Separation of Liquid Pig Manure by Flocculation and Ion Exchange
Part 2: Pilot-Scale System

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This paper reports the function and working results from a pilot plant in which liquid pig manure was flocculated with Geko-bentonite. The supernatant was irrigated on agricultural land throughout the year, but in the wintertime, only after ion exchange of ammonium with Agrolith. Earlier laboratory experiments showed that it is possible to purify the liquid to exactly the concentration wanted, although higher purity costs more. Hence, it is possible to use the method according to the legislation of individual countries to spray or irrigate the liquid onto fields.

The thicker slurry fraction must be stored and treated as ordinary liquid manure. In order to maintain ability for pumping, the treatment should be stopped at approximately 12% dry-matter content, which represents a concentration of the liquid manure to approximately one-quarter to one-third of the original volume.

1. Introduction

Danish farmers have to face large investments in slurry tanks after revision of environmental laws in 1992 which increased the requirements for storage capacity to nine months' production. Farmers in other EU countries have similar problems, in France for example, the requirement is four months.

The necessary tank capacity can be reduced considerably if the liquid manure is separated into a thin fraction (nearly water) which may be irrigated directly onto the field, and a concentrated slurry fraction with less volume which may be stored until spreading on the field is appropriate. This means that the cost of slurry transport is reduced considerably. In addition, the farmer will have better possibilities for disposal of the manure at the optimum time. The nutritional value will increase and this means better crop production or reduction of fertilizer use.

Laboratory experiments\(^1\) showed that it is possible to flocculate liquid pig manure with bentonite and that an almost clear liquid is obtained. This liquid is suitable for irrigating in summer, even on sensitive crops. However, in wintertime, due to increased pollution risks, it is necessary to clean the liquid additionally before irrigation and the laboratory experiments showed that this can be done by ion exchange.

A pilot plant was built near Jyderup at Zealand and this paper reports the results when liquid pig manure was flocculated with Geko-bentonite and ion exchange of ammonium was carried out with Agrolith, for waste disposal during winter.

2. Experimental arrangement and method

2.1. The process

The separation starts in the liquid manure storage tank [(1) in Fig. 1], where the pig slurry is separated naturally into three fractions by gravity and time: a floating layer (2), liquid fraction (3) and sediment (4). The liquid fraction is taken out by means of a pump on a “suction float” (5) in order to ensure that the liquid is taken below the floating layer. This liquid passes a simple filter (6) where objects such as hair, straw, plastic bags, teeth, clods of faces, remnants of fodder, etc., are removed. The suction filter will automatically be flushed back when the pump stops.

After passing the filter, the liquid manure is treated at the plant in two steps (7 and 8). First the flocculent (9) is added by a mixer (10). In the laboratory experiments, the clay mineral Geko-bentonite was found to be appropriate. During this process, the organic matter is captured in the clay flocks and settles at the bottom. The treatment in vessel (7) separates the major part of the volatile solids, and the liquid is transferred to vessel (8).
where the flocculating process is repeated. In that way, the two treatments with bentonite result in an almost total removal of organic matter from the fluid. The slurry from the bottom of both vessels is led back to the storage tank.

After the two flocculation steps there is no more organic matter in the water fraction, which explains why the ammonium production resulting from the breakdown of the organic matter stops. But the ammonium and other dissolved inorganic salts remain nearly unreduced in the liquid. At the final stage, the ammonium is removed from the water fraction by cation exchange (11). For this purpose, the mineral Agrolith (a refined glauconite) was found to be appropriate.

If Agrolith is spread on fields, the ammonium ions associated with it might easily be removed by the plant roots or microorganisms and used as nutrients. But Agrolith is too expensive to spread on the soil and therefore it is regenerated by calcium chloride (12). The ions released to the liquid from the ion exchanger (calcium) are environmentally neutral and will not induce any risks. The product from the regeneration, ammonium chloride, can be used as fertilizer for some crops, e.g. sugar beet.

2.2. The pilot plant

The farm, where the pilot plant was built, has 200 sows and produces 5000 fattening pigs per year. This production is equivalent to 270 animal units, resulting in a liquid manure production of 5500 m$^3$/yr. An animal unit is equivalent to eight fattening pigs or three sows with their small pigs.

A 4·0 m deep storage tank for liquid manure of 1060 m$^3$ belongs to the farm. This volume matches approximately one-fourth of the requirements according to present Danish environmental regulations.

For flocculation, two concrete bins were built, 4·0 m high and 1·25 m in diameter, each with a volume of 4·9 m$^3$. Two other bins with the same dimensions were built as buffer tanks.

In the plant where Geko-bentonite with a dose of 0·2% was used, the flocks settle slowly with a velocity of about 0·17 mm/s. It is important that the velocity of the liquid (flow rate divided by sectional area) is a minimum of 15% less than the flocculating velocity, as otherwise, some of the flocks will leave the tank with the overflow. Consequently, the velocity of the liquid manure must not exceed 0·14 mm/s. For a manure production of 5500 m$^3$/yr it gives a calculated diameter of 1·25 m. A larger diameter would eventually be of advantage, since it would give a higher safety for flocculation in the daily manure production and would allow for variations in the efficiency of the flocculating agent. The inlet point must be placed at a lower position than the outlet (see Fig. 1), so for practical reasons 0·50 m was used.

For ion exchange, five plastic storage tanks, each holding 540 l were installed in parallel. The ion exchanger remained in one tank, whereas the liquid manure was passed through the four tanks (marked 11 in Fig. 1), while the fifth tank was regenerated with calcium chloride.

Fig. 1. Flow diagram for the pilot plant. The numbers refers to the text
(marked 12 in Fig. 1). After completion of regeneration of the first tank, the next ion-exchanger tank was set to take over the regeneration, and the one just regenerated again took part in the ion exchange.

2.3. Experimental details

The pilot plant was in continuous operation one year before this paper was written and samples were taken two to three times per week. Samples were taken from untreated liquid manure, after the filter, after flocculation 1, flocculation 2 and after the ion exchanger. Samples were analysed for dry-matter content, nitrogen (N-Kjeldahl) and ammonium.

The plant was established on a pig farm in order to gain experience from practical use and from continuous processing instead of batchwise as in the laboratory experiments.

3. Results from the pilot plant

Experiments in the pilot plant show that it was an advantage to have the 4.0 m height in the flocculation tanks instead of the 0.35 m height in the measuring glasses from the laboratory experiments. Table 1 shows the content of dry matter, nitrogen and ammonium in the liquid after the different processes in the pilot plant. The numbers in parentheses are the corresponding values from the laboratory experiments.

The experiments showed that it is possible to reach a dry-matter content in the sediment of 15% or higher. No attempt was made to reach a higher percentage because it is of no practical interest. In order to maintain pumpability of the liquid most experiments was carried out at 12% and this gave a volume of the slurry of less than 30% of the original volume.

Figure 2 shows how the content of ammonium in the liquid varies as a function of the flow of liquid being pumped through the ion-exchanger tank. In the first period, the unit collects ammonium from the flocculated liquid. The figure shows a test where regeneration started after the passage of 200 l of liquid. For practical use, this should be done when the unit is 75% “used” (about 150 l on the x-axis) and continued until an equal amount of regeneration chemical is applied. The cycle then begins again.

4. Strategy for application

Reliability is important, and even if the laboratory experiments showed that 0.2% bentonite dose was sufficient in most cases, we have chosen, to be sure the flocculation is safe, the use of a two-step flocculation process.

From the filter (6) after the buffer tank the liquid fraction is irrigated on land in summer. On most crops, which will be damaged by untreated liquid manure, it is necessary to employ the flocculation process (7 and 8). In winter, the bentonite-treated liquid passes to the cation-exchange unit (11), where the ammonium and some

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Table 1

Values measured in the pilot plant from treatment of liquid pig manure with 0.3% bentonite and Agrolith ion exchanger. The numbers after the fractions refer to Fig. 1.

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Dry matter %</th>
<th>Total-N kg/m³</th>
<th>NH₄-N kg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manure from animal house</td>
<td>3.70 (3.5)</td>
<td>4.40 (4.5)</td>
<td>3.20 (2.8)</td>
</tr>
<tr>
<td>Liquid after filter (6)</td>
<td>1.43 (1.5)</td>
<td>3.20 (3.5)</td>
<td>2.70 (2.5)</td>
</tr>
<tr>
<td>Liquid after flocculation 1 (7)</td>
<td>1.03 (1.12)</td>
<td>2.94 (3.2)</td>
<td>2.60 (2.4)</td>
</tr>
<tr>
<td>Liquid after sedimentation 2 (8)</td>
<td>0.84 (0.94)</td>
<td>2.74 (3.0)</td>
<td>2.56 (2.3)</td>
</tr>
<tr>
<td>After cation exchange (11)</td>
<td>0.85 (0.96)</td>
<td>0.25 (0.05)</td>
<td>0.08 (0.03)</td>
</tr>
</tbody>
</table>

Note: Numbers in parentheses are the corresponding values from laboratory experiments.
potassium is removed, because of the demands for purity imposed by environmental regulations.

According to the results from the laboratory experiments, it is possible to ion exchange to the exact concentration desired, it is only a question of cost, in order to fulfill the requirements of individual countries for irrigating in wintertime.

Each farmer has to calculate the legal ammonium concentration. In Denmark, farmers must have sufficient area for irrigation, and no more than 40 kg N per ha is allowed in the winter. Farmers with large fields and a small liquid-manure production can manage with less ion exchange than farmers with small fields and large production.

This has an influence on the economics of the process because ion exchange is relatively the most costly part and costs increase progressively with purity.

It is not necessary to make a full treatment of liquid manure all the year round, it depends on the season and the crops to be fertilized. In the *summer* growing season (May–July), the liquid manure may, without further treatment than the filtering, be irrigated directly on the field by means of an ordinary irrigation system. For some crops the slurry has to be diluted with water. This procedure was tested on oscillating spray lines as well as mobile irrigation systems with sprinkler nozzle. No difficulties were observed.

In *autumn* (August–October) and the early growing season April, only the bentonite two-stage process is needed.

In the *early winter* period (December and January) the slurry can be stored in the tank, or if capacity is limited, the full process can be used.

In the *late winter* period (February and March) it is necessary to use the full-process system consisting of the two-stage bentonite process, followed by ion exchange.

The use of calcium as regenerating component is not optimal in connection with ion exchange, but, if seen from an environmental point of view, is more correct than the use of sodium or potassium. Control of the potassium part of the nutritive salts from the liquid manure, is not unimportant when irrigating small areas during the winter season.

The slurry fraction which is sedimented and parts of the lower fraction is returned to the main storage tank for liquid manure. The slurry will settle at the bottom of the tank and form a stable sediment. Before spreading, the tank is stirred in the usual way.

### 5. Economics

Expenses for establishing a treatment plant of this type will vary, depending on capacity of the present storage tank, irrigation system and distance to the fields on which the liquid has to be spread.

For many farmers, with insufficient storage capacity for liquid manure, the investment in a bentonite and Agrolith processing system will save them from building a new additional, expensive storage tank. If the farmer has a reasonably large production, the necessary investment will be considerably less.

The economics for the above-mentioned plant size is given in the following and the calculation is made by comparing the total costs of building the new system or building a traditional storage tank, starting from the assumption that no plant exists.

#### 5.1. Construction of traditional storage tank system

**Investments costs**

<table>
<thead>
<tr>
<th>Storage tank for 4125 m³</th>
<th>620 000 DKK</th>
</tr>
</thead>
<tbody>
<tr>
<td>(150 DKK/m³)</td>
<td></td>
</tr>
</tbody>
</table>

**Variable costs**

<table>
<thead>
<tr>
<th>Stirring and transport (4 km)</th>
<th>110 000 DKK/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>of liquid manure</td>
<td></td>
</tr>
<tr>
<td>5500 m³/yr (20 DKK/m³)</td>
<td></td>
</tr>
</tbody>
</table>

#### 7.2. Construction of a unit for flocculation and ion exchange

**Investments costs**

<table>
<thead>
<tr>
<th>Unit for flocculation and ion exchange</th>
<th>235 000 DKK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigation system</td>
<td>70 000 DKK</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Storage tank for 1100 m³</th>
<th>165 000 DKK</th>
</tr>
</thead>
<tbody>
<tr>
<td>(150 DKK/m³)</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Total investment costs</th>
<th>470 000 DKK</th>
</tr>
</thead>
</table>

**Variable costs**

<table>
<thead>
<tr>
<th>Irrigation</th>
<th>20 000 DKK/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stirring and transport (4 km) of concentrated liquid</td>
<td>31 000 DKK/yr</td>
</tr>
<tr>
<td>1400 m³/yr (22 DKK/m³)</td>
<td></td>
</tr>
<tr>
<td>Costs of agents for flocculation, ion exchange and regeneration</td>
<td>37 000 DKK/yr</td>
</tr>
<tr>
<td>Service, maintenance, electricity for equipment</td>
<td>20 000 DKK/yr</td>
</tr>
</tbody>
</table>

In addition, the farmer has better possibilities for disposal of the manure at the optimum time of the year, giving a better crop production — 35 000 DKK/yr

Total variable costs 73 000 DKK/yr
5.3. Economic results

The conclusion of this calculation is that investment is reduced by 150,000 DKK and variable costs are reduced by 37,000 DKK/yr.

These figures have to be regarded as examples, because conditions vary considerably from farm to farm. Each farmer has to analyse the situation in order to decide if the technique using flocculation and ion exchange is an advantage. What is the present storage capacity? What will be the new requirements? What is the distance to transport the slurry? Is it possible to irrigate close to the treatment plant, and is a suitable irrigation system available? Is it possible in the present system to utilize the optimal nutritional value in the slurry? Or are there special environmental problems? In general, large farms would benefit most by investing in the new system.

Furthermore, the farmer’s time will be reduced compared to the use of traditional storage tanks for liquid manure, which involves some work with pumping to a primary tank and then to a storage tank, stirring and spreading on the soil. Some of these operations are automatically controlled in the system investigated.

It is evident that the economic perspective depends on many factors. It is to be decided in every individual case, whether the new methods will be advantageous or not. In some cases, e.g. for small farms a traditional system would be better.

6. Conclusions

1. Flocculation in 4.0 m high cylindrical tanks worked satisfactorily and even better than in the laboratory cylinders of 0.35 m height.
2. The diameter must be designed to give a liquid manure velocity in the tank less than the flocculation sinking velocity.
3. Using the two-stage flocculation system almost all organic matter will settle.
4. It is possible to reach a dry-matter content of 12%. It is even possible to obtain a considerably higher dry-matter content, but then the pumpability becomes difficult.
5. The need for storage capacity for the liquid manure produced can be reduced to about 30% of the original volume. The costs of transport and spreading the liquid manure will also be reduced to less than one-third, as the liquid fraction can be irrigated.
6. The technique enables a more timely and correct application of the liquid manure to be made as a fertilizer and the impact on the environment is reduced.
7. The ion exchanger can be regenerated by means of calcium chloride.
8. The economics of building a flocculating plant will be influenced by several factors such as investment in storage tanks, handling equipment, transport, etc. The method is likely to be of interest to medium and large farms.

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References