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AN ECONOMIC AND ENVIRONMENTAL ANALYSIS OF SLURRY SEPARATION

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Abstract

With increased pressure to redistribute animal manure in order to lower the environmental pressure from agriculture, it seems obvious to consider processing slurry into nutrient rich fractions which can easily be transported. In this paper, an overall analysis of four different separation technologies is presented. The four technologies are Decanter, Funki Manura 2000, Green Farm Energy and Staring. These technologies are all implemented on a full scale in Denmark. In this paper both the economic and environmental aspects are considered, looking at the entire chain from stable to the field. The total investment costs range from 50 000 to 4 million € and the total extra costs range from 1 to 7 € per tonne of the f [illegible] feeding is a cheaper first step when reducing phosphorus surplus. Improved nitrogen utilisation is only apparent with the Staring and Green Farm Energy concepts.

The conclusion is that the Funki Manura 2000 system is too expensive and the Decanter system a fairly cheap way to reduce phosphorus levels, but other benefits are limited. Staring and Green Farm Energy show the greatest potential, but these systems have not been running long enough to validate the expected results included in this paper.

1. Introduction

In a number of regions in Europe the amount of animal manure is high compared to the agricultural land where it can be applied, leading to applications of nitrogen and phosphorus which exceed the crops requirements. These regions cover the Western part of Denmark, The Netherlands (especially the Southeast), Belgium, as well as parts of France and Spain (Brower, 1999). In these areas there is a need to transport slurry for distances of up to 100 km (e.g. The Netherlands) (Brower, 1999). In order to comply with the Nitrate directive, some EU-countries will need even stricter rules regarding e.g. livestock manure application than they have presently, as only Sweden and Denmark currently, have had their nitrogen policy accepted by the EU-commission. On top of that, comes further environmental regulation following the Water Framework directive (2000/60/EF) which has to be implemented in the coming years. The need to transport slurry is, therefore, not diminishing over time given the current livestock production in Europe, let alone in case of an increase.

It could here be noted that Danish legislation allows only a maximum of 1.4 livestock units (pigs) and 1.7 livestock units (dairy) per hectare. One livestock unit is 100 kg N (ab storage). The area needed for distribution of slurry needs to be owned, rented or guaranteed through 5 year slurry contracts. A percentage of the area needed to distribute animal manure has to be owned by the farmer and this percentage increase with farm size.

The largest part of slurry is water and it is natural to consider separation of slurry into fractions where the water fraction stays on the farm. This will e.g. reduce the transportation costs and lower the storage costs, as some of the fractions might not need to be stored as long as slurry. Furthermore, higher utilisation of nutrients in the fractions will lead to lower purchase of mineral fertiliser. Separation will especially help to decrease the phosphorus load if the phosphorus rich fractions are exported away from the livestock intensive farms (Jacobsen, 2002). Finally, the use of separation techniques might reduce the smell from pig production and lower the frequency of animal diseases from slurry as the process might reduce the number of harmful bacteria (pathogens). The use of separation techniques could in a range of ways lead to a reduction in the environmental impact from agriculture.

On the other hand, one should be aware that any additional cost related to processing slurry has to be recovered in one way or another and that the additional costs which can be added to this low value product is limited. Transportation is here the obvious alternative.

The development of separation techniques has been going on for years and has involved a range of different technologies (Jacobsen et al. 2002). Some of these are low-technology concepts using relatively simple separation methods (such as decanter), whereas others use high-technology concepts, where a water fraction is separated. Several low-technology concepts and some high technology techniques (e.g. Funki Manura and Green Farm Energy) have been implemented in The Netherlands and Denmark (Funki, 2002 and GFE, 2002). The Staring concept has not yet been implemented full scale, but this will happen shortly. However, many technology concepts have, at the pilot stage, faced technical and economical problems, which is why only few technologies have reached full scale implementation.

The purpose of this paper is to analyse and compare four different separation concepts in order to evaluate the overall costs and the environmental impact from stable to field. The separation concepts investigated are a decanter technology (Peralisi FP600/M) and Funki Manura 2000, where detailed analysis can be found in Jacobsen et al. (2002). Furthermore

the Green Farm Energy and Staring-concepts have been included to show two new technologies using different approaches.
Firstly, the paper gives a short description of the four separation systems. The paper then describes the costs and revenue related to using the four technologies from stable to field. The following section discusses the environmental aspects. The final chapter looks at conclusions and future trends and barriers for an increased uptake of separation techniques.

The paper is unique in its holistic analysis of separation techniques including both the environmental and economic dimension, looking at the entire chain from stable to the field, with focus on nitrogen usages and phosphorus. The paper should hence be of interest to farmers around the world who are farming in livestock intensive areas and facing increased environmental regulation.

2. Model

The calculations for the Decanter and the Funki Manura system are based on Danish norm figures for pig slurry (ab stable) (Poulsen et al., 2001), as it is assumed that the slurry comes directly from the stable to the separation plant. The farm chosen has 1,000 sows and a production of 23,200 slaughter pigs a year, which is 1,000 livestock units. The annual manure produced is 17,311 tons. The area of the farm is 714 ha cropped land, which is equivalent to the maximum livestock intensity allowed in Denmark at present of 1,4 LU per ha. The phosphorus production from the pigs is equivalent to 40 kg phosphorous (P) per ha, whereas the norms for the crop rotation is only 21 kg P per ha. This size of the farm has been chosen to utilise the economics of scale on the two separation plants. Alternatively, co-operation between more farmers could be envisaged.

With respect to Staring and Green Farm Energy, the analyses have been based on budgets for the plants prepared by the producers or local advisors. The analysis especially for Green Farm Energy is different, as it is not based on pig slurry as the sole input, but also relies on inputs like straw and bone meal to increase the gas production. Comments will be made on what the results would have been if the inputs had only been pig slurry. At present, only some of the data has been verified by production results, but it is the intension at the congress to present results based on actual production results if they are available by then.

3. Description of the four technologies

3.1. Decanter centrifuging

When using a decanter centrifuge the slurry is separated into two fractions called the fibre (humus) and liquid fraction. The fibre fraction contains 14% dry matter, 75% of the P and 25% of the N. The liquid fraction, or the reject, contains the rest of nutrients and has a dry matter content of 3%. The technique has been used for years and is thoroughly tested. A range of companies like Pieralisi, Alfa Laval and Westphalia sell decanter centrifuges.

3.2. Funki Manura

The Funki Manura 2000 system is an example of a high-technology separation system without biogas. The system consists of three parts; a decanter centrifuge, drying procedure and an ammonia stripper. In the first stage, the decanter separates the dry fraction as with the decanter in the previous section. Then the reject is divided into three fractions: an NPK fraction, an N-fraction and a water fraction. The water fraction can be sprinkled on the ground, but is not allowed in streams, as the N content is 80 mg/l. The N-fraction contains as much as 160 kg N/tonne. The Manura system requires much energy use (50 kWh/tonne). There is only one plant in Denmark and a few plants in The Netherlands. The technology has been tested over a few years and the full-scale plants seem to be running according to expectations.

3.3. Green Farm Energy

This high technology concept includes the production of biogas. Apart from slurry the input can be bone meal, energy crops and manure from chicken production. The process starts with ammonia being striped (the N-fraction) from the material. Some of the striped slurry is then lead back to the stables in order to reduce NH3-emssions here. The striped slurry then goes into a biogas reactor. The biogas produced in this system is enhanced by the use of straw and bone-meal, but animal fat could also have been used. After the biogas has been produced the material goes into a decanter centrifuge where the fibre (humus) fraction is taken out.

The remaining part is divided into potash concentrate and water using reversed osmoses. The entire separation ends with four fractions named: fibre, N, K and water. The first three fractions each contain a high portion of P, N and K respectively, which is close to the properties of mineral fertiliser. In Denmark there is currently one plant operating (more less continually) and another, which has just been built. Reliable production results from this technology are not yet available.

3.4. Staring

This concept consists of two parts, namely the acidification (phase 1) and the actual separation (phase 2). The acidification is made by adding sulphur-acid (H_2SO_4-96%) to the slurry in the storage just outside the stables. A total of 5 kg per ton slurry is added. As this slurry is re-circulated in under the stable in the slurry canals the pH value of 5.5 helps to reduce the ammonia emission in the stable by approx. 70%. The second phase is where the precipitant is added to the acid slurry, dividing the slurry into three fractions; a solid fraction, an NK-fraction and a liquid fraction based on a chemical process. The solid fraction consists of over 90% of the phosphorus and just under half of the nitrogen depending on the amount of precipitant added. The liquid fraction contains about 85% of the total volume. In the spring of 2003 several farms (pig and dairy farms) installed phase 1. The results suggest that it is working according to expectations and the working conditions in the stables have been improved. The lower pH value also helps to reduce ammonia emissions in storage and increases the N-utilisation in the field. The calculations regarding this second phase are based on assumptions regarding the performance.

4. Cost of separation using the four techniques

The cost of using the four techniques can be divided into three main cost items, namely the cost related to the investment of the separation plant, the running costs of the plant and the costs associated with handling the slurry, like storage, application or export. It is assumed that the slurry is received free of charge from the stables and that the revenue generated comes from the nutrient value in the fields or from export revenue. The cost estimations in table 1 are on an aggregated scale, but more details for the first two technologies can be found in Jacobsen et al. (2002) and for Green Farm Energy in appendix 1.

For comparison, the costs for storage and application using traditional handling are included in table 1. The decanter investment of 131,000 € gives an annual cost of 1.0 € per tonne. With running costs like labour, electricity and maintenance of the screw the total cost is around 2.3 € per tonne. The storage and application costs are larger than traditional handling as the humus fraction is more expensive to store and apply. The total cost is 7,8 € per tonne, but for larger decanter models dealing with 100,000 tonne yearly, the total cost is around 1 € per tonne lower due to economics of scale.

Table 1. Additional investment and costs related to the four technologies (/tonne)

Type	Raw slurry	Decanter Pieralisi	Funki Manura 2000	Green Farm Energy	Staring (phase 1)
Amount (tons)	17.300	17.300	17.300	35.000	4,300
Area for N-application (140 kg N/ha)	714	714	714	4,400	
Area for P balance (21 kg P/ha)	1.350	1.350	1.350	11,000	
Investment in separation plant (€)	0	131,000	600,000	4,000,000 1)	56,000
Annual costs (€ /tonne)					
Interest and depreciation		1.0	5,2	19,2	1,8
Electricity		0.2	3,2	1,2	0,2

Other materials			0,5	2,3	0,7
Maintenance		0.5	0,3	3,7	0,3
Labour		0.2	0,4	1,4	0.2
Other		0.4	0,8	2,4	0,4
Total		2.3	10,5	30,2	3,5
Storage and application	4.6	5.5	2,5		4,6
Total cost	4.6	7.8	13,0	30,2	8.1

Source: Jacobsen et al. (2002), Green Farm Energy (2003) and Staring (2003).

[1] It is assumed that the investment includes storage facilities, but not application or transport equipment.

[2] The area owned by farmers sending slurry to Green Farm Energy constitutes 1,424 ha.

The Funki Manura 2000 system is more expensive as the plant costs 600,000 **€**. The annual cost related to the investment is 5.2 **€** per tonne. On top of that comes the same running costs as for the decanter, but the electricity costs are somewhat higher at 3.2 **€** per tonne. The total separation costs are 10,5 **€** per tonne, but with lower storage and application costs the total costs come to 13,0 **€** per tonne.

The total costs are highest for Green Farm Energy, but as this includes a biogas plant this is hardly surprising (see also appendix 1). The energy costs are relatively low as the biogas produced provides all the heating. The electricity consumption of 11 kWh/tonne seems relatively low based on experience from biogas plants (Birkmose et al., 2001). The materials used include mainly lime. The total cost of 30 **€** per tonne is assumed to include storage facilities for the incoming biomass and the fractions. There are no application costs as the fractions are sold to export at the gate of the plant. This might influence the income received as many livestock farmers provide slurry freely and pay the application on the field of the receiving farmer.

The size of the Staring plant is a prototype, but more sizes might be available in the future. The investment is fairly low at 50,000 **€**, giving a cost of 1.8 **€** per tonne. The use of electricity is fairly low and the cost of acid only constitutes 0.7 **€** per tonne slurry. Including maintenance and labour, the total running cost is 8.0 **€** per tonne. It is expected that this phase 1 would require storage similar to traditional slurry storage as the consistency here is similar to normal slurry, which is why the application costs are similar. The costs of phase 2 are yet uncertain and hence not included in the table, but it could increase the net costs by 1-3 **€** per tonne (Rasmussen and Jørgensen, 2003). On the other hand, the storage and application costs might be lower as the fractions in this phase should be stable products.

Table 2. Revenue and values from fractions for the four technologies (/tonne)

Type	Raw slurry	Pieralisi	Funki Manura 2000	Green Farm Energy	Staring (phase 1)
Amount (tons)	17,300	17.300	17.300	35.000	4,300
Sold electricity (GWh)				11,300	
Income (€ /tonne):					
Sold electricity				24.1	
Nutrient value on farm	4.7 [4]	4.5	4.6		6.5
Revenue from sales		0	0	12.0[1] / 4.8[2] /6.0[3]	
Total income	4.7	4.5	4.6	36.1/28.9/30.1	6.5
Net cost for system	0.1	3.1	8.0	-5.9/1.3/0.1	1.4

Source: Jacobsen et al. (2002), Green Farm Energy (2003) and Staring (2003).

[1] Nutrient value as estimated in budget (appendix 1).

[2] Nutrient value as estimated by DLG, which is 30% under nutrient value in mineral fertiliser.

[3] Nutrient value is 50% for N and 0% for P.

[4] P has a nutrient value only until it exceeds the plants requirements.

The total income is described in table 2. The main value here is the value of using the nutrients on the farmers' own fields. The value is based on the effective N and P available for the crops. The nutrients have a value only up to the crops requirement. The nutrient value is the price of nutrients in mineral fertiliser. In case some of the nutrients are transported and applied on other farms, it is assumed that the farm has to pay the transportation costs as well as the application costs. In case of export (long distance), the value received for N is 0% unless they fraction have properties like mineral fertiliser. The value of phosphorus in the fractions exported are 0 € per tonne. The income for decanter and Manura are, therefore, not very different from the traditional handling as the fractions exported (humus) do not receive a sales price.

The income in the Green Farm Energy concept comes mainly from export of electricity and nutrients as the firm does not own farmland. The biogas production is estimated to 124 m^3 biogas per tonne of biomass. This is a high figure taking into account the fact that slurry and manure normally produce less than 50 m^3 biogas per tonne of biomass, but as the concept is different it is technically possible (Hjort-Gregersen, 2003 and Nielsen et al., 2002). Often however, the actual performance falls short of the expectations predicted earlier in the process. A conservative and perhaps more realistic estimate would be that the actual gas production would be around 100 m^3 gas per tonne biomass. This would reduce the income from electricity sold by 20% or 5 € per tonne biomass.

A large part of the biogas is used to produce heat that is used at the plant, which is why the electricity sold (40%) constitutes the only income from the biogas part. Note also that in case Green Farm Energy only received pig slurry the gas production would be considerably lower (see appendix 1) and the plant would not be profitable.

In all technologies apart from Green Farm Energy, it is expected that most of the nutrients stay on the farm, but for Green Farm Energy, the concept is based on export of all fractions. This implies that they are more dependent on the price they receive than for the other concepts. In table 2, three levels of revenue from the sale of nutrients have been included for Green Farm Energy. The first figure of 12 € per tonne equals the income presented in their budget (appendix 1). The second level is 30% of the nutrients' value as proposed by the company, which is expected to buy the fractions. The third value is the conservative estimate used for the other separation plants equal to 50% of the N-nutrient value and 0 for the phosphorus. In case some of the nutrients can be delivered back to the farmer's providing the slurry the value would be slightly higher than 6 € per tonne. However, this would also increase the cost of application and storage. As can be seen the lower estimates reduce the income by 5 € per tonne making the overall profit close to zero.

However, more and more Danish farmers are wiling to pay a fee to deliver manure to a separation plant in order to avoid trying to find a partner for a slurry contract and buying land. With the costs livestock farmers are paying today, it is not unlikely that they would pay 5 € per tonne to sell it to a separation plant. This is equal to an additional production cost of 90 € per sow with baconers.

The higher nutrient value for Staring reflects the higher utilisation of N in the fractions. This is due both to a lower ammonia emission in the stables and a higher utilisation in the fields (+10-15%).

The economic conclusion is that Funki Manura 2000 is too expensive, but perhaps the cheaper little brother, not included in this analysis, called Funki Manura Compact could be an option. The decanter technology is a relatively cheap option, which can be used by smaller farms alone or based on a mobile decanter plant as it is done in The Netherlands. The decanter can also be used in biogas plants at a low cost.

Green

5. Environmental aspects of the four technologies

The overall environmental assessment of the four technologies suggests that Green Farm Energy and Staring perform equally well and that their performance is clearly better than Funki and Decanter on a range of measures (see www.foi.dk/publications/conference for the full conference paper). As the investment costs are lower for the Staring concept than Green Farm Energy more farmers will probably use this concept, whereas Green Farm Energy provides a clear improvement of the N-utilisation of deep bedding and utilise animal waste like bone meal efficiently. With reliable production results, we would know whether the technologies can live up to these expectations.

6. Conclusions and future perspectives

- The main driving force for slurry separation in Denmark is the prospect of loosening the link between animal production and required land in order to avoid high land prices. Another force is a better distribution of phosphorous which is beginning to be an important factor when farms what to increase their production. The conclusions from the research that has been made into separation plants like Decanter and Manura in Jacobsen, et al. (2002) has the following conclusions:
- The prerequisite for establishing a separation plant is that it is a large farm placed in a livestock intensive area, with high land prices (over 15.000 € /ha) and where slurry agreements are very hard to get.
- The pig production has to generate a clear profit over time (after all the production costs are subtracted). If this is not the case then neither land at high prices nor investments in a separation plants are profitable.
- In order to support the separation technologies, the amount of land owned has been reduced if 75% of the slurry is separated. The reduction in owned land is 50% when using high technology concepts and 25% when using low technology concepts. This increases the profitability of separation technologies, but not enough to make e.g. Funki Manura viable.
- Danish farmers are paying more and more for land in livestock intensive areas and often pig farmers are also giving the slurry away as well as paying the transport and application costs. For a limited share of the slurry it seems economically viable with this extra cost of 5-15 € per tonne (including the potential nutrient value). However, with a separation plant, the additional costs will be on the total amount of slurry.

The results then show that:

1. Decanter separation plants have a lower cost than Manura plants, but the physical amount, which needs to be exported from the farm in order to gain phosphorus balance, is similar.
2. Most farms can transport the excess slurry a long distance (over 20 km) before the total cost exceeds the cost of using decanter or Funki Manura.

3. Farmers should first reduce the P-loss by using phytase in the feed, as this is a cheaper option compared to separation plants.
4. The sales price of the fractions has only a little impact on the overall profitability in case the export is limited (P-export). On the other hand export prices are crucial in concepts like Green Farm Energy where all fractions are sold (N and P-export).
5. Current sales prices for nutrients in fractions are estimated at 30% of the value in mineral fertiliser, but can be lower or even negative for phosphorus.
6. The clearest advantage for the separation systems is the better utilisation of phosphorus, but a market for fractions has to be established first.
7. The Green Farm Energy concept has yet to prove the expectation in order to recover the high investment costs, but the system offers a unique handling of several types of biomass, including deep bedding and bone meal. The system is not viable if only slurry is used as is the case with biogas plants in general.
8. Staring offers a clear improvement on the ammonia emission in the stable and on working conditions. As the costs are relatively low, this concept seems to fit the requirements of many farmers, independent of farm size.

The lack of a market for fractions is clearly a major problem for all concepts, and until this is solved, no efficient redistribution of mainly phosphorous is ensured. Legislation on phosphorous is on its way in order to reduce the P surplus at the farm level. It is, therefore, required that arable farmers start using the fractions. As they can receive them free of charge, this should be tried. There is still a need to see whether the technologies can deliver the potential stated and work continually over a period of time, but some of the new technologies do seem to offer a range of environmental benefits at an acceptable cost.

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Appendix 1

Green Farm Energy A/S

- officiel estimate April 2003 **01-05-03**

Total investment	48.000.000	DKK	6.434.316 €
Depreciation period	15	years	
Interest	6	%	
Maintenance	2	%	

Gasproduction

Type	**Amount (tons)**	**Dry matter %**	**Gas (m3/m3)**	**Total gas production**	
Slurry	25.000	6	**30**	750.000	
Chicken manure	6.300	60	**300**	1.890.000	
Bone meal	3.300	100	**500**	1.650.000	
Total amount	**34.600**		**124**	**4.290.000**	
Electricity sold with 6,5 kWh per m3 gas :		27.885	**41%**	11.304	MWh
Electricity produced :		8000 hrs	1,413 KWh	11.304	MWh

Nutrient flow

Type	**Amount (tons)**	Kg N/tons	Kg P/tons
Pig slurry	25.000	5,86	1,6
Chicken manure	6.300	41,6	9,8
Bone meal	3.300	**63,1**	**40**
Total amount (tons)	**34.600**	**616.810**	**233.740**

Profit - loss account

Income :	**Units**	**Price per unit**		**1000 DKK**	**1000 EURO**	**€ / tonne**
Electricity	11.304	0,55		6.217	833	24,1
Manure (N)	616.810	3,5		2.159	289	8,4
Manure (P)	233.740	4		935	125	3,6
Total income				**9.311**	1248	36,1
					0	
Costs:					0	
Lime			600.000		80	2,3
Transport bone meal	3300	100	330.000		44	1,3
Labour			350.000		47	1,4
Administration			300.000		40	1,2
Electricity	700000	0,45	315.000		42	1,2
Sum				1.895	254	7,3
Maintenance	48.000.000	0,02		960	129	3,7
Interest and depreciation (15 years and 6%)			0,103	4.944	663	19,2
Total costs				**7.799**	1045	30,2
Profit				**1.512**	**203**	**5,9**

The slurry and manue are delivered to the plant free of charge
The farmers delivering have the neccesary storage facilities
The farmers delivering receive replacement nutrients from other farmers free of charge
The fractions are collected free of charge at the plant for further distribution