Manure treatment and utilisation options

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1 Introduction

Origin of a manure surplus (= nutrient surplus)

In modern animal nutrition, much attention is paid to the provision of adequate levels of nutrients in the animal feed for maximum production of meat, milk and eggs. Since the nutrient uptake by the animals from the feed is only around 30% of the intake, the bigger part of the nutrients (e.g. nitrogen (N), phosphorus (P) and potassium (K)) are excreted with feces and urine, as partly digested feed leftovers, dissolved minerals and in bacterial biomass.

Animal manure also contains other important plant nutrients, like magnesium, calcium, sulphur and a long list of trace elements or micro nutrients (e.g. sodium, iodine, cobalt, copper, zinc, manganese, selenium, molybdenum) and, last but not least, decaying organic matter (carbon, hydrogen, oxygen) that helps in maintaining soil life and soil quality. Soil organic matter is essential for soil structure, water holding capacity, nutrient holding capacity and erosion resistance.

If the manure production in a certain region exceeds the manure receiving capacity of the agricultural land, there is a regional manure surplus. These manure surpluses, or rather the nutrient surpluses, are threatening the environment. The challenge is to distribute the manure nutrients to other regions where they can be used responsibly and profitably as fertilizer in agriculture.

With regard to the importance of phosphorus as fertilizer nutrient for arable farming and as a feed additive, and the predicted exhaustion of the worldwide phosphate rock reserves, recycling of phosphorus in manure is of great importance.

Liquid and solid manure as input

With liquid or solid animal manure as input materials and the application of different manure treatment technologies, many different fertilizer products can be made. These fertilizer products have to be applied to agricultural land, since no other destination is allowed. Under EU legislation, products that are made from manure normally keep the status of 'animal manure'. This means that manure has the status of organic fertilizer, and is not considered as 'waste'.

Liquid manure can be the mixture of feces and urine under slatted floors, as is common in pig and cattle farming in Western Europe, or from scraped solid floors, as is common in cattle farming in North America and Asia. The daily flushing with tap water of pig and cattle houses in regions with a warm climate adds water to the manure, resulting in liquid manure with a reduced dry matter content. Liquid manure will have a dry matter content of 6 to 12% but much less if flushing is applied.

> *'When liquid manure is separated, a solid (stackable) manure fraction is produced'*

Solid (or stackable) manure can be pig or cattle feces only, or feces mixed with bedding material. Poultry manure is mostly solid manure. Solid manure will have a dry matter content of 20 to 65%. When liquid manure is separated, a solid (stackable) manure fraction is produced. The liquid fraction from manure separation has a reduced dry matter content, compared to the liquid input manure. Liquid fraction will have a dry matter content of 3 to 6% or less if the input manure was diluted with flushing water.

By-products from manure treatment

Three non-manure by-products from manure treatment are:

- Biogas from anaerobic digestion that can be used for energy generation,
- Electricity from the incineration of dry manure in a fluidized bed furnace with superheated steam driving a turbine,
- Water from nitrification/denitrification (biological treatment) and from reverse osmosis (membrane filtration) that can be discharged into the sewer or into surface water, depending on quality. Clean water can only be discharged into surface water if it meets the required quality standards; otherwise it has to be applied to agricultural land or discharged into the sewer.

2 Description of manure treatment techniques

Anaerobic digestion or biogas production

Both liquid and solid manure can be used for biogas production in anaerobic digestion systems, as long as the mixture remains pumpable. Fresh manure gives higher biogas yields than manure that has been stored for several weeks or months. Because of its high water content, the biogas production from manure is low, compared to other feedstocks with higher levels of degradable organic matter. To increase the biogas production, other products with a higher biogas potential can be added, like fats, agricultural residues and food processing waste. This is called co-digestion. Without government subsidies anaerobic (co-) digestion is normally economically unfeasible.

Liquid manure can yield 20-30 m^3 of biogas per ton, solid manure can yield up to 60-80 m^3 per ton, grass and corn can yield 80-200 m^3 biogas per ton and fats and glycerine can yield up to 800 m^3 of biogas per ton.

In an airtight reactor, mostly at a temperature of approx. 37 °C (mesophilic), anaerobic micro organisms convert degradable organic matter into gaseous methane (CH_4) and carbon dioxide (CO_2) and some impurities. This mixture of approx. 60% methane and 35% carbon dioxide is called biogas. The most common biogas reactors are of the CSTR type (Completely Stirred Tank Reactor). After removal of the toxic and corrosive hydrogen sulphide (H_2S), biogas can be used directly for heating (e.g. cooking) and for electricity generation in a gas engine. Biogas can also be upgraded to natural gas quality by removal of carbon dioxide. Especially in colder climates, a substantial part of the energy in the biogas is needed for keeping the reactor at the desired temperature level.

The remaining digestate still contains the same quantities of nutrients (N, P, K, etc.) that were present in the input materials. As such, anaerobic digestion is not able to reduce mineral surpluses. By the partial degradation of organic matter during anaerobic digestion, a part of the organically bound nitrogen is transformed into dissolved ammonium nitrogen (NH_4^+). Ammonium nitrogen can be lost to the atmosphere as gaseous ammonia (NH_3) when the digestate is applied to agricultural land, justifying low emission application technology.

Separation

Liquid manure and liquid digestate can be mechanically separated into solid and liquid fractions. The solid fraction (10-20% of the input manure mass) contains 30-95% of the phosphorus. The liquid fraction (80-90% of the input mass) contains 75-90% of the nitrogen and potassium.

Different types of manure separators have different separation efficiencies with regard to mass, phosphorus, nitrogen, and other nutrients, resulting in solid and liquid fractions with different nutrient levels. The separation efficiency of a manure component is the percentage of the total input quantity of that component that ends up into the solid fraction after separation.

If the aim of manure separation is the maximum concentration of phosphorus in the solid fraction, a centrifuge/decanter is the first choice. A centrifuge/decanter has a separation efficiency for phosphorus of approx. 65% without the use of additives.

A sieve belt press in combination with Dissolved Air Flotation (DAF-unit) can even reach up to 95% separation effiency for phosphorus, but the use of various chemical additives is necessary, like metal salts, acid and synthetic polymer, to increase separation efficiency.

If the aim of manure separation is the production of dry bedding material for cattle cubicles, a screwpress separator is the first choice. A screwpress separator is relatively cheap and can produce a solid fraction with 30-40% dry matter. But the separation efficiency for phosphorus of a screwpress separator is less than 40%.

Other separators, like sloped screens, brushed screens, drum separators, mostly have inferior separation efficiencies, except for mass. These low-tech separators often produce solid fractions with a high moisture content and a low phosphorus level.

Manure separation is often the first step in a liquid manure processing chain: the solid fraction can e.g. be composted, dried and eventually pelletized or incinerated, while the liquid fraction can be used as fertilizer or further treated (e.g. by precipitation, evaporation, nitrification/ denitrification, ultrafiltration, dissolved air flotation and eventually reversed osmosis).

'A screwpress separator is relatively cheap and can produce a solid fraction with 30-40 % dry matter'

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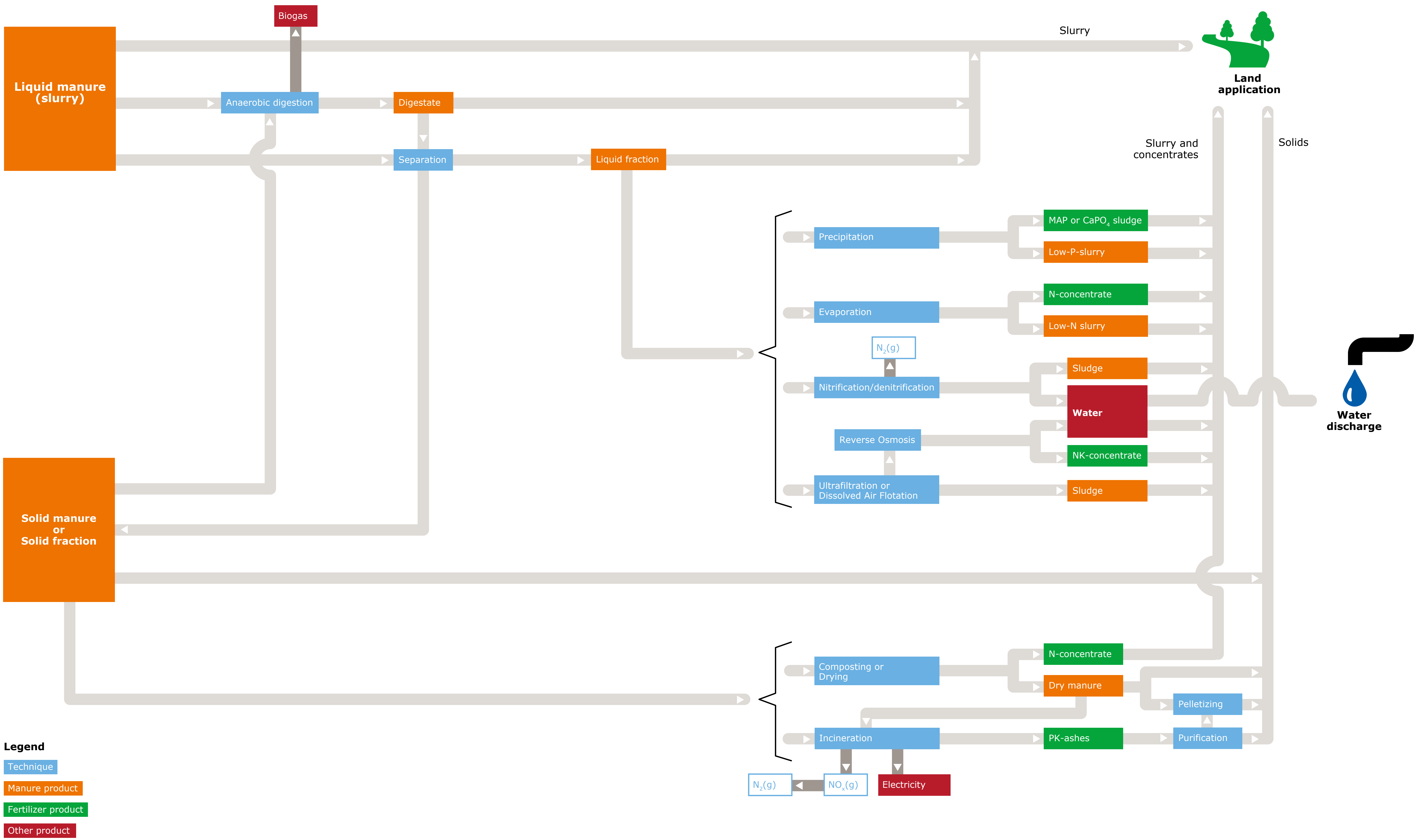

3 Composting and thermal drying of solid manure

Composting or 'biothermal drying'

The natural process of decomposition of organic matter by microorganisms under controlled aerobic conditions is called composting or 'biothermal drying'. In this process, aerobic microorganisms break down organic matter and produce carbon dioxide, water(vapor), ammonia, heat and humus, the relatively stable organic end product. Composted manure is a rich source of nutrients and stable organic matter. Soil organic matter plays an important role in sustaining soil fertility, and hence in sustainable agricultural production.

The aerobic composting process starts with the formation of the pile. First, mesophilic organisms (optimum growth temperature range 20-45 °C) multiply rapidly on the available sugars and amino acids. They generate heat by their own metabolism and raise the temperature to a point where their own activities become suppressed. Then thermophilic fungi and thermophilic bacteria (optimum growth temperature range 50-70 °C or more) continue the process, raising the temperature of the material to 65 °C or higher. This peak heating phase is important for the quality of the compost as the heat kills most pathogens and weed seeds. Regular turning of the pile will improve aeration and hence speed up the composting process and ensure that all material has been sufficiently heated.

The active composting stage is followed by a curing stage, when turning no longer reheats the pile and the pile temperature decreases. At this stage, another group of thermophilic fungi starts to grow. These fungi bring about a major phase of decomposition of plant cell-wall materials such as cellulose and hemi-cellulose.

The weight loss during composting can be more than 50% and also a considerable part of the nitrogen (20-60%) can be lost, mainly by emission of ammonia. The dry matter content of composted manure can reach 60-70%. Extensive outdoor composting in windrows with limited turning can take several months but intensive tunnel composting with forced aeration can take one or two weeks. When composting is carried out in a controlled system, gaseous ammonia can be stripped from the outgoing ventilation air with an air scrubber with diluted sulphuric acid, producing a liquid ammonium sulphate solution that can be used as a liquid fertilizer.

Thermal drying

Manure can be dried with an external heat source, like heated air or heated oil. The process is known as 'thermal drying'. The aim is to remove moisture as much as possible. Drying may result in a dry matter content of 75-85% and a substantial weight loss. Drying with an external energy source is expensive, compared to composting. In contrast to composting where microbial decomposition produces stable humus as end product, the end product from manure drying is dry manure. Dry manure is more suitable for incineration because of its lower ash content and hence higher heating value, compared to composted manure. Composted manure is more suited for direct land application as soil improver in agriculture. Drying of manure produces an airflow with gaseous ammonia that can be stripped in an air scrubber with diluted sulphuric acid, producing a liquid ammonium sulphate solution that can be used as a liquid fertilizer.

Incineration of dry solid manure

Dry manure with at least 60% dry matter and at least 45% organic matter can be used for incineration with excess air in a fluidized bed furnace, heating a steam boiler. The superheated steam drives a turbine for electricity generation. With dry poultry manure as input, 1 ton of manure can produce 550 kWhe and aprox. 140 kilograms of ashes (bottom ash and fly ash). The ashes are rich in phosphorus, potassium, calcium and magnesium and can be used as a raw material in fertilizer production. Nitrogen and organic matter are lost. Because of the high investment costs, the technical complexity and high costs of flue gas cleaning, large-scale installations are preferred. Without government subsidies for the production of sustainable energy, manure incineration is economically unfeasible.

> *'With dry poultry manure as input, 1 ton of manure can produce 550 kWhe and aprox. 140 kilograms of ashes'*

Flue gas cleaning (removal of NH_3, NO_x, SO_x, particulate matter) is complicated and expensive because of the high levels of nitrogen and sulphur and other potential pollutants in poultry manure. Emission thresholds and emission regulations differ between EU memberstates and countries worldwide. Dry manure from layers and parent stock is less suited for incineration because of its higher ash content, compared to manure from broilers and meat turkeys in floor housing. Composted manure is also less suited for incineration because of its higher ash content.

Precipitation of phosphorus from the liquid manure fraction

Phosphorus recovery from manure can help in reducing the need for mined phosphate rock. Worldwide phosphate rocks reserves are predicted to be exhausted within the next century, because of the increasing demand for phosphorus fertilizers and feed additives.

When liquid manure is separated into a solid fraction and a liquid fraction, a substantial part of the phosphorus (30-95%, depending on the applied separation technique) is concentrated in the solid fraction. The phosphorus content of the liquid fraction can be further reduced by adding various magnesium compounds (e.g. MgO, MgOH) that react with dissolved phosphorus and ammonium, forming a Magnesium-Ammonium-Phosphate or MAP sludge with an increased phosphorus content.

Struvite crystals are created when magnesium, ammonia and phosphate combine in water in a mole to mole to mole ratio of 1:1:1. The formula of pure ammonium struvite is $NH_4MgPO_4.6H_2O$. If no ammonium is present, e.g. after biological treatment with nitrogen removal, the NH_4^+ ion can be replaced by potassium K^+ , forming potassium struvite $KMgPO_4.6H_2O$. Struvite crystals precipitate, together with organic material, into a sludge and it has proven very difficult to separate pure struvite from this organic sludge. The sludge can be used as such as an organic fertilizer.

Another possibility to precipitate phosphorus, is the addition of calcium (as calcium chloride $CaCl_2$ or slaked lime $Ca(OH)_2$) to produce calcium phosphate (e.g. $CaHPO_4$ or $Ca_3(PO_4)_2.4H_2O$) that will also precipitate into an organic CaP sludge.

Liquid fractions from manure separation contain ammonium, potassium, magnesium, calcium and phosphate in variable concentrations and varying degrees of solution. The sludge from phosphate precipitation will contain mixtures of a.o. organic bound phosphates, ammonium and potassium struvites and calcium phosphates, which complicates the recovery of pure phosphorus compounds from the organic sludge matrix.

As phosphate precipitation needs a high alkalinity (pH > 9), addition of caustic soda (NaOH) in the process is common and causes an increased ammonia emission that justifies the use of an acid scrubber in order to capture gaseous ammonia into an ammonium sulphate solution that can be used as fertilizer on agricultural land. The treated liquid fraction, with a reduced phosphorus content, must be applied on agricultural land.

Evaporation and condensation of the liquid manure fraction

After manure separation, the liquid fraction can be treated with vacuum evaporation and mechanical vapor recompression to remove water and concentrate non-volatile nutrients (e.g. phosphorus, potassium) into a sludge. Ammonia vapors can be scrubbed from the gas phase in order to produce a nitrogen sulphate solution that can be used as fertilizer. The water vapor is condensed into liquid water.

Evaporation and condensation of liquid manure fraction results in the following end products:
- 20% sludge that remains after water evaporation, high in potassium,
- 70-75% water from condensation of the vapor phase,
- 5-10% nitrogen concentrate from scrubbing the vapor phase.

If the quality of the condensate meets the required standards, it can be discharged into surface water. Otherwise it has to be discharged into the sewer or on agricultural land.

When ammonium nitrogen is removed from the liquid fraction before the evaporation phase, e.g. by biological treatment (nitrification/denitrification), the ammonium content of the condensate is also decreased and meeting the standards for discharge into surface water becomes more obvious.

Nitrification/denitrification or biological treatment
After manure separation, the liquid fraction can be aerated from below, with aerators on the bottom of an open basin, generating tiny air bubbles that oxidize ammonium to nitrate (nitrification) and subsequently, in a settling basin without aeration, anoxic bacteria reduce nitrate via nitrous oxide mainly to harmless nitrogen gas (N_2) that is released into the atmosphere. However, considerable amounts of nitrous oxide (N_2O) may be produced as a by-product of this process. All ammonium nitrogen is removed and remaining volatile solids with the bigger part of the phosphorus are sedimented into a sludge. The remaining liquid effluent still contains some organic nitrogen and dissolved salts (Na, Cl, S, K etc.) and can be discharged into the sewer or on agricultural land. For discharge into surface water, an additional polishing step like evaporation/condensation or reverse osmosis is necessary.

This process is similar to the treatment process that's used in municipal Waste Water Treatment Plants, but the nutrient load when using liquid fraction from manure separation as input is much higher than when using strongly diluted domestic wastewater. Hence, the energy requirement for aeration is higher too.

When instead of liquid fraction from manure separation, the liquid fraction from separation of digestate from anaerobic digestion is used as input, an additional carbon source like ethanol or acetic acid has to be added for providing the anoxic bacteria with sufficient carbon.

Reverse osmosis (production of clean water and a mineral concentrate)

After manure separation, the liquid fraction is pretreated to remove all solid, suspended and colloidal particles. A clean liquid is required to avoid scaling and fouling of the reverse osmosis membranes. Technologies used for pretreatment of the liquid fraction are ultra-filtration, micro-filtration and dissolved air flotation. Usually, coagulants and flocculants are added to support both the mechanical separation and the pretreatment.

After pretreatment, the liquid fraction passes a reverse osmosis unit, ending up in two streams: a permeate (approx. 60% of the volume), which is clean water with very low nutrient concentrations, and a concentrate (approx. 40% of the volume), being a liquid with relatively high nitrogen and potassium concentrations (approx. 1% of each). The RO-concentrate is often called 'Mineral concentrate' and can be used as liquid fertilizer.

The water can be discharged into the sewer, or, after a polishing step in an ion exchanger to remove the last traces of ammonia nitrogen, be discharged into surface water.

The membranes used in reverse osmosis plants for the treatment of liquid manure fraction are the same salt water membranes as those used in sea water desalinization plants, for the production of drinking water, allthough the safety requirements are much stricter with regard to possible membrane failure and related microbial contamination risk from manure treatment.

4 Conclusions

- With different manure treatment technologies, different fertilizer products can be made from animal manure. These fertilizer products all contain nutrients that must be recycled to agricultural land, to avoid pollution of groundwater and surface water.

- Three non-fertilizer by-products can be made from animal manure:
  - Biogas from anaerobic digestion for energy production,
  - Electricity from the incineration of dry manure, using heated steam in a turbine,
  - Clean water from membrane filtration of pretreated liquid manure fraction.

- Surplus manure nutrients have to be transported from surplus regions to deficit regions where these nutrients can be responsibly and profitably applied as fertilizer, partially replacing synthetic fertilizer nutrients. Concentrated fertilizer products with a low moisture content and high nutrient levels are most suited for long distance transport.

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