house and the rest is pumped to the storage tank (Figure 12). The slurry is reverse-pumped in the manure channels, which allows the pH of the manure in the channels to be reduced too.

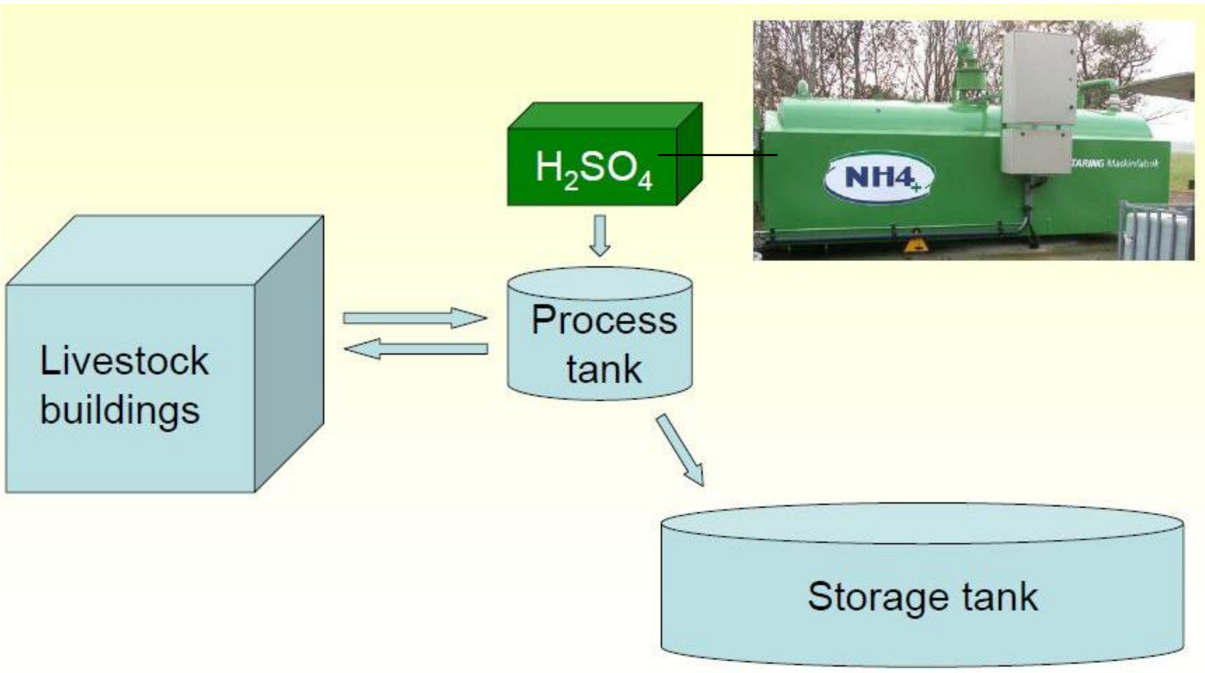

Figure 12. Process of acidifying slurry stored in the InFarm tank. Source: Eriksen and Sørensen, 2006.

4.1.2 Investment and operating costs versus income and savings

General investment costs for an InFarm unit are around 100 000 EUR (buffer tanks, pumps and controllers). Operating costs consist primarily of expenditure on sulphuric acid, electricity and maintenance, which total approximately 1.35 EUR per pig produced on the case study farm. Natural crust covers are generally not well formed after acidification and therefore, in accordance with Danish regulations, there might be a need for an artificial cover for the slurry storage tanks.

Benefits of the acidification system are related to improved N budget on the farm, with 7-13% more ammoniacal N in the slurry. Air quality in the pig houses is also improved due to decreased ammonia emissions. In addition, in most cases there is no extra need for sulphur fertilisation.

4.2 Acidification of slurry in the storage

Technology for acidification of slurry during spreading, as described in section 4.3, reduces ammonia emissions during spreading but misses losses further up the chain. Technology for acidification of slurry in the barn, as described in section 4.1, have the advantage of reducing ammonia losses from the animal house, storage and during spreading, however, this can only be used if slurry is stored under slatted floors in the housing system. For the great number of livestock housing systems that do not store slurry under slatted floors, a technology for acidification of slurry before storage could provide a greater reduction in nitrogen loss than simply acidification before spreading. A compilation of ammonia emission factors from Denmark indicated that acidification reduces ammonia emissions by over 80% in storage without cover and by 67% during spreading, as long as the pH is at least 6.0 (Nørregaard Hansen et al., 2008).

Manure has a high buffer capacity which makes it necessary to add relatively large amounts of acid to lower the pH (Ndegwa et al., 2008). After acidification, this buffer capacity of manure also contributes to a gradual increase in pH over time (Petersen et al., 2012), which would in practical terms either limit the time acidified slurry should be stored, or create the need to add more acid over time to maintain the appropriate pH. In one study of in-house acidification of pig slurry in Denmark, acid consumption was between 4-8.5 litres of sulphuric acid per m^3 of slurry (Frandsen and Schelde, 2007). This level of sulphuric acid addition would result in over-fertilisation with sulphur if slurry application rates are based on nitrogen contents.

Currently there are at least two technologies developed in Denmark for acidification directly in the storage basins. Both technologies add sulphuric acid during mixing of the slurry storage, however with slightly different techniques (Figure 13 and 14). One is from Harsø Maskiner (www.harso.dk) which adds sulphuric acid from standard IBC tanks (1 m^3), and the other is from Ørumsmeden (www.oerum-smeden.dk) which adds sulphuric acid direct from a transport tanker.

Both of these systems are have been bought by a number contractors in Denmark which offer the acidification service to farmers. However, acidification with these techniques is typically performed just prior to spreading so the benefits of reduced emissions from storage are missed.

Figure 13. Harsø Maskiner slurry mixing and acidification system (Photos: Harsø Maskiner).

Estonia

In Estonia, there are currently at least 2 dairy farms which acidify slurry in their storage lagoons. One is a dairy farm which produces approximately 14 000 m^3 of slurry, all of which is acidified. The farm has acidified slurry with sulphuric acid for three years now using its own technology. The farmer buys sulphuric acid in 1 m^3 IBC tanks (129 EUR per tank) and uses 1 litre sulphuric acid per 1 m^3 of slurry to achieve a N:S ratio of 5:1. The primary reason behind acidification is that sulphuric acid is less expensive than mineral S fertilizers. The farmer also mentioned the added benefit of reduced ammonia loss, but that was secondary. The pH of the acidified slurry is not measured, but the farmer plans to start measuring pH to adjust slurry pH to 5.5 to minimize nitrogen losses.

The slurry storage is mixed first, and then the sulphuric acid is added into the slurry while mixing continues. There is some foam during acidification but it has not been more than 15-20 cm. The acidified slurry is spread at 30 m^3 per ha by a contractor on arable land using injection techniques.

Figure 14. Ørum TF-12 slurry acidification system (Photo: Ørumsmeden A/S). Top left, acid injectors mounted onto a Ørum GMD slurry mixer. Top right, mixing and acidification process. Bottom, Ørum TF-12 rear mounted a tractor with a safety shower and water tank mounted on the front. The sulphuric acid tanker truck is behind the tractor.

4.3 Acidification of slurry during spreading on a pig farm

Acidification of slurry during spreading has been implemented on a fattening pig farm in Denmark that currently has 3 800 places for fattening pigs and produces about 12 000 pigs annually. The pigs generate 6 000 m^3 of manure slurry per year and the farm has 300 hectares of arable land available for spreading manure. Manure is stored initially in deep pits (750 m^3) under slatted floors in the pig housing units, and then pumped approximately every 6 weeks to an outdoor storage tank (3 200 m^3) covered with a PVC-reinforced roof. A contractor is hired for all manure transport and spreading on the fields.

In 2008, the farm expanded its pig production to the current levels and, as a condition of planning permission; the local authority demanded the implementation of technologies to reduce total farm ammonia emissions. SyreN has been certified by the Danish environmental authorities through an internationally recognised protocol known as VERA (Verification of environmental technologies for agricultural production), and is documented as an ammonia emission reducing technology relating to slurry spreading (M. Toft, personal communication 2012). The reduction in ammonia emissions due to applying all slurry with the SyreN technology is enough to reduce farm-level emissions within compliance, so the farmer pays the contractor for that extra service.

4.3.1 SyreN slurry application system

Because the use of SyreN is becoming quite common in Denmark, the farm example described above was created as a likely average example of a contractor's customer.

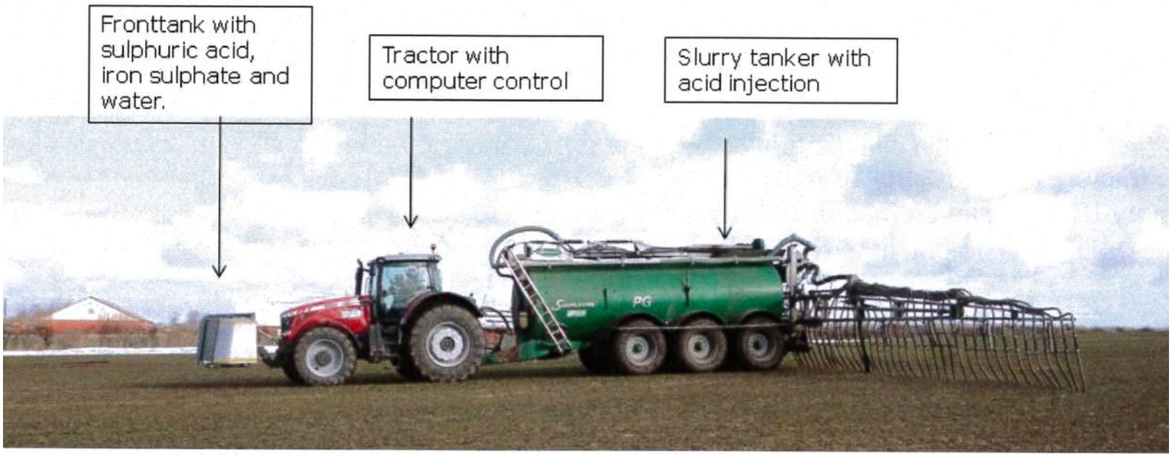

Figure 15. The SyreN system for slurry acidification.

The basic principle of the SyreN slurry application system is to acidify the animal slurry during land application (Figure 15). The sulphuric acid is mixed with the slurry at the back of the tank using a static mixer, which is placed close to the slurry distributor. The static mixer contains solid turbulence elements that ensure effective mixing in just a few seconds (Figure 16).

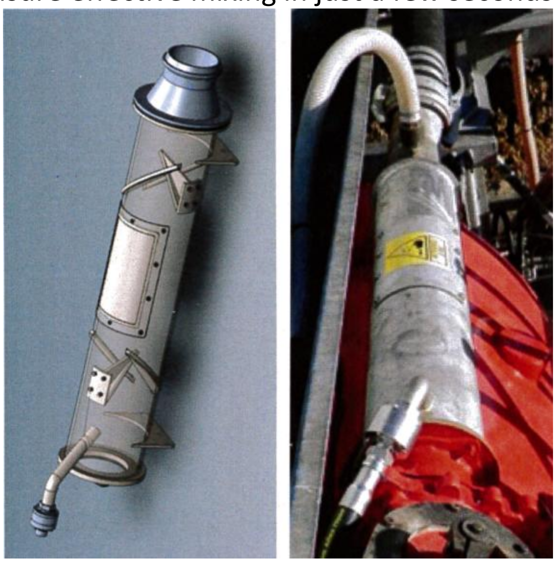

Figure 16. The acid injector and static mixing device, which is mounted close to the distributor on the back of the tank.

Treated slurry goes directly to the hose distributor, which further mixes the slurry and ensures that problems with pressure build-up cannot occur. A pH sensor is placed on the boom before the end of a trailing hose to continually monitor pH and automatically adjust the amount of acid to be added. All controllers for the SyreN system are built on ISOBUS standards and use existing onboard electronic equipment.

SyreN is an add-on system to be installed on existing slurry application machinery, normally consisting of a tractor and a slurry tanker. There are three main parts of the SyreN system (Figure 17):

1. Front tanks for storage of sulphuric acid and iron sulphate during land application.
2. Terminal software for regulation of dosage of sulphuric acid and iron sulphate to the slurry tank.
3. Pumps for addition of sulphuric acid and iron sulphate to the slurry tanker.

Figure 17. The SyreN-system includes three tanks installed on the front of the tractor. 1) Tank for iron sulphate, 2) site of tank for sulphuric acid, and 3) tank for water for cleaning the system.

With SyreN, a wide variety of additives can be added to the slurry together with the sulphuric acid, such as various micronutrients or additives for reducing odour. For example iron sulphate ($FeSO_4$) can be added to reduce hydrogen sulphide (H_2S) which, together with ammonia, is largely responsible for odour problems. Iron sulphate reacts with hydrogen sulphide to produce FeS precipitates and sulphuric acid (SO_4H_2).

The SyreN system has been crash-tested and has multiple safety mechanisms built in to ensure safe and easy operation and maintenance. SyreN also has a built-in Fleet Management System with GPS/GMS data collection based on CANbus/ISOBUS standards to automatically record amount of acid added, slurry pH before and after acidification, application rate, time, geographical location and more. This makes it ideal for contracting firms and for demonstrating compliance with environmental planning regulations and permits.

4.3.2 Use of end products

No changes have been made to the end use of the processed manure compared with before processing. Slurry is used for fertilising approximately 300 hectares of winter wheat, at an application rate of 20 tonnes per hectare.

4.3.3 Costs versus income and savings

Since the acidification processing is performed by a contractor, there are no investment or maintenance costs for the farmer. The cost of spreading the manure is neglected here too, since this cost is applicable even without acidification. On top of normal charges for band spreading with trailing hose applicators, the contractor charges 0.55 EUR per m^3 plus the cost of the sulphuric acid, which averages 1.5 litres per m^3 at a cost of 0.35 EUR per litre (Vestergaard, 2013). The total costs for the farmer are thus 1.10 EUR per m^3, or 6600 EUR for all slurry on the example farm.

Income and savings are calculated based on two factors. First, the yield increase in winter wheat from applying acidified slurry compared with untreated slurry, without extra N applications, is between 120 - 380 kg per ha (as determined by experiments performed by the Danish Videncentret for Landbrug; A.V. Vestergaard, pers. Communication, 2013). Calculating conservatively with an increase of 120 kg per ha worth 16 EUR per 100 kg winter wheat, this amounts to an income of 5750 EUR for the cultivation of 300 ha winter wheat. Second, savings from not needing to apply additional sulphur fertilisers, which cost about 0.55 EUR per kg, at an application rate of 15 kg S per ha gives a savings of 2475 EUR. The total income/savings for the Danish farmer is about 8225 EUR.

So despite extra application costs, acidification of slurry with SyreN results in a net annual income for the Danish farm of about 1 625 EUR.

As regards reducing ammonia emissions for compliance with local authority demands, injection of slurry could be used as an alternative to acidification. However, increased draught requirements for application with injection techniques together with small working widths increase the cost of injection compared with band spreading with trailing hose and sulphur fertilisation is still necessary.

4.3.4 Use of SyreN in Denmark

Current regulations in Denmark require that all slurry application on grasslands or sensitive soils must be either injected or acidified. Currently, over 50 contractors in Denmark offer acidification during application using the SyreN system. In addition, a number of individual farms producing 10 000 m^3 of slurry per year or more have purchased the SyreN system (M. Toft, personal communication 2012).

5 Drum composting

Erik Sindhöj and Lena Rodhe, JTI

Composting is an aerobic and thermophilic (40-65°C) microbial decomposition process that transforms raw organic substrates into more stable organic material, called compost. The composting process is best suited for solid organic matter, although wet composting techniques do exist. Large-scale composting requires oxygenation, regulation of moisture, mixing and substrates with adequate amounts of carbon and N to ensure an efficient process and quality of the compost.

Large-scale manure composting is generally achieved in compost reactors (in-vessel composting) or in windrows (long piles). In-vessel composting with large rotating drums has numerous advantages over windrow composting, since the process occurs in a controlled environment. There is also potential with in-vessel systems to capture gases (primarily NH_3, NO_x and N_2O) generated during the composting process and to clean the outlet air before it is released to the environment.

5.1 Co-composting horse and cattle manure

Rölunda farm is located in Uppsala County in east-central Sweden, approximately 5 km outside Bålsta. The farm has 250 hectares of arable land, of which two-thirds are cultivated with winter wheat, one-sixth with peas and one-sixth with rapeseed. It has 25 beef cattle. For many years the farm has been producing different kind of soil products and organic fertilisers for sale. The capacity of the drum composter exceeds the production of manure on the farm, so additional solid manure from nearby horse stables as well as fruit and vegetable residues from food wholesalers is also composted. For delivering manure, there is a mandatory tipping fee.

Figure 18. The composting plant at Rölunda farm.

5.1.1 Description of the composting plant

The drum composter at Rölunda farm is installed in a building, as the drum insulation is sensitive to sunlight, which allows some of the excess heat to be captured during winter (Figure 18 and 19a). The building is surrounded by asphalt hard standings, which slope towards a collection pond for rainwater. Water from the collection pond is used to add additional moisture to dry substrates that have low moisture content or if the composting process needs additional water, which is common during the summer. If there is too much rainwater, it is discharged into an adjacent constructed wetland after sedimentation. Organic material intended for composting is stored in containers on the lower side of the sloping storage area around the building (Figure 19b). The

materials are pre-mixed with a front loader and then left to settle for about a week. A 30 m^3 container adjacent to the building is filled with input material once a day (Figure 19c). The container floor has a hydraulically driven bed conveyor, which moves materials at controlled rates to a transverse screw, which deposits it into an angled screw conveyor that loads material directly into one end of the reactor (Fig. 19c). Retention time in the reactor is about 2-3 days. Compost is continually removed from the opposite end of the reactor with another screw conveyor and deposited onto a concrete pad outside the building (Figure 19d). Once daily, composted material is removed from the pad and then placed in windrows behind the house, on the upper end of the sloping hard standings. The material is allowed to mature for an additional 2-6 weeks, depending on the time of year.

Figure 19. The composting plant at Rölunda farm, which consists of: a) building for the drum composter, b) concrete hard standings for receiving and pre-mixing materials, c) substrate loading container, and d) screw conveyor depositing finished compost.

5.1.2 QuantorXL® by ESCAB

The QuantorXL® system is a patented, fully automatic, process-orientated, continuous drum composter that is manufactured and delivered ready for operation by European Composting Systems AB (ESCAB) in Enköping, Sweden (www.escab.com). QuantorXL® provides control over aeration, temperature and mixing of the substrate and fulfils EU regulations for treatment of animal by-products and composing manure. It has been approved and validated for hygienisation

by the Swedish Board of Agriculture to maintain a minimum temperature of 52°C for at least 13 hours, which is equivalent to 70°C for 1 hour. The drum is 3.4 m x 14 m, with a total volume of 125 m^3 and weighs 20 tonnes (Figure 20a). Operating capacity is between 15-50 m^3 of organic material per day depending on substrate type and retention time can be adjusted between 1.5 and 14 days depending on feeding rate and desired quality of the output product.

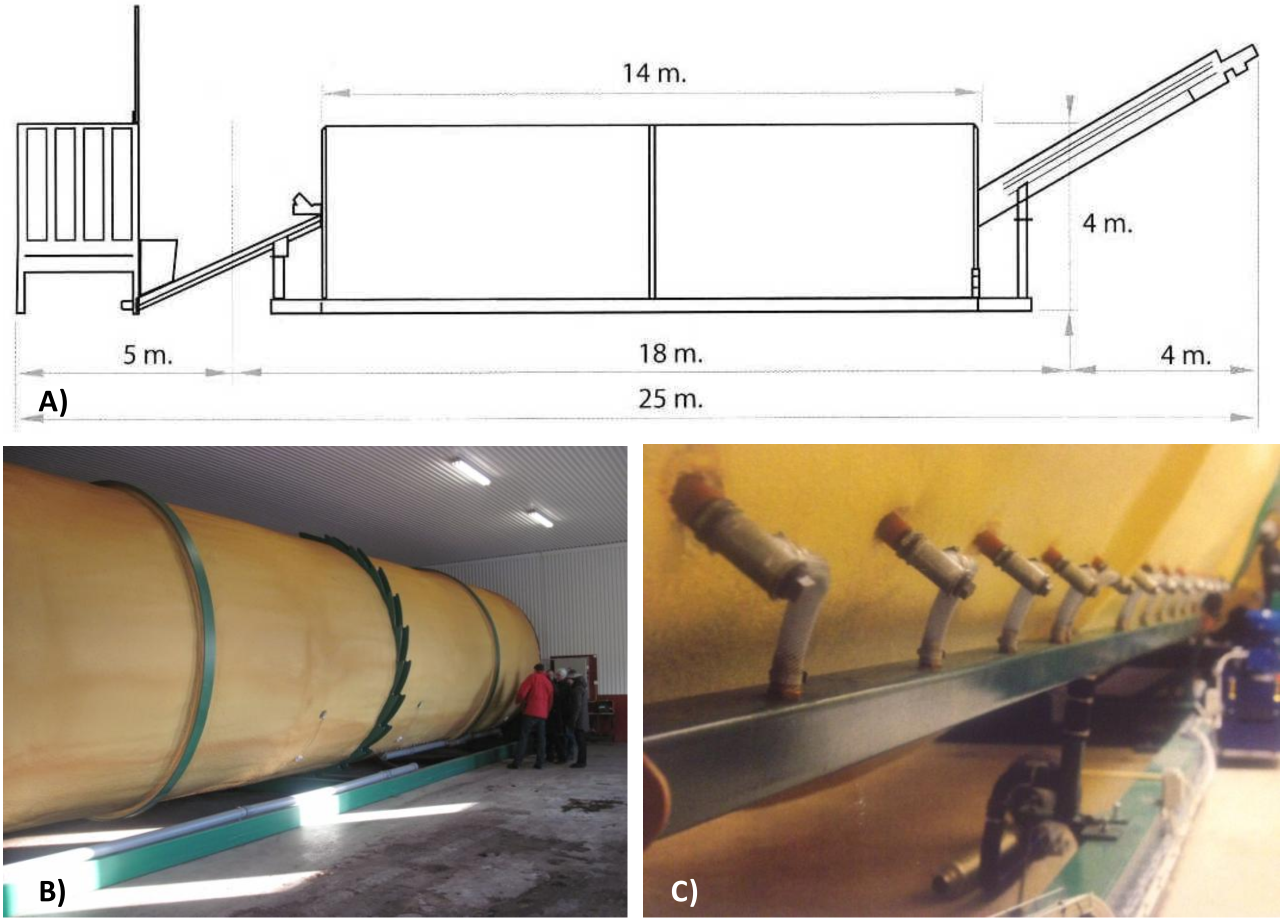

Figure 20. a) Schematic diagram of the QuantorXL® drum composter supplied by ECSAB, including input (left) and output (right) system, b) QuantorXL® drum composter installed at Rölunda farm, and c) close-up of the air inlets in the side of the reactor.

The drum rotates approximately 75° every 10 minutes, which amounts to about 30 complete rotations per day. Different types of metal wings inside the drum tumble the material, break up clumps, and slowly move it forward through the drum. This type of transport mixes and helps aeration to ensure an optimum structure of the substrate. Air is continually blown into small inlets at a pressure of 21 kPa along the length of the drum (Figure 20c), while another fan sucks out air in the end of the drum at the outlet. Heat is naturally generated by the microbial activity and temperature is monitored with four thermocouples inside the drum, with wireless transmitters sending signals to the control equipment. The temperature is maintained between 52 and 70 °C throughout the process and is controlled by adjusting the loading rate and retention time. It is possible to programme the reactor, for instance to slow down during weekends in order to reduce the workload. The entire process is monitored and controlled from a display terminal, which is accessible through the internet and alarms can be sent directly through GSM data connections.

The excess heat produced, up to 100 000 kWh per year under optimal conditions, can be utilised for warming close-by buildings, but is currently not utilised. ESCAB also markets solutions for odour reduction using biofilters, ozone or water filters.

5.1.3 Feed materials

The composting plant at Rölunda is used to process approximately 30 m^3 of organic material per day, or about 10 000 m^3 per year. Solid manure from approximately 500 horses is the primary substrate and accounts for 95% of the input, followed by solid manure from cattle and organic food residues (Table 5). The horse manure has a large amount of straw included, so additional carbon-rich materials do not need to be added. The horse manure is often relatively dry, so water may be added to the input substrate to obtain optimum moisture levels. Water for this purpose is taken from the stormwater pond that collects runoff from the hard standings around the plant. The volume reduction of the organic material by the composting process is around 15% (Table 5).

Table 5. Average characteristics of the feed material and the compost at the Rölunda composting plant

Material	Volume/yr	Mass/yr
IN: Horse manure	10 000 m^3	3 000 tonnes
IN: Deep litter manure	300 m^3	150 tonnes
IN: Fruit and vegetable residues		25 tonnes
OUT: Compost		3 000 tonnes

5.1.4 End product use

All of the finished compost is used to produce commercial soil and organic fertiliser products.

5.1.5 Investment and operating costs vs. income

The QuantorXL® drum composter costs 320 000 EUR installed, which includes the mixing container, input and output screw conveyors, all the controlling and monitoring equipment, staff training and a year’s service. In addition, there are costs for the building around the drum composter, the asphalted hard standings, the collection pond and the constructed wetland.

Operating costs include between 15-20 000 kWh of electricity, fuel and maintenance costs for 1 hour per day of front loader operation, and approximately 400 man-hours of labour annually.

Incomes include tipping fees for the horse manure and food residues, and sales of the soil amendment product.

5.2 Co-composting pig manure solids, solid cow manure and horse manure

Mellby Gård Lantbruk AB is located in Sweden’s most southerly county, Skåne. The farm has 550 hectares of arable land plus forestry. It has modern integrated pig production facilities, with places for 640 sows and 5 500 finishers, and produces around 17 000 fatteners per year. The sows have a solid manure handling system and the fatteners a slurry system. The farm also has a beef

production unit with 150 suckler cows, and stables for 60 trotting horses. Manure production from all these facilities amounts to about 9 000 m^3 of solid manure per year (Table 6) and 15 000 m^3 of slurry from the pig fattening facility.

All pig slurry produced on the farm is processed with mechanical separation using first an AL-2 Agro band separator, followed by a SB screw press (al-2teknik.dana9.dk). Approximately 1 500 m^3 of manure solids are separated from the slurry, all of which is used as compost substrate. The liquid fraction is stored in one of several covered storage tanks on the farm, with a total volume of 17 000 m^3. Liquid manure is stored until the spring, when it is spread on arable land as fertiliser.

5.2.1 Description of composting plant

The composting drum at Mellby farm was installed in an insulated building previously built for storing straw. On one side of the building there is a 3500 m^2 concrete manure pad used to receive the manure (Figure 21a). Here the manure is premixed with a front loader and then left to settle for a couple days before feeding into the composter. Rainwater runoff from the hard standings and the manure pad is collected and added to the covered stored liquid manure, which is then spread on fields as a fertiliser.

A 60 m^3 substrate container is mounted on the side of the building directly adjacent to the input for the composting drum (Figure 21b). The container is loaded once a day with the premixed manure. The container floor has a hydraulic bed conveyor which moves materials at controlled rates to an angled screw conveyor that continually loads the substrate directly into one end of the composter (Figure 22).

Figure 21. a) Hard standings and manure pad used for receiving and mixing solid manure from cows, horses and pigs and the separated manure solids from slurry and b) the loading container and input screw conveyor for substrate loading into the composter.

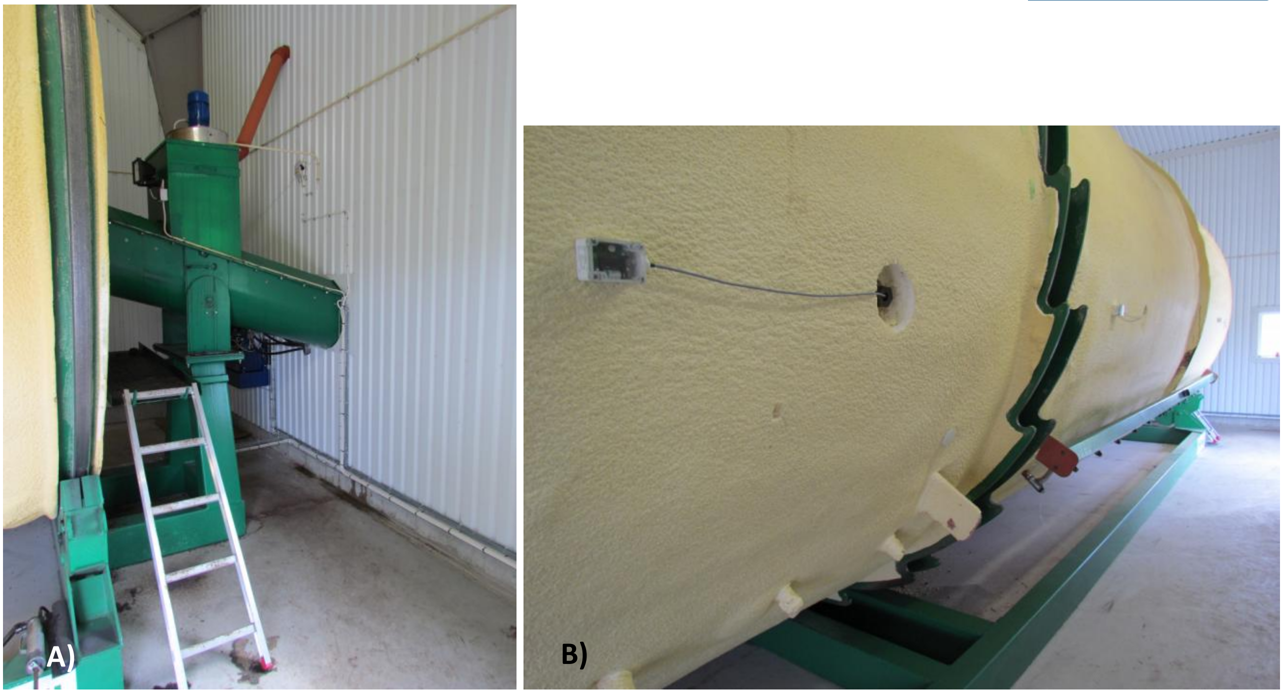

Figure 22. a) The input screw conveyor for substrate loading into the composter drum as seen from inside the building and b) temperature sensors in the drum composter.

The retention time for the substrate within the drum composter is about 1.5-2 days. Compost is continually removed from the opposite end of the drum with an angled screw conveyor that transports and deposits the compost outside at the opposite end of the building from the input (Figure 23). Another concrete hard standing is used to collect the finished compost and store it in windrows for 1-3 months to mature, depending on the season. The composting process results in an approximately 30% volume reduction in the organic material.

Figure 23. a) Output screw conveyor for compost from the drum and b) loading the finished compost on a trailer for transport to the packaging facility.

5.2.2 Quantor XL® drum composter by ESCAB

For a detailed description of the composting drum and how it functions, see section 4.1.2.

5.2.3 Feed materials

All solid manure produced on Mellby farm is composted, plus the separated manure solids from the pig slurry (Table 6). In addition to this, approximately 4 000 m^3 of solid manure is received from surrounding farms. Mellby farm does not pay for the manure or charge the farmers for taking it.

Table 6. Average amounts of substrate used for the compost mixture per year

Material	Volume (m^3)/yr
IN: Horse manure	3 500
IN: Cow deep-litter manure	3 500
IN: Pig deep-litter manure	2 000
IN: Separated pig manure solids	1 500
IN: Extra manure imported from surrounding farms	4 000
OUT: Finished compost	11 000

5.2.4 End product use

All of the finished compost is sold to a company that packages and sells a variety of soil improvers for home gardening use.

5.2.5 Investment and operating costs versus income

The QuantorXL® drum composter costs 320 000 EUR installed, which includes the mixing container, input and output screw conveyors, all the controlling and monitoring equipment, staff training and one year's service. In addition to this, there are investment costs for the building around the drum composter, the asphalted hard standings, the collection pond and the constructed wetland.

Operating costs include between 15-20 000 kWh of electricity, fuel and maintenance costs for 1 hour per day of front loader operation, and approximately 400 man-hours of labour annually.

Direct income includes the sales of soil amendment products. Indirect incomes include costs saved for transportation and spreading solid manure and a reduced volume of pig slurry that needs to be transported to fields and spread.

6 Separation

Erik Sindhöj, JTI
Pellervo Kässi, MTT

Separation technologies have the objectives of separating slurry or liquid manure into a solid fraction and a liquid fraction. There may be many reasons for separating slurry. Separation can reduce the volume of the liquid fraction by 15-30% compared with untreated slurry (depending on separator type and efficiency). The liquid fraction generally requires little or no mixing prior to spreading. There is less contamination of crop leaves when the liquid fraction is spread on grassland and, owing to its lower dry matter content, it infiltrates more quickly into the soil after application and reduces ammonia emissions compared with applying unprocessed slurry (Hansen et al., 2005; Amon et al., 2006). However, total ammonia emissions from both the solid and liquid fractions during storage and spreading can be higher than those from unprocessed slurry, depending largely on the storage techniques used for the solid fraction (Hansen et al., 2005). Therefore if separation techniques are used it is important to cover the solid and the liquid fractions during storage. Depending on separation technique used, the liquid fraction can also have a lower P content, since most of the P is bound in organic matter and separated into the solid fraction. This can result in a more balanced N:P ratio in the liquid fraction and allow application rates based on N requirements without exceeding P application limits. The solid fraction, with its much lower water content, has more rational logistic costs for transportation to fields far away. Furthermore, due to its increased transportability, the solid fraction can be exported off-farm as a soil amendment or as substrate for biogas digestion.

Many types of technologies are available for separating manure into solid and liquid fractions. This typically comprises relatively 'coarse' separation, since the separation efficiency of dry matter between the fractions can vary widely depending on numerous factors (Hjorth et al., 2009). Separation techniques can be passive or mechanical. Passive techniques include sedimentation, which can be used for slurries and weeping walls. Mechanical techniques can be more effective, but have greater investment and operating costs. Mechanical separation technologies can include screens, belt press, screw press, centrifuge decanters and flotation or aeration techniques with scrapers. Chemical additives for coagulation and flocculation can be used to increase the separation efficiency of many of these techniques.

6.1 Mechanical separation of slurry on a pig farm

Mechanical separation of pig slurry was implemented on a pig farm in Finland with integrated production in 2006 and is still in use. The farm invested in the separator as part of a change in manure management strategy accompanying expansion of its pig production unit. Objectives for the separation system were to increase the efficiency of manure nutrient distribution on the farm, particularly P, as well as improving odour emissions and facilitating handling of the liquid manure.

There are 600 places for sows and approximately 2 300 finishers are produced annually. All piglets are finished on the farm. There are two main animal housing units; the sows are managed on a solid manure system and the weaned and finishing pigs on a slurry-based system. About 1 700 m^3 of slurry are produced annually, all of which is processed by mechanical separation. The farm is self-sufficient in producing feed grain for the pigs and only some protein and mineral concentrates are purchased off-farm. The farm has 180 ha of arable land and distance to fields is 0-8 km from the piggery, with about 100 hectares within a 2-km radius.

6.1.1 Description of separation plant

An extension to the housing unit for the finisher pigs was built specifically for the separation plant, since no other good space was available on the farm. A Bauer screw press separator (www.bauer-at.com) was mounted on a 3 m high concrete wall next to the collection pad (Figure 24). The separator machine is fed with slurry direct from the pumping pit outside of the finishing house. The dry fraction falls into a pile on a concrete floor under the separator, and this covered pad is also used for storage of the solid fraction. The liquid fraction from the separator drains to the slurry storage tank (Figure 25). Before the separation plant was built, slurry from the pumping pit was pumped directly to the storage tank. The same pump is now used to feed the separator.

The separator has a processing capacity of about 20 m^3 slurry per hour, which means it is currently operated twice a week for about 1 hour each time. The labour required for operating the processing system is only a few minutes for each batch. This results in a labour requirement of about 10-20 hours per year and separator running time of around 100 hours per year.

There are some operating problems when the temperature falls below -10°C, and installation of insulation around the separator is being considered.

Figure 24. The Bauer screw press separator mounted above the solid fraction collection pad.

6.1.2 End product use

The end products are a liquid fraction of 1 500 m^3 and a solid fraction of 400 m^3 (Table 7). The solid fraction is spread together with the other solid manure generated on the farm, using a broadcasting solid manure spreader owned by the farm. The solid manure is typically spread on the fields farthest away, and is tilled into the soil before drilling of spring cereals. The liquid fraction is spread by a contractor on fields that are relatively close to the farm buildings.

Table 7. General characteristics of the slurry and separated products. DM = dry matter content, TN = total nitrogen, NH_4-N = ammonium nitrogen, TP = total phosphorus

Material	Volume or mass (m^3 or tonnes /yr)	DM (%)	TN (kg/tonne)	NH_4-N (kg/tonne)	TP (kg/tonne)
IN: Slurry	1 700				
OUT: Solid fraction	165	31.9	7.7	4.1	4.4
OUT: Liquid fraction	1 500	4	5.9	3.9	1.1

Figure 25. Storage for the liquid fraction of the separated slurry.

6.1.3 Costs versus savings

Costs include initial investment and operation/maintenance costs. Investments costs for the separator amounted to 20 000 EUR, not including the cost of the buildings for processing and storage of the solid fraction. Other initial costs included pipelines for transporting slurry from the collection pit to the separator and the liquid fraction from the separator to the storage tank, but these were minimal.

Operating and maintenance costs have been relatively low to date. Both the screw and the screens in the separator have a limited technical lifetime. The screw was replaced after 6 years, which cost 7 000 EUR, but wear on the screen is low so it should last another 2-3 years under current operating conditions. Screen replacement will cost 3 000 EUR. Thus maintenance is expected to cost 10 000 EUR over 10 years, or 5% of the investment cost annually. The labour requirement for replacing the screw was 12-20 hours and changing the screen is estimated to take the same amount of time, so this should be a maximum of 40 hours every 10 years, or about 4 hours per year. There are also two greasing spots on the separator which must be regularly maintained, possibly requiring 5 hours of maintenance per year, plus 10-20 hours operating labour. Other operating costs include electricity to run the separator, which has a 5.5 kW motor, for about 100 hours per year, or about 550 kWh.

Savings include the avoided need for additional slurry storage owing to the volume reduction from slurry separation. Time and energy are also saved, since considerably less mixing of the slurry is necessary before spreading.

6.2 Mechanical separation of digestate on a dairy farm

Odensviholm is a dairy farm in Kalmar County in south-east Sweden. It has about 450 milking cows, plus heifers and calves but is expanding production. Most of the manure handling is slurry-based, although some solid manure is generated in the calf barn. About 20 000 m^3 slurry and 1500 tonnes solid manure are produced annually. Both the slurry and the solid manure are first treated with anaerobic digestion for the production of biogas. The digestion chamber is 2 000 m^3 and is fed daily with 46 m^3 of slurry and 4.9 tonnes of mixed solid manure and spoiled feed. Retention time in the reactor is about 30 days. Biogas is converted using a combined heat and power (CHP) plant that produces approximately 1 GWh of electricity per year.

Odensviholm recently expanded its herd size to the current level and built a new cow shed. There were two main reasons behind investing in a separation plant: 1) to reduce the volume of liquid digestate and the associated logistical costs associated with handling and spreading, and 2) to lower the P concentration in the liquid fraction so nutrients can be more rationally distributed on the farm.

6.2.1 Description on separation plant

An insulated building was built to house a GEA separating decanter (www.westfalia-separator.com), which operates on centrifuge technology (Figure 26). Incoming digestate is pumped from the digestate storage tank to the separator. The solid fraction falls onto a diagonal screw transporter which deposits it onto a concrete storage pad outside. The storage pad has 2 m high walls on three sides and is uncovered. The liquid fraction is then drained by gravity into nearby storage tank (1 500 m^3) that is not covered with a roof. The separating plant is turned on and off manually and operates between 6-8 hours most days.

6.2.2 End product use

The end products of the separation processing are a liquid fraction and a solid fraction (Table 8). All processed manure is used on the farm as fertiliser. It shares a Samson slurry tanker (20 m^3) with a boom and trailing hose applicators and a solid manure broadcaster with a neighbouring farm. The solid fraction is typically spread on the fields farthest away, and is tilled into the soil before drilling of spring cereals.

Figure 26. GEA centrifuge decanter manure separator (www.westfalia-separator.com).

Table 8. General characteristics of the slurry and separated products. Amounts estimated by the farmer and dry matter content (DM) measured in samples taken during visits

Material	Mass (tonnes/yr)	DM (%)
IN: Slurry	20 000	8.5
OUT: Liquid fraction	17 250	4.8
OUT: Solid fraction	2 750	32.1

6.2.3 Costs versus savings

Costs include initial investment and operating/maintenance costs. Initial investment costs included the separator, the building which houses the separator and the storage pad for the solid fraction. Other initial costs included pipelines and electrical connections. Total fixed costs were about 180 000 EUR.

Variable costs include maintenance and operating costs include the electricity to run the separator. This is estimated to about 5% of initial investment.

Savings include the avoided cost of having to build additional slurry storage. The costs of spreading the liquid fraction are also reduced due to the reduction in volume. The solid fraction is currently spread on arable land, but a local topsoil producer is interested in using this solid fraction as an organic soil amendment. Before being sold commercially, it must be thermally treated or composted according to EU regulations. Savings are also obtained since considerably less mixing of the slurry is necessary before spreading. The farmers own economic calculation estimated that savings should pay for the investment in 6-7 years.

7 Cooling and heat recovery from slurry

Ilkka Sipilä, MTT

The first slurry channel cooling systems on Finnish pig farms were built around 2005. Heat recovered from slurry with a heat pump can produce a substantial amount of the total energy required in a pig house (Figure 27). In addition to slurry, soil, deep wells and inside air can be used as heat sources.

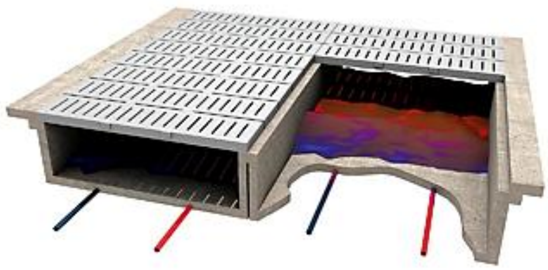

Figure 27. Heat recovery piping is placed in the bottom of slurry channels and connected to a heat pump, which heats water in an accumulator tank (http://www.pellon.com/In_English/Pig_Husbandry/Heat_pump).

The recovered heat can be used to heat buildings, drinking water or washing water. The main benefit is the savings in heating energy, usually heating oil, although the use of electricity for heating is increasing. Usually, 1 kW of electricity produces 2-4 kW heating energy.

Besides the energy savings, cooling the slurry channels decreases ammonia, methane and carbon dioxide emissions (Figure 28). Due to the reduced emissions, the air exchange rate can be reduced, which means lower heat losses and less odour problems in the surrounding environment.

Under Finnish climate conditions, only part of the required heating capacity can be recovered from slurry cooling. During the coldest winter periods, additional energy for the heat pump has to be obtained from soil, deep wells or inside air. There is usually also an oil or wood chip-based heating system for back-up. Since cooling of the slurry usually only produces part of the required heating energy, a control system for the various heat sources used is necessary.

On one Finnish pig farm, 600 m of heat recovery piping has been installed under a total area of 670 m^2 of slurry channels, meaning about 0.9 m of piping per 1 m^2 of slurry channel area. On this farm (1 000 fattening pig places), 1 200 m^3 of the total amount of 2 000 m^3 of slurry are annually cooled to 12°C and from this slurry, the heat pump can produce 40 kW heating capacity. The system also contains a 200 m deep well as a heat source, which in summertime is used as a heat sink. The farmer estimates that without the heat recovery system, the yearly heating oil consumption would be 15 000 litres. With the heat recovery system, annual consumption is about 2 000 litres.

Similar results have been reported for another Finnish pig farm using only heat recovered from slurry channels (http://www.environment.fi/download.asp?contentid=139566&lan=fi). The annual slurry production on the farm is about 2 500 m^3 (900 fattening pig places) and the oil consumption per year has dropped from 6 000 litres to less than 1 000 litres. The heating period is about 4 months, from December to March. The electricity consumption of the heat pump is about 8 000 kWh during the heating period.

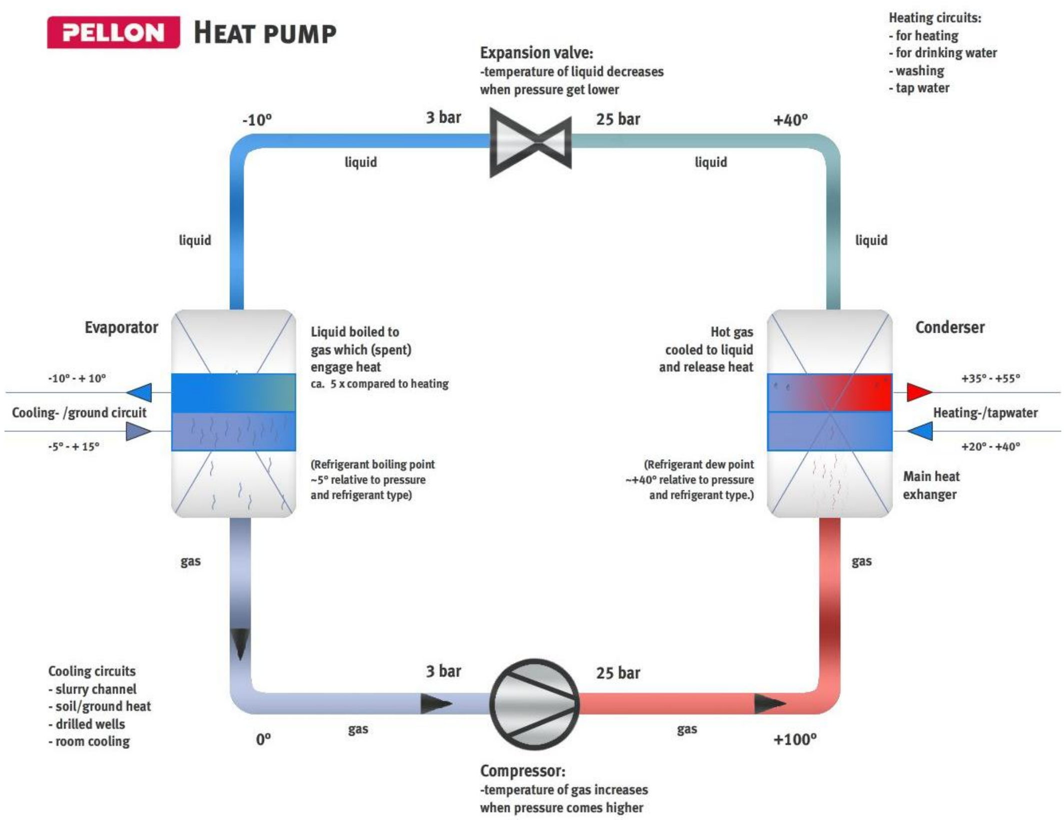

Figure 18. The principle of recovering heat from slurry, soil or air with a heat pump to heat up the building, drinking water or washing water.

Lower slurry temperature means also less ammonia, methane and carbon dioxide emissions into the house air. This means that if air exchange is not needed to remove heat from the house, the air exchange rate can be substantially lower. Less electricity is thus needed for air exchange and less heat is lost. Cooling the slurry in the house increases the freezing duration of slurry during winter storage, but according to this farm's experience, this has not delayed spreading.

The investment cost for the system with a deep well was about 80 000 EUR in spring 2012. The investment subsidy was 15% and 70% was covered by interest rate guaranteed loan. The heat recovery system from slurry only cost about 20 000 EUR in 2010, of which about 50% was covered by the subsidy paid for animal welfare.

According to Finnish guidelines for environmental protection in animal husbandry (http://www.ymparisto.fi/download.asp?contentid=117243&lan=fi), slurry cooling is one of the best available techniques in manure handling.

8 Anaerobic digestion

Erik Sindhöj, JTI
Sari Luostarinen, MTT

Anaerobic digestion is currently one of the most widely used manure processing technologies for livestock manure (Foged et al., 2011), although still quite rare in some countries. The anaerobic decomposition of organic material is a natural microbiological process that occurs under oxygen-free conditions by specific groups of bacteria that convert organic carbon to methane and carbon dioxide. Anaerobic digestion uses different technological solutions to optimise the conditions for the microbial population, with the aim of converting as much as possible of the organic matter into methane-rich biogas. During anaerobic digestion, the nutrients in the raw organic material, particularly N and P, are conserved in the residues. Furthermore, while the total amount of N does not change, anaerobic digestion converts a portion of the organic N to NH_4-N, which is a N form readily available for plant uptake and increases the fertiliser value of the digestate compared with the raw manure. Thus, anaerobic digestion not only leads to utilisation of the energy potential in the raw material, but also increases the potential for utilising the nutrient resources it contains. However, it also increases the risk for N losses as ammonia emissions during storage and after spreading, as the pH is increased by digestion (Clemens et al., 2006; Sommer et al., 2006). Furthermore, the conditions are less favourable for natural crust formation on the digestate surface compared with non-digested slurry, which also promotes N losses as NH_3 (Sommer et al., 1993). In total, as the digestate has a higher rate of total ammoniacal N in total-N than non-digested slurry, best available technology is needed to prevent high losses of N and ammonia emissions (Frandsen et al., 2011).

Livestock manure is an excellent material for anaerobic digestion. It is continuously produced, the quality is stable, its buffering capacity is high and it contains all the nutrients required by the bacteria for their metabolism and growth. The energy content of manure is not particularly high, but it can be increased with suitable co-substrates when desired (Luostarinen et al., 2011). Digestate from manure-based anaerobic digestion also has sufficiently similar physical characteristics to the raw manure that it can be handled with much the same machinery as liquid manure.

The main purpose in using anaerobic digestion to process livestock manure is currently the production of biogas, and interest in this technology is largely driven by the potential for renewable energy production. However, there is growing interest in the technology for other significant reasons too, e.g. more efficient utilisation of nutrients and mitigation of greenhouse gas emissions.

The Baltic Manure project works with “Manure Energy Potentials” in Work Package 6, which has produced a detailed overview of anaerobic digestion techniques and technologies focusing on maximising biogas output from livestock manure (Luostarinen et al., 2011). It has also described in detail an example of a dairy farm using anaerobic digestion of livestock manure for biogas production, and the effects of this on farm finances (Luostarinen et al., 2011). Several other examples of farm-scale anaerobic digestion for processing livestock manure for biogas production can be found in the BSR (Sindhöj and Rodhe, 2013). Because of the work that has already been done on this subject, it is not repeated here.

Similarly, some studies have concluded that anaerobic digestion of livestock (pig) manure, aside from its potential to produce renewable energy, is the best available technology for reducing N leaching (Foged et al., 2011). This conclusion is based on the increased fertiliser effect of the digestate compared with raw slurry. Since digestate has a higher ratio of ammonium N to total N than raw slurry, more N is available for plant uptake and less organic N is left for mineralisation during the autumn and winter, when the leaching potential is greater. In addition, digestate is generally more homogeneous, which allows higher precision when spreading it as a fertiliser. There are also other benefits of anaerobic digestion such as reduced odours and, depending on process temperature, reductions in pathogens and weed seed viability. While these are obvious benefits that follow the new paradigm of manure as a resource which should be fully utilised, there are also a number of risks associated with digestate handling that can increase the environmental impact compared with raw slurry handling. These risks can be minimised with proper digestate handling from storage to spreading, allowing the environmental benefits of manure anaerobic digestion to be maximised.

Since digestate has a higher ammonium concentration than raw slurry, care should be taken in handling to reduce the risk of N losses through ammonia emissions. The pH of digestate is also higher than that of raw slurry and therefore the risks of ammonia evaporation from the surface are correspondingly greater. Previous reports (Luostarinen et al., 2011; Luostarinen, 2011) also contain some basic information on the digestate and matters to be considered when storing and utilising it. Some data on the effects of manure anaerobic digestion on the environment are also given. Furthermore, due to the similarities between digestate and raw slurry, some of the innovative manure processing technologies described earlier in this report might also be well applied to digestate on farm scale.

8.1.1 Post-digestion tanks

Post-digestion tanks are paramount for reducing methane emissions from digestate and are generally integrated into the design of biogas plants and situated directly after the actual digester. The temperature of the digestate released to storage is related to the methane and ammonia emissions during storage (Clemens et al., 2006). Therefore the volume of the post-digestion tanks should either be large enough to ensure an adequate retention time to lower digestate temperature before storage, or heat exchangers should be used to cool the digestate.

8.1.2 Storage

Many of the same recommendations for reducing greenhouse gases and ammonia emissions from stored raw slurry can also be applied to digestate. When designing a new storage structure, minimising the surface area in relation to the overall volume of the storage container is essential, since ammonia evaporation occurs at the surface boundary between liquid and air. As with raw slurry storage, a cover is essential to minimise ammonia evaporation from the surface. However, unlike raw slurry, digestate typically does not form an adequate natural crust for covering the surface so artificial covers or roofs should be used. The purpose of these is to slow the velocity of air over the open surface of the liquid and thereby reduce the evaporation rate. Roofs or covers that keep out rainwater offer the additional advantage of preventing further dilution of the digestate. Closed, gas-tight covers with gas collection techniques are most effective at reducing greenhouse gas emissions from storage tanks and have been recommended for optimum environmental benefit of anaerobic digestion plants (Clemens et al., 2006). They also enable collection and energy use of the post-gas produced. For example in a Finnish farm-scale biogas plant digesting cattle slurry, 10-15% of all biogas produced originates from the post-digestion tank (S. Luostarinen, personal communication 2012).

8.1.3 Spreading

Spreading digestate on arable land as a fertiliser is the final step in the handling chain. In order to conserve the extra N that has been made available through anaerobic digestion, it is very important to incorporate the digestate spreading strategy with the overall crop nutrient management for the farm. Samples of digestate must be analysed for nutrient content and the digestate spread at a time when plants are able to take up the nutrients, and in a quantity that the plants can utilise.

Similar techniques and technologies for reducing ammonia emissions from spreading raw manure should also be applied to digestate. Soil injection techniques and direct mulching into the soil after slurry application have been shown to reduce ammonia emissions by as much as 90% compared with broadcasting techniques (Malgeryd, 1996). When spreading with trailing hose techniques, digestate should be applied only under optimum weather conditions (cool, humid and no wind). Irrigating directly after spreading can also reduce ammonia emissions, which can be practical when spreading on leys or other growing crops that cannot be incorporated into the soil. Acidification techniques, described in an earlier chapter, are also well suited for treating digestate to reduce ammonia emissions.

9 Overview of the processing technologies studied in this report

The manure processing technologies studied on farms in this report are summarised in Table 9.

Table 9. Estimated costs of manure processing technologies. Annuity method used for calculating depreciation, investment lifetime 10 years and interest rate 5%.

Method	Type of farm	Capacity	Motive for use	Economy					
Nutrient concentration technologies				**Investment cost, €**	**Annuity, € yr^{-1}**	**Operational cost, € yr^{-1}**	**Total cost, € yr^{-1}**	**Cost, € m^{-3} yr^{-1}**	**Incomes and savings not included**
Split-Box (SE) *prototype*	Dairy farm	Targeted capacity 15000 m^3 yr^{-1}	Reduce volume of manure-fertiliser to store and spread, alternative use for solid fraction, remove water that is clean enough for infiltration treatment.	300 000	38 851	35 000	73 851	4,92	Income from reduced volumes to store, transport and spread; possible fertiliser sale
Pellon (FI) *prototype*	Pig farm	Targeted capacity 6000 m^3 yr^{-1}, test farm produced 2200 m^3 yr^{-1}	Reduce amounts of fertiliser to store and spread.	130 000	16 836	6 000	22 836	3,81	Income from reduced volumes to store, transport and spread; possible fertiliser sale
Reverse osmosis (NL)	Pig farm with 1050 sows	10 000 m^3 yr^{-1}	Reduce volume of manure-fertiliser to store and spread, exports solid fraction off-farm for composting to produce soil amendance, export concentrate off farm and recieves some income for the concentrate if sold when fertlizers are needed.	200000^	25 901	39 000	64 901	6,49	Income from reduced cost of exporting manure and for liquid fertiliser sold
Slurry acidifications									
InFarm A/S (DK)	Pig farm, produces 6500 fatteners yr^{-1}	Max capacity unknown. Farm produced 3250 m^3 yr^{-1}	Ammonia abatement technique is required by local authority when expanding pig production.	100 000	12 950	8 775	21 725	6,68	Saved N; S fertilisation unnecessary
BioCover (DK)	Fictive farm with 3800 pig places, typicle for Denmark	Max capacity unknown. Farm produced 6000 m^3 yr^{-1}	Acidification or injection of slurry at spreading is demanded by local authorities in order to limit ammonia emissions after spreading.	0~	0~	6 250	6 250	1,04	Saved N; S fertilisation unnecessary
Composting									
Drum composting 1 (SE)	Beef animals, import horse manure	10 000 m^3 yr^{-1} horse manure, 300 m^3 yr^{-1} deep litter manure, 25 tonnes yr^{-1} organic residues	Produce commercial soil and fertiliser products.	320 000	41 441	16000*	57 441	5,55	Income from tipping fees, and sold commercial soil and fertiliser products
Drum composting 2 (SE)	Integrated pig production (640 sows, 5500 places for finnishers), beef cattle (150 nursing cows)	3500 m^3 yr^{-1} horse manure, 5500 m^3 yr^{-1} deep litter manure, 1500 m^3 yr^{-1} separated solids from pig slurry, 4000 m^3 yr^{-1} imported manure	Less manure to handle on farm, income from compost sold to a company that produce soil improvers.	320 000	41 441	16000*	57 441	3,96	Income from reduced volumes to store and spread and sold commercial soil and fertiliser products.
Separation									
Separation, screw press (FI)	Integrated pig production (600 sows, 2300 finnishers yr^{-1})	Max capacity 20 m^3 hr^{-1} cattle slurry, 25 m^3 hr^{-1} pig slurry. Farm produced 1700 m^3 yr^{-1}	Increase efficiency in allocating of manure nutrients on the farm as well as improving odour emissions and for easier handling of the liquid manure.	20 000	2 590	1000*	3 590	2,11	Saved logistic costs, better allocation of nutrients on farm
Separation, centriguge (SE)	450 milking cows plus recruitment animals	Dairy farm produced approx. 20 000 m^3 digestate yr^{-1}	Reduce volume of liquid digestate and associated costs for storage and handling, lower P concetnration in the liquid fraction.	180 000	23 311	9000*	32 311	1,62	Less costs for liquid manure handling (but costs for solids)
Heat pump									
Cooling and heat recovery (FI)	1000 fattening pig places	1200 m^3 yr^{-1} (out of 2000)	Save energy for heating, decreasing ammonia and carbon dioxide emissions by cooling and thereby lower need of air exchange of housing.	20 000	2 590	1000*	3 590	2,99	Saved N and energy

^Calculated from the yearly annuity fee on initial investments given in de Hoop et al., 2011

~Equipment is owed by contracting firm so farmer has 0 investment cost

*Estimated as 5% of initial investment

10 Research and development needs for processing technologies

Lena Rodhe, JTI

A key factor in environmentally friendly manure processing is to eliminate nutrient losses or other pollutants to the environment during and after processing. Furthermore, fertiliser end products should have chemical properties that render the nutrients readily available for plant uptake and physical properties that allow precision application (rate, evenness of spreading). This reduces the risks of other environmental pollution (emissions, odour, bacterial contamination, etc.).

Mass and nutrient flows IN and OUT and WITHIN processing units were not monitored in this report and in general are not well known for the processing technologies described. Evaluation of manure processing technologies on-farm is time-consuming, complicated and costly, which is why few processing technologies have been thoroughly evaluated. There are rarely adequate data on emissions of gases such as ammonia, methane and nitrous oxide during processing and subsequent handling, storage and utilisation of the end products. This means that essential data on mass and nutrient balances of processing technologies, which are needed in order to confirm that the processing is actually beneficial for the environment, are still lacking. It is also important to examine the processing technologies under different farm conditions in order to develop operating guidelines that are optimised for “lowest-emission” under specific conditions.

Recommendations on how to use commercial mineral fertilisers in crop production are based on more than 50 years of specific research for each crop species and climate zone. There are also many years of research behind recommendations for manure use in crop production and regulations for avoiding losses of nutrients to the environment. In addition, the market currently offers appropriate technologies for handling, storage and spreading of both mineral and organic fertilisers. However, new manure processing technologies will create new fertilisers and other end products, which will require new knowledge-based recommendations on optimal use in crop production, while avoiding pollution of the environment. Handling technologies for these new end products will also need to be developed, so that storage and application are optimal. For example, nutrient concentrates may be spread with field sprayers, but nozzle types have to be tested to identify the best spreading results. If the risks of ammonia emissions are high, as they are with ammonia water scrubbed from stripping towers, injection or acidification techniques may need to be adopted to minimise emissions.

In general, manure processing could offer opportunities for better manure management on regional or farm scale if can reduce manure volumes, and thereby logistic handling costs, or otherwise reduce the environmental impact of manure handling, storage and spreading. There is also the possibility of the new product having a better fertiliser value than the original livestock manure. For example, organic N is converted to ammonium N. Processed manure could be a possible commercial fertiliser, attractive for other farmers as well as gardeners, which mean business opportunities for the fertiliser producer. However, the processing and use of the end products as fertilisers must be optimised from an environmental and economic point of view. This raises demands for knowledge about how to run the processes under different farm conditions and with minimum nutrient losses and how to achieve high plant nutrient utilisation from the end products.

11 Conclusions

- Different kinds of processing technology for manure can be found on farms in BSR
- Motives for farm-level manure processing vary and include:
  - *Decreased volume of liquid manure to handle*
  - *Easier handling of liquid manure due to lower viscosity*
  - *Reduced ammonia emissions and thereby compliance with legislative requirements*
  - *Improved air quality in livestock housing and recovered heat energy*
  - *Production of different qualities of fertilisers for different uses (solid P for distant fields)*
  - *Production of commercial soil and fertiliser from manure, mainly solids but also liquids, income from tipping fees*
- Most technologies are for processing slurry and only one (drum composting) is for solid manure
- Current technologies for concentrating nutrients in manure are not yet commercially viable
- Acidification of slurry is commonly practised in Denmark, reverse osmosis in the Netherlands
- Mechanical separators work well with animal slurry and use well-known technology
- Drum composting is used for making commercial soil amendment products from non-attractive solid manure and separated manure solids in Sweden
- Heat pumps are used for heat recovery from slurry and for improving air quality in houses (condition for reduced ventilation rate) in Finland.
- The processing technologies presented have a capacity of 1 200 to 20 000 m^3 slurry per year
- Some economic data are presented, but costs per m^3 are often unknown.
- Some environmental data are available for specific technologies but are lacking for many processing technologies.

12 Recommendations

- Make a farm-specific business plan for investment (realistic, accurate)
- External income could be the driver for good economics of use
- Look at the whole handling chain, all components should be resolved (for instance, how to spread new fertiliser products, plant availability, etc.)

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This report in brief

This report presents case-study examples of manure processing technologies that have been implemented and used on livestock farms in the BSR. Farm conditions and the technologies are described and information such as capacity, motive for use and the economics of use are summarised for the different technologies.

The motives for using manure processing technologies were many, including decreasing the volume of liquid manure to handle, lowering the viscosity of liquid manure, reducing ammonia emissions and thereby complying with legislative requirements, improving air quality in livestock houses, recovering heat energy by cooling, and producing different qualities of fertilisers with higher nutrient concentrations for different applications.

Other reasons were producing commercial soil and fertiliser products from manure (mainly solids but also liquids) and obtaining income from selling those products on market, and getting tipping fees for organic products such as horse manure or vegetable residues.

This report on Manure Handling Techniques was prepared as part of work package 3 on Innovative Technologies for Manure Handling in the project Baltic Manure.

About the project

The Baltic Sea Region is an area of intensive agricultural production. Animal manure is often considered to be a waste product and an environmental problem.

The long-term strategic objective of the project Baltic Manure is to change the general perception of manure from a waste product to a resource. This is done through research and by identifying inherent business opportunities with the proper manure handling technologies and policy framework.

To achieve this objective, three interconnected manure forums has been established with the focus areas of Knowledge, Policy and Business.

Read more at www.balticmanure.eu.

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