Manure Processing Activities in Europe - Project reference: ENV.B.1/ETU/2010/0007

MANURE PROCESSING TECHNOLOGIES

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Manure processing technologies

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Front page photos	Upper left: Decanter centrifuge for after-digestion separation of digestate. Upper right: Composting of separated solid fraction of slurry in roofed store. Lower left: Dried and pelletized separation fraction from biogas plant. Lower right: Reception facilities at biogas plant.
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PREFACE

Manure processing is presently a subject that enjoys considerable attention in EU due to the ongoing revision of the Reference Document on Best Available Techniques for Intensive Rearing of Poultry and Pigs (BREF), as well as due to current efforts to implement policies and legislation on EU and Member State level, for instance concerning renewable energy targets, targets for reducing the loss of plant nutrients to the environment, targets for reduction of greenhouse gases, and targets for waste handling in agriculture.

This report is dealing with the characterization of processes and technologies applicable to manure treatment. Some possible objectives of treatment systems have been identified, depending of the local constrains. The main driving force for adopting a manure processing plant is considered to be the Nitrates Directive (91/676/EEC) implementation, and the consequent nutrients management requirements, followed by the incentives for renewable energy production (biogas). In this report, 45 unitary processes have been identified and explained. Some of these processes can be found working alone if these are enough for solving the problem that motivated its adoption. Others must be combined for fitting a given objective. Usual combinations have been identified at every unitary process description section and a synthesis of these main combinations is presented. Anaerobic digestion is found to be a key process in strategies dealing with nutrients recovery.

This report is prepared for the European Commission, Directorate General Environment, as part of the implementation of the project “Manure Processing Activities in Europe”, project reference: ENV.B.1/ETU/2010/0007. The Report includes deliveries related with Task 2 concerning Manure Processing Technologies.

We greatly acknowledge all the persons, companies, farmers or farmers associations, who kindly shared information and photos to illustrate the technologies that are described in this report.

Tjele, 28 October 2011

Henning Lyngsø Foged

Project Manager

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EXECUTIVE SUMMARY

The objective of the current report is to describe and to characterize manure processing technologies.

Techniques are classified based on their objective (energy production, phase separation, nutrients recovery, nitrogen removal, etc.), distinguishing between processes that can work alone and complete strategies, which combine different processes to fit given objectives and boundary conditions. Boundary conditions will configure different scenarios and problems to be solved (regional or local nutrients surplus, density and intensity of farming, etc.)

Every process is explained in chart form, and every chart contains the following information (when available): diagram, some pictures, process definition, short description of its theoretical fundamentals, technical variations of the process, effects of the process on the end products, advantages, disadvantages, operational data, efficiencies, energy and/or reagents consumption, economical costs (investment and operational), applicability (on-farm, large scale; raw manure, liquid or solid fractions; alone or combined), selected literature references and real scale (commercial or pilot) references.

45 processing technologies have been identified as standalone technologies or belonging to combined treatment systems. These processes have been classified in the following groups:

- **Separation techniques**: System with the objective of separating manure into two flows: a concentrate (solid fibre fraction) and a diluted fraction (liquid fraction). 10 technologies have been identified.
- **Additives and other pre/1st treatments**: Set of processes which objective is the preparation of the material for a further purpose or treatment. 4 technologies have been identified.
- **Anaerobic treatment**: Series of biological processes in which microorganisms break down organic molecules in absence of oxygen, resulting in the production of a mixture of gases, named biogas, mainly composed of methane and carbon dioxide. 2 technologies have been identified. (mesophilic and thermophilic).
- **Treatment of the fibre/solid fraction**: Processing methods especially suitable for solid manures or solid fractions obtained after separation. 9 technologies have been identified.
- **Treatment of the liquid fraction**: Processing methods especially suitable for much diluted manures or liquid fractions obtained after separation. 17 technologies have been identified.
- **Air cleaning (as part of manure processing plant)**: Methods applied to clean process air used during some manure treatment (i.e. exhaust air from composting. 3 technologies have been identified.

A treatment strategy is a unitary process or a combination of unitary processes leading to the fulfilment of a given objective. Such objective must be determined for every farm or groups of farm in a given local area, based on nutrients mass balance in the area and considering local constrains and opportunities, such as incentives for renewable energy production. A clear definition of what a treatment is expected to provide is basic for a successful implementation. There is not a unique technological strategy suitable for all situations and, clearly, there is not a process capable of removing manure. Only nitrogen (N) and carbon (C), besides of water, can be “removed” through the conversion of different N-forms to dinitrogen gas (N_2, air component), and organic-C to methane (CH_4) or carbon dioxide (CO_2). Other components of manure can just be separated or concentrated. Nitrogen is the unique nutrient that can be both removed, as innocuous N_2 gas) or recovered, while other nutrients can only be recovered using different techniques. Therefore, technological strategies can be classified taking into account this fact. There are also other factors in which focusing when planning treating manure, such as odours removal, sanitation, removal of xenobiotic compounds (emerging pollutants), or just energy recovery through anaerobic digestion.

Manure processing technologies

A primary classification of strategies focusing on nutrients management, could divide processes depending whether or not there is a nutrient surplus in the area. When there is no surplus, processes are focused on increasing the management capacity, increasing economical value of manure (e.g. increase its efficiency) and decreasing economical costs related to manure management (e.g. decrease manure transportation costs). These methods are solid-liquid separation, anaerobic digestion and composting. This can be done either at farm or centralized scale, depending on whether or not the balance in nutrients is found at farm scale or at regional scale.

When the problem to be solved relates to nutrients surpluses, processing methods can be classified in three types, where the first two include nutrients recovery methods and the third includes nitrogen removal methods. These strategies can be applied at farm or centralized scale, depending on whether the nutrients surplus problems to be solved are found at farm or regional level, or on the technological complexity of the process. The three groups of technological strategies are:

1. Nutrients recovery without anaerobic digestion. It includes the following sub-groups:
    a. mechanical/physic-chemical separations for exporting solid fraction
    b. composting solid manure or solid fractions, for reducing volumes and exporting compost
    c. membrane processes for concentrating nutrients and subsequently export them
    d. evaporation/drying/pelletizing techniques for exporting pellets
2. Nutrients recovery with anaerobic digestion. It includes the following sub-groups:
    a. anaerobic digestion (AD) for energy production
    b. AD combined with composting of solid fraction and export of compost
    c. AD combined with stripping and absorption of ammonia of the liquid fraction and export of ammonia
    d. AD combined with membrane separation of liquid fractions, composting and export of concentrates and compost
    e. AD combination with evaporation and drying and export of pellets

    These kinds of strategies benefits from co-digestion with other organic waste.
3. Nitrogen removal. It includes the following sub-groups:
    a. nitrification-denitrification (NDN) process
    b. separation of solid/liquid fractions and NDN of liquid fraction, without or with composting and export of solid fraction or combustion and pyrolysis of the solid fraction
    c. previous processes combinations with membrane separation technologies or water evaporation, drying and export of pellets.

It has been analyzed whether a given process can be considered as BAT (Best available technology), following definitions of IPPC (1996), that is technically feasible and allows a high environmental protection at an acceptable cost. For the identification of candidate processes to be BAT, it was considered that all processes operate under the best conditions, being only the economical acceptability the variable that could be considered conditional, requiring a deeper economical analysis about gross margins of every livestock production activities for characterizing the acceptance for every production sector. The results has been that a majority of processes are BAT in certain circumstances, being necessary to analyze the applicability of every process strategy in a given context, defined by the local constrains and opportunities.

1: BACKGROUND

In the last decade, many countries and institutions in Europe have addressed efforts to structure the knowledge and the diffusion of manure treatment technologies dealing with manure transformation in order to improve its management and, specially, to manage nutrients surplus in some geographical areas. Some reference documents are:

- Burton C. H. and Turner C. (2003). Manure Management: Treatment Strategies for Sustainable Agriculture. Silsoe Research Institute. 2nd ed. Wrest Park, Silsoe, Bedford, UK.
- Campos E., Illa J., Magrí A., Palatsi J., Sole-Mauri F. and Flotats X. (2004). Guía de los Tratamientos de las Deyecciones Ganaderas. Waste Management Agency of Catalonia and Department of Agriculture, Farming and Fishing of Generalitat de Catalunya, Barcelona. 70 pp. (In Spanish).
- Foged, H.L.(2010). Best Available Technologies for Manure Treatment – for Intensive Rearing of Pigs in Baltic Sea region EU Member States. Published by Baltic Sea 2020, Stockholm. 102 pp.
- IAEA (2008). Guidelines for Sustainable Manure Management in Asian Livestock Production Systems. Animal Production and Health Section. Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture. International Atomic Energy Agency, Vienna. 118 pp.
- Pascal Levasseur (2004). Traitement dels effluents porcins. Institut Technique du Porc, Paris. 36 pp. (in French)
- Sommer, S.G., Christensen, K.V., Jensen, L.S. (2009) Environmental Technology for Treatment and Management of Bio-waste. University of Southern Denmark. 103 pp.

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Every process is explained in chart form, and every chart contains the following information (when available): diagram, some pictures, process definition, short description of its theoretical fundamentals, technical variations of the process, effects of the process on the end products, advantages, disadvantages, operational data, efficiencies, energy and/or reagents consumption, economical costs (investment and operational), applicability (on-farm, large scale; raw manure, liquid or solid fractions; alone or combined), selected literature references and real scale (commercial or pilot) references.

1.1: Definitions

The manure processing technologies has been selected on the basis of the following criteria:

- Technologies designed to control processes that change the physical and/or chemical properties of the livestock manure, as an objective itself, or in order to recover energy from the livestock manure, to make the livestock manure more stable, or to remove nutrients (N and/or P) from the main stream.
- Technologies which have not reached the marketing phase, and although full scale plants/installations are not in operation on a commercial basis are also included. However, only technologies in commercial operation will be dealt with concerning case studies, and description of the technologies as well as their by-products and end-products.

- Conventional technologies related to logistics handling of livestock manure, like pumping, propagation, storing, and spreading, will not be considered unless they are performed, as an objective itself, in order to change the physical and/or chemical properties of the livestock manure as controlled processes. In this sense, although long term storage affects manure composition, with emissions to the atmosphere, this unit will not be considered as treatment technology.

While a manure processing technology deals with unitary processes adopted for changing physical or chemical properties, for energy recovering, for nutrients removal or for nutrients recovery from the main stream, a manure treatment strategy will be defined as a process or combination of processes dealing to the fulfilment of an objective determined by the problem to be solved, usually a result of applying a nutrients mass balance under local constrains. This mass balance, between nutrients produced in manure form and nutrients demand of field crops, is done during a Nutrient Management Planning (NMP), which can be defined as a set of actions performed to adjust manure production to the demand of quality products for the agricultural soils (Teira-Esmatges and Flotats, 2003). This set of actions must include on-site minimization of volumes and limiting components (i.e.: water, nutrients, heavy metals, etc.); the enhancement of animal diets and management practices; a fertilization planning depending on soils and field crops characteristics; the analysis of economical costs; and the assessment of feasible treatments, adopted in order to fit the objectives defined by the local constrains and opportunities.

As a consequence, a given processing technique of manure or a given treatment strategy is a *best available technology* (BAT), following the definition of IPPC (2006) (see section 12), under certain circumstances. IRPP BREF (2003) defines the techniques that are evaluated as BAT in certain conditions as *conditional BAT*, and concludes that the "conditions of on-farm manure processing that determine if a technique is BAT relate to conditions such as the availability of land, local nutrient excess or demand, technical assistance, marketing possibilities for green energy, and local regulations". With the current information, it is not possible to identify completely a BAT for manure processing technology, but it is possible to identify candidates. In general, it must be considered that the technical and economical feasibility of a given process or strategy and its environmental impact depend of local conditionals.

1.2: Objectives of the processing strategies

Manures which are potentially valuables as fertilizers or soil conditioners are resources that need to be managed adequately. According to this simple concept, manure must be handled as a by-product of livestock production and, when required, processed, just for fitting the objective of an optimal management within the context of the farm and considering local conditions (Table 1.1).

With the previous definition of NMP, the local constrains and opportunities can lead to many possible objectives (see Table 1.1), that can be complementary in some cases. Since some objectives can be reached through different techniques, there does not exist a unique technological option, which is suitable for all situations and, clearly, there does not exist a process capable of removing manure. Only nitrogen and organic matter concentrations can be decreased, by transforming nitrogen into dinitrogen gas (N_2) and organic carbon into a reduced (CH_4) or oxidized (CO_2) forms. In general, manure components can be split into different flows aiming at improving manure management.

The general trend of animal protein production is the concentration and specialization in regional clusters. This fact can become responsible for higher productions of manure than the fertilizing requirements in the area, and to an excess in the availability of nutrients. This could be the situation of Denmark, Flanders in Belgium, The Netherlands, Catalonia in Spain or Brittany in France, where manure surpluses have prompted to develop and apply different manure processing technologies and, in some regions (e.g. Flanders), farmers are obliged to process part of their surplus manure. Therefore, in some cases management options are not only market driven.

Problems caused by nutrients surplus have been described profusely (Burton and Turner, 2003). Of increasing concern are emissions to the atmosphere of ammonia and greenhouse gases (GHG), water resources pollution through leaching, and soil accumulation of undesired elements. By the establishment of Actions Plans and of Good Agricultural Practices, under the EU Nitrate Directive, farmers have been prompted to design and follow NMP. This planning can be individual or collective, being the transportation cost and the density and intensity of farming some of the limiting factors for adopting centralized or on-farm treatment strategies (Flotats *et al.*, 2009).

Table 1.1: Factors to be considered when designing Nutrient Management Plans (NMP), and possible objectives to be reached by manure treatments

Factors to be considered
▪ Availability of accessible field crops to be fertilized ▪ Nutritional requirements and productivity of the field crops ▪ Presence of other competitive/synergic organic fertilizers in the area ▪ Mineral fertilizers price ▪ Climatic factors ▪ Density and intensity of farming ▪ Property structure of farms and agricultural lands ▪ Distances and transportation costs ▪ Energy prices ▪ Economical profile of the area: industrial, farming, tourist, residential ▪ Existence of professional technology suppliers and consultants ▪ National or local regulation constrains
Possible objectives of the adopted treatment strategy
▪ To adjust manure production to seasonal crop requirements ▪ Reduction of transport cost by reducing the manure/slurry volume ▪ Transformation of manure into valuable products ▪ Adjustment of manure production and composition to the agricultural demand ▪ Nutrients recovery ▪ Nitrogen removal ▪ Removal of easily biodegradable organic matter ▪ Sanitation ▪ Removal of xenobiotics and other emerging pollutants ▪ Production of renewable energy ▪ Decreasing gaseous emissions (ammonia, methane and nitrous oxide) caused during manure management and storage ▪ Prevention of nitrates pollution due to run-off or leaching

Transportation may become an important bottleneck when planning manure management. In the case of liquid manures, pumping through a pipeline can represent an interesting alternative for substituting transport by tracks from some farms to a centralized treatment plants (Ghafoori *et al*., 2006; Dauden *et al.*, 2010). Transportation cost also provides a simple criterion to decide when a manure treatment strategy can be adopted. Treatment may become feasible if the global net cost of treatment, transportation and soil application of effluents is less than the cost of transportation and application of raw manure at an adequate nutrients dosage (Campos *et al*., 2004).

The following driving forces are considered for the establishment of objectives, in order of priority for farmers:

- Nutrients management, following Nitrate Directive (remove or recover)
- Renewable energy production
- Greenhouse gases emission mitigation

- Odours abatement
- Economical optimization of animal production as a whole activity including manure management

The relative importance of the above factors depends of the characteristics of the geographical area considered. I.e., a farm placed alone with no limitations around for land use and manure application, probably will fit the requirements of the Nitrate Directive and the driving force for the farmer will be to decrease production costs, by producing biogas and selling renewable energy; moreover, a farm located in a touristic area could be obliged to adopt systems dealing with odours abatement.

1.3: Scenarios based on nutrients management

Manure re-use as fertilizer is the most adequate option for the management of such material. Nevertheless, higher productions of animal manure in a given region than fertilizing requirements of field crops/grass leads to an excess in the availability of nutrients. Problems caused by nutrients surplus have been described profusely and policies have been designed in many countries to orientate management methods dealing with the minimization of negative environmental effects. In the European Union, the Nitrate Directive (EEC, 1991) has been the main driving force to develop and apply management methods adopting adequate fertilization plans, adapted to field crops needs. By the establishment of Good Agricultural Practices in each country, farmers have been prompted to make decisions, and to design and use NMPs. Also, the same actions become compulsory for farms located in nitrates vulnerable zones, where the action programmes are obligatory.

NMP designing factors are related to the geographical scale of the analysis. Several situations can be considered depending on the structure of the property of farms and agricultural land and its combination with the offer and demand balance. These situations can lead to the following scenarios:

a) Nutrients equilibrium at farm scale.

b) Nutrients equilibrium at area scale (joining one livestock farmer and one land owner).

c) The same as b) but with a relation of many animal and agricultural farmers.

d) Nutrients excess at area scale (joining livestock farmers and agricultural land owners).

Scenario a) leads to a farm scale planning and makes it possible a simple and cheap management. Complexity only appears when it is interesting to produce biogas (high public energy prices and/or high thermal energy demand at farm scale). In this case, the limiting factor will be the benefit defined by the energy balance. Treatment facility must have a simple design and farmer should integrate its operation in the usual farm tasks.

Scenario b) leads to a similar situation than scenario a). Transportation can be the limiting factor and treatment processes must be modulated to decrease its cost. Scenario c) requires a collective management planning which can conclude in the building up of a centralized processing system or in a combined solution farm – centralized systems. In this scenario, the operation of the global NMP and all the organizational issues are the limiting factors whereas in lesser extend the technology adopted.

Finally, in scenario d) each farmer can decide adopting individual or collective strategies. When global treatment costs are less than individuals, the collective approach could be the best solution. The objective of the management planning is the establishment of the procedure to transform manure surplus into a product to be transported, sold or used in another area. Management planning and technology must be designed, implemented and operated following the rule of minimum complexity, but taking into account that this is a complex project with many variables to be considered.

2: METHODOLOGY AND ORGANIZATION

2.1: Long list processing technologies

45 processing technologies have been identified as standalone technologies or belonging to combined treatment systems. These processes have been classified in the following groups:

- **Separation techniques**: System with the objective of separating manure into two flows: a concentrate (solid fibre fraction) and a diluted fraction (liquid fraction).
- **Additives and other pre/1st treatments**: Set of processes which have the objective to prepare of the material for a further purpose or treatment.
- **Anaerobic treatment**: Series of biological processes in which microorganisms break down organic molecules in absence of oxygen, resulting in the production of a mixture of gases, named biogas, mainly composed of methane and carbon dioxide.
- **Treatment of the fibre/solid fraction**: Processing methods especially suitable for solid manures or solid fractions obtained after separation.
- **Treatment of the liquid fraction**: Processing methods especially suitable for much diluted manures or liquid fractions obtained after separation.
- **Air cleaning (as part of manure processing plant)**: Methods applied to clean process air used during some manure treatment (i.e. exhaust air from composting)

2.2: Description and characterization of every process

Every process has been symbolized by a diagram (defined in Annex B), in order to identify and express a process in an easy way. Similar or comparable processes use similar diagrams. Characterization of every process has been expressed in chart form, following the guidelines detailed in Annex C.

The amount of information obtained for every identified process, its technical and economical characterization, is unequal, with processes characterized by extended experience and others with a lack of accessible information due, sometimes, to commercial issues. Efficiencies or performance characteristics of some processes present very different values, which is comprehensible since raw materials (different kind of manures) present a wide range of composition values also.

Since some processes can only be operated properly if another previous process is included in the plant layout, these processes are not processing raw manure but the product of the previous process. This is why in the box of the chart indicating to what kind of material can be applied, it is included the usual combination where the current process is acting as final step. In example, for vacuum evaporation process (process number 54A, Annex A), a previous acidification is necessary to avoid ammonia emissions (process number 21, Annex A) and a previous removal of organic matter is necessary to avoid condensates pollution with volatile fatty acids, recommending a previous anaerobic digestion step (Process number 30, Annex A). Since vacuum evaporation can only works with liquids, some separation process (processes referred with number 10 in Annex A) is required before acidification, and in order to minimize acids consumption. This means that a possible combination of processes for having an appropriate operation of the vacuum evaporation unit is: 30-10-21-55A.

2.3: Combination of processes

Based on the explanations for every chart, and the usual combination of processes found (see the above section), a Table of possible combinations has been build in Chapter 9. Based on it, main processes combinations have been identified. This Table indicates in raw figures a given process that requires previous processing of the treated stream and in columns the previous processes that can be found in the plant layout.

The above combinations constitute technological strategies, which are tried to be classified based on their objectives. This is done in Chapter 9, which is prepared for providing a general overview of the technologies, their combinations and strategies, concluding that anaerobic digestion is a key process in any sustainable manure treatment strategy.

2.4: Complementary remarks

The efficiency of some processes (i.e. solid/liquid separation techniques, anaerobic digestion) has shown to be dependent of the previous or initial storage time. A final chapter analyses this effect.

3: SOLID/LIQUID SEPARATION TECHNIQUES

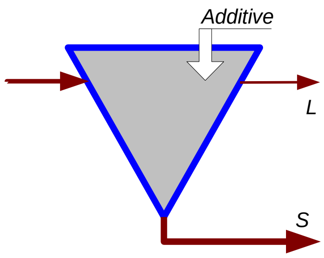
3.1: Coagulation - Flocculation

Objectives

The main objective of chemical pre-treatment such as coagulation and flocculation is to improve the mechanical separation of livestock slurries by particle properties modification (aggregation/sedimentation/flotation)

Level of complexity	Usual scale	Innovation stage
☒ low	☒ on-farm	☐ laboratory/research
☐ medium	☒ medium	☐ pilot plant
☐ high complex	☒ large scale	☒ industrial/commercial

General diagram



Applied to

☐ Solid pig manure; ☒ Liquid pig manure; ☒ Pig slurry; ☐ Pig deep litter;

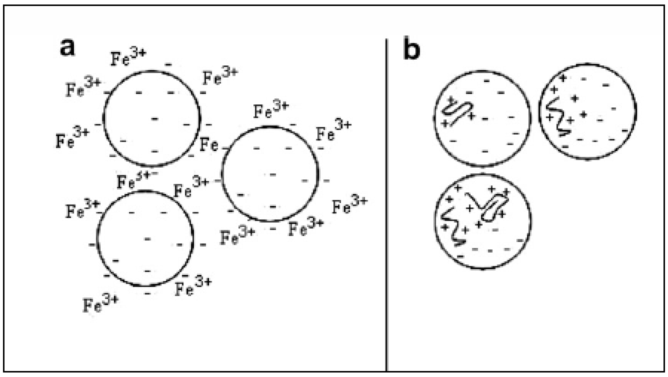
☐ Solid Cattle manure; ☒ Liquid Cattle manure; ☒ Cattle slurry; ☐ Cattle deep litter;

☐ Poultry slurry; ☐ Poultry deep litter.

☒ Products of other processes. In this case, a possible combinations is:

12 + 10A (see process codes in Annex A)

Pictures



Mixing chamber of pig manure with a polymer followed by a rotating screen at Pigneto di Prignano, MO, Italy, (left) courtesy of SELCO MC; (a) coagulation, (b) patch flocculation, schematic (Hjorth *et al.,* 2008) (right).

Theoretical fundamentals and process description

Coagulation and flocculation are chemical pre-treatments that improve the mechanical solid-liquid separation of many suspensions. In most suspensions, colloidal particles will not aggregate because the particles are negatively charged and repel each other. However, aggregation will be facilitated by adding (1) multivalent cations ($Al_2(SO_4)_3$, $FeCl_3$, etc.) that cause coagulation and/or (2) polymers (polyacrylamide -PAM-, chitosan, etc.), whereby flocculation occurs. The addition of multivalent cations will also enhance the precipitation of phosphorus. Multivalent ions and polymers need to be added carefully to the slurry to achieve satisfactory particle aggregation. If both additives are used, the multivalent ion is added first to the slurry, which is then stirred to ensure homogeneous distribution of ions and dry matter. Then, several minutes of slow stirring are necessary for the charge neutralization and coagulation to occur. Next, the polymer is slowly added in small doses during vigorous stirring, followed by slow stirring, which is necessary for polymer bridging and patch flocculation to occur. The stirring applied (for example, by the impeller, i.e. time and speed), has a large impact on the formation of the aggregates; too low stirring causes the aggregates to be non-uniform and unstable with low particle catchment, while too high stirring causes the aggregates to be destroyed. After the coagulation-flocculation process, the slurry may be transferred to ordinary solid-liquid separators.

Environmental effects

Effects on air (emissions)

- Performance of some systems implies a high exposition of manure/slurry to atmosphere (high stirred systems) and therefore a risk of gaseous emissions (COV) and odour problems arises.
- Also during flotation (aeration) a high proportion of ammonia can be discharged into the air. It is therefore necessary to treat or collect the exhaust air from flotation equipment

Effects on water/soil (and management)

- As many of solid/liquid separation techniques, nutrients (N, P, K) can be concentrated in the solid fraction enhancing the capability of manure/slurry management. Solid fractions can be more easily exported to areas with low livestock density, reducing problems derived from nutrient surplus, whereas liquid fractions can be used or further processed in site

Other effects

- Separated products are often destined to be deposited in landfills or applied to cultivated fields. Thus, the environmental and health consequences of the polymer used must be considered. The monomers of PAM (acrylamide), used in most slurry separation studies, can be toxic, and specifically carcinogenic. However, a study on separated slurry products showed the risk to be minimal if a biological post-treatment is applied, since PAM is degraded in biological processes without acrylamide accumulation (Campos et al., 2008). In any case, a minimal concentration of the monomer can be found in raw PAM and it must be managed carefully. There is a need for further studies to determinate the potentially toxic effect of other alternative polymer types or components produced during its degradation. The possible problems related to PAM use limit the acceptability of this technology as BAT.

Technical indicators

Components conversion/efficiencies	Energy consumption or production
Coagulation-flocculation can increase the amount of nutrients in the solid fraction, compared with other S/L separation techniques. Average separation indexes following coagulation and flocculation using different separation techniques were identified by Hjort *et al.* (2010) as: 22% volume; 70% dry matter; 43% Total-N; 20% NH4-N; 79% Total-P. *Summary on separation efficiencies reported using different reagents or polymers can be found in the same reference.*	Energy consumed during stirring (low) **Reagents** Chemical reagents used as flocculants or coagulants such as multivalent cations, or polymeric substances

Observations: Improvement of separation efficiencies compared to other techniques (by reagent addition).

Economical indicators
Investment cost: ~ 50,000 € (Foged, 2010)
Quantifiable incomes: NA
Non economically quantifiable benefits: Improved separation efficiency
Operational costs: ~ 0.80 €/tonne input slurry (Foged, 2010)

Selected literature references

- Campos, E., Almirall, M., Mtnez-Almela, J., Palatsi, J., Flotats, X. (2008). Feasibility study of the anaerobic digestion of dewatered pig slurry by means of polyacrylamide. *Bioresour. Technol.*, 99, 387-395. DOI: http://dx.doi.org/10.1016/j.biortech.2006.12.008
- Estevez-Rodríguez M.D., Gomez-del-Puerto A.M., Montealegre-Meléndez M.L., Adamsen A.P.S., Gullov P., Sommer S.G. (2005). Separation of phosphorus from pig slurry using chemical additives. *Appl. Eng. Agric.* 21, 739-742.
- Foged H.L. (2010). Best Available Technologies for Manure Treatment: for Intensive Rearing of Pigs in Baltic Sea Region EU Member States. Baltic Sea 2020. Stockholm.
- Garcia M.C., Szogi A.A., Vanotti M.B., Chastain J.P., Millner P.D. (2009). Enhanced solid-liquid separation of dairy manure with natural flocculants. *Bioresour. Technol.* 100, 5417-5423. DOI: 10.1016/j.biortech.2008.11.012.
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- Martinez-Almela J., Barrera J.M. (2005). SELCO-Ecopurin pig slurry treatment system. *Bioresour. Technol.* 96, 223-228. DOI: 10.1016/j.biortech.2004.05.017.
- Zhang R.H., Lei F. (1998). Chemical treatment of animal manure for solid-liquid separation. *Trans. ASAE.* 41, 1103-1108.

Real scale (commercial or pilot) references

- Faculty of Veterinary Sciences; University of Murcia
  Granja Veterinaria
  Avda. Libertad s/n
  E-30071 Guadalupe, Murcia, Spain
  Tlf.:+34 968 899860

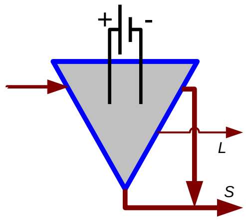
3.2: Electro coagulation

Objectives

The objective of electro coagulation is to unstabilize suspended, emulsioned or dissolved particles within an aqueous media, by applying electric power. The electricity unstabilizes those particles favouring aggregation of colloidal particles as chemical reagents do in a conventional coagulation-flocculation process.

Level of complexity	Usual scale	Innovation stage
☐ low	☒ on-farm	☐ laboratory/research
☒ medium	☐ medium	☐ pilot plant
☐ high complex	☐ large scale	☒ industrial/commercial

General diagram



Applied to

☐ Solid pig manure; ☒ Liquid pig manure; ☒ Pig slurry; ☐ Pig deep litter;

☐ Solid Cattle manure; ☒ Liquid Cattle manure; ☒ Cattle slurry; ☐ Cattle deep litter;

☐ Poultry slurry; ☐ Poultry deep litter.

☒ Products of other processes. In this case, a possible combinations is:

12-10B (see process codes in Annex A)

Pictures

Illustration of an electro coagulation unit in a pig farm at Errentería (Spain). Photo: Lekuona (2004)

Theoretical fundamentals and process description

An electro coagulation reactor includes series of iron plates working as “sacrifice electrodes” through which flows slurry to be treated. Direct current (DC), for instance: 1 kA and 20 v, is supplied to those plates forcing the solubilisation of Fe^{2+} in the slurry, which acts as coagulant agent. It results in the separation of organic matter from water, and the formation of little flocks. The injection of a flocculant in the reactor outlet line will produce an increase in the size of flocks. Subsequently, these flocks may be removed from the liquid phase by using some separation device such as a band filter.

Environmental effects

Effects on air (emissions)

- Performance of some systems implies a high exposition of manure/slurry to atmosphere (high stirred systems), and thus, risk of gaseous emissions (COV) and odour problems could arise.
- Also during flotation (aeration) a high proportion of ammonia can be discharged into the air. It is therefore necessary to treat or collect the exhaust air from flotation equipment

Effects on water/soil (and management)

- As many of solid/liquid separation techniques, nutrients (N, P, K) can be concentrated in the solid fraction enhancing the capability of manure/slurry management. Solid fractions can be more easily exported to areas with low livestock density, reducing problems derived from nutrient surplus, whereas liquid fractions can be used or further processed in situ

Other effects

- Separated products can be applied to cultivated fields. Thus, the effect of Fe enrichment must be considered in sensitive field crops.

Technical indicators

Components conversion/efficiencies:

For electro coagulation in combination with a band filter, Lekuona (2004) reported the following efficiencies:

	Concentration in Slurry (mg/l)	Concentration in Effluent (mg/l)	% removal
Total Suspended Solids (TSS)	20,000-30,000	100-200	>99
Chemical Oxygen Demand (COD)	25,000-35,000	1500-2500	>90
Total N	2,000-3,000	600-800	>60
Total P	200-350	<2	>99

Energy consumption or production: consumption of 20-22 kW·h/m^3 liquid fraction pig slurry with about 1.1-1.3 % TS

Reagents: Additional flocculants when considered.

Observations: Improvement of separation efficiencies compared to other techniques (by electric supply) but sacrifice electrodes, consisting on iron plats, should be regularly replaced due to the release of Fe2+ in the slurry.

Economical indicators

Investment cost: NA – cost of electrodes

Quantifiable incomes: NA

Non economically quantifiable benefits: Improved separation efficiency and manure/slurry management

Operational costs: related to electrical energy consumption and electrodes replacement

Selected literature references

- Lekuona, A. (2004). Planta de tratamiento de purines de Egiluze. *RETEMA: Revista Técnica de Medio Ambiente.* 103: 20-24 *(in Spanish)*.

Real scale (commercial or pilot) references

NA

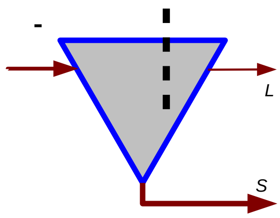
3.3: Separation by grid

Objectives

Separation of big elements contained in slurry.

Level of complexity	Usual scale	Innovation stage
☒ low	☒ on-farm	☐ laboratory/research
☐ medium	☒ medium	☐ pilot plant
☐ high complex	☒ large scale	☒ industrial/commercial

General diagram



Applied to

☐ Solid pig manure; ☐ Liquid pig manure; ☒ Pig slurry; ☐ Pig deep litter;

☐ Solid Cattle manure; ☐ Liquid Cattle manure; ☒ Cattle slurry; ☐ Cattle deep litter;

☐ Poultry slurry; ☐ Poultry deep litter.

☐ Products of other processes. In this case, a possible combinations is:

Pictures

Illustration of separation by grid at the influent of Sending centralized biogas plant (Denmark).

Theoretical fundamentals and process description

When the size of the solids in the slurry is very heterogeneous, even with presence of big elements that can block transfer elements such as pumps and pipes it may be interesting to work with a combination of separation systems. In this case, it is possible to consider a less efficient separation system such as those based in the use of a grid followed by a finer separation stage. Accumulation of solids in the grid should be avoided In order to prevent clogging episodes.

Environmental effects

- *Effects on air (emissions):* -

- *Effects on water/soil (and management):* -

Other effects: It can be considered a pre-process protective equipment, rather than a real separation technology. No environmental effects are identified.

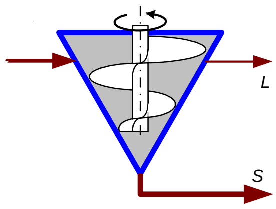
Technical indicators
Components conversion/efficiencies: Low.
Energy consumption or production: Not usual, use to be passive
Reagents:
Observations: Accumulation of solids in the grid should be avoided In order to prevent clogging episodes.

Economical indicators
Investment cost: cost of the grid
Quantifiable incomes: NA
Non economically quantifiable benefits: NA
Operational costs: NA

Selected literature references
-

Real scale (commercial or pilot) references
-multiple

3.4: Separation by screw pressing

Objectives			
Separation of solids from a (semi)liquid stream in two different fractions, one solid and the other liquid by pressure filtration.			
Level of complexity	**Usual scale**	**Innovation stage**	**General diagram**
☒ low ☐ medium ☐ high complex	☒ on-farm ☒ medium ☒ large scale	☐ laboratory/research ☐ pilot plant ☒ industrial/commercial	

Applied to

☐ Solid pig manure; ☐ Liquid pig manure; ☒ Pig slurry; ☐ Pig deep litter;

☐ Solid Cattle manure; ☐ Liquid Cattle manure; ☒ Cattle slurry; ☐ Cattle deep litter;

☐ Poultry slurry; ☐ Poultry deep litter.

☐ Products of other processes. In this case, a possible combinations is:

Pictures

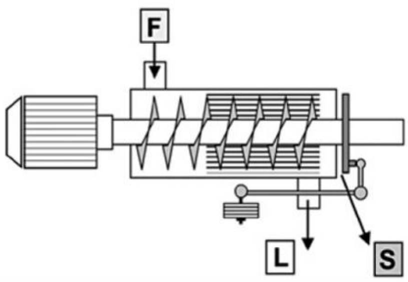


Illustration of a screw press (left) at Balenyà (Spain), and a scheme of an screw press system (right) from Burton (2007).

Theoretical fundamentals and process description

This is a physical process consisting on the application of pressure to separate by filtration suspended solids, and also dissolved, contained in a (semi)liquid stream in two different fractions (i.e.: solid and liquid fractions).. The material to be separated enters into a cylindrical screen (0.5-1 mm) by means of a screw. The liquid will pass through the screen and will be collected in a container surrounding the screen. At the end of the axle the dry matter rich fraction will be pressed against a plate. The slurry filter cake is compressed during pressure filtration ensuring that the screw press can produce a solid fraction with high dry matter content; often being twice as high as for gravity drainage. Increasing the applied pressure will increase the dry matter content of the solid fraction.

Environmental effects

Effects on air (emissions):

- Performance of some systems implies a high exposition of manure/slurry to atmosphere, and thus, risk of gaseous emissions (COV) and odour problems. Nevertheless, this can be considered as a closed system, consequently emissions are decreased as compared to other S/L separation techniques

Effects on water/soil (and management)

- As many of solid/liquid separation techniques, nutrients (N, P, K) can be concentrated in the solid fraction enhancing the capability of manure/slurry management. Solid fractions can be more easily exported to areas with low livestock density, reducing problems derived from nutrient surplus, whereas liquid fractions can be used or further processed in situ.

Other effects:-

Technical indicators

Components conversion/efficiencies	**Energy consumption or production**
Mass-flow, outlet percentage as liquid fraction: 75-90%	Consumption: 0.1-0.5 kWh/m^3 of input
Efficiencies (%): 20-40% TS; 5-20% N; 10-30% P in the liquid fraction	**Reagents :** Not usual

Observations Although aggregation of particles on the filter may, to some degree, contribute to the retention of small particles in the screw press, this has no significant effect, as the applied pressure forces small particles through the filter pores. A large proportion of small particles are therefore found in the liquid fraction after separation. Thus, the filter cake contains little N, P or K, because these are primarily found in the liquid phase and in the small particles which are drained off the filter cake with the permeate.

Economical indicators

Investment cost: 17,000-21,000 € (Levasseur, 2004). For the Calldetenes plant located in Catalonia (Report IV), treating 10.000 m3/y the estimated investment cost of the screw press is 28.000 €

Quantifiable incomes: NA

Non economically quantifiable benefits: Improvement of manure management capacity.

Operational costs: Treatment cost between 0.5-0.9 €/m^3 of input (Levasseur, 2004). For the Calldetenes plant located in Catalonia (Report 4. Annex D), treating 10.000 m3/y the estimated operational cost of the screw press is 0.66 €/m^3

Selected literature references

- Burton C.H. (2007). The potential contribution of separation technologies to the management of livestock manure. *Livest. Sci.* 112, 208-216. DOI: 10.1016/j.livsci.2007.09.004.
- Hjorth M., Christensen K.V., Christensen M.L., Sommer S.G. (2010). Solid-liquid separation of animal slurry in theory and practice. A review. *Agron. Sust. Devel.* 30, 153-180. DOI: 10.1051/agro/2009010.
- Levasseur P. (2004). Traitement des effluents porcins. *Guide Practique des Procédés*. ITP *(in French)*.
- Møller H.B., Lund I., Sommer S.G. (2000). Solid-liquid separation of livestock slurry: efficiency and cost. *Bioresour. Technol.* 74, 223-229. DOI: 10.1016/S0960-8524(00)00016-X.
- Westerman P.W., Arogo J. (2005). On-farm performance of two solid/liquid separation systems for flushed swine manure. *Appl. Eng. Agric.* 21, 707-717.

Real scale (commercial or pilot) references

-multiple

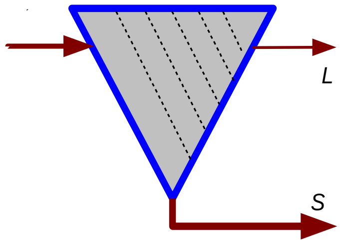
3.5: Separation by sieves

Objectives

Separation of solids from a (semi)liquid stream in two different fractions, one solid and the other liquid, by filtration.

Level of complexity	Usual scale	Innovation stage
☒ low	☒ on-farm	☐ laboratory/research
☐ medium	☐ medium	☐ pilot plant
☐ high complex	☐ large scale	☒ industrial/commercial

General diagram



Applied to

☐ Solid pig manure; ☐ Liquid pig manure; ☒ Pig slurry; ☐ Pig deep litter;

☐ Solid Cattle manure; ☐ Liquid Cattle manure; ☒Cattle slurry; ☐ Cattle deep litter;

☐ Poultry slurry; ☐ Poultry deep litter.

☐ Products of other processes. In this case, a possible combinations is:

Pictures

Illustration of static screen (left) in a pig farm at Gurb (Spain), and an illustration of a vibrant screen (right) (http://wn.com/manure).

Theoretical fundamentals and process description

Sieve separators may be static or vibrant. They involve a screen of a specified pore size that allows only solid particles smaller in size than the openings to pass through. The liquid flows through the screen and is drained off. This type of separator generally works better if slurry have a low solids content (<2%)

There is a compromise between sieve size, separation performance, and risk of clogging. Indeed, sieve clogging is one of the most usual problems of static screens. Such risk is diminished in vibrant sieves due to vibration. If the flow is too high, a large amount of water can remain in the solid fraction. On the other hand, such devices need a constant supply of slurry to prevent the particles to dry.

Separation by sieves is usually used as pretreatment in order to avoid sedimentation phenomena during storage, as conditioning process before pumping or coupled with more efficient separation systems.

Environmental effects

Effects on air (emissions)

- Performance of some systems implies a high exposition of manure/slurry to atmosphere, and thus, risk of gaseous emissions (COV) and odour problems.

Effects on water/soil (and management)

- As many of solid/liquid separation techniques, nutrients (N, P, K) can be concentrated in the solid fraction enhancing the capability of manure/slurry management. Solid fractions can be more easily exported to areas with low livestock density, reducing problems derived from nutrient surplus, whereas liquid fractions can be used or further processed in situ

Other effects: -

Technical indicators

Components conversion/efficiencies	**Energy consumption or production**
5-15% N in the liquid fraction 5-15% P in the liquid fraction	NA (only pumping or transfer operations)
	Reagents Not usual
Observations	

Economical indicators

Investment cost:

3,500-8,000 € (sieve)

15,000 € (vibrant)   (Levasseur, 2004)

Quantifiable incomes: NA

Non economically quantifiable benefits: Improvement of manure management capacity.

Operational costs: NA

Selected literature references

- Ford M., Fleming R. (2002) Mechanical solid-liquid separation of livestock manure, Literature review. Ridgetown College. University of Guelph, Ridgetown, Ontario.
- Hjorth M., Christensen K.V., Christensen M.L., Sommer S.G. (2010). Solid-liquid separation of animal

slurry in theory and practice. A review. *Agron. Sust. Devel.* 30, 153-180. DOI: 10.1051/agro/2009010.

- Levasseur P. (2004). Traitement des effluents porcins. Guide Practique des Procédés. ITP *(in French)*.
- Pieters J.G., Neukermans G.G.J., Colanbeen M.B.A. (1999). Farm-scale membrane filtration of sow slurry. *J. Agric. Eng. Res.* 73, 403-409.

Real scale (commercial or pilot) references
-multiple

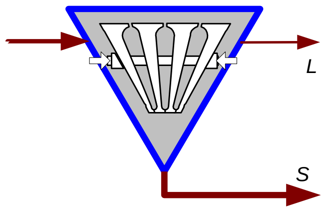
3.6: Separation by filter pressing

Objectives

Separation of solids from a (semi)liquid stream in two different fractions, one solid and the other liquid, by pressure filtration.

Level of complexity	Usual scale	Innovation stage
☐ low	☒ on-farm	☐ laboratory/research
☒ medium	☐ medium	☐ pilot plant
☐ high complex	☐ large scale	☒ industrial/commercial

General diagram



Applied to

☐ Solid pig manure; ☐ Liquid pig manure; ☒ Pig slurry; ☐ Pig deep litter;

☐ Solid Cattle manure; ☐ Liquid Cattle manure; ☒ Cattle slurry; ☐ Cattle deep litter;

☐ Poultry slurry; ☐ Poultry deep litter.

☒ Products of other processes. In this case, a possible combinations is:

10A + 14 (see process codes in Annex A)

Pictures

Illustration of a rotary press at Tyndall Farm (SC, USA) (left), and a filter belt applied to pig slurry courtesy of Mr. Martínez-Almela (right).

Theoretical fundamentals and process description

Most of the filter-pressing separators are screen-type devices which may have a large variety of designs.

- Rotary press: Manure to be separated is continuously fed into a channel, and rotate between two parallel revolving screens. The filtrate will pass through the screens as the solid fraction will advance within the channel. The solid material will continue to dewater as it travels around the channel, eventually forming a cake near the outlet side of the press. The frictional force of the slow moving screens, coupled with the controlled outlet restriction, will result in the extrusion of a dry cake. Use of polyelectrolyte is normally considered in order to enhance separation efficiency.

- Filter belt: the band filter is constantly turning on rollers to make the material moving and to gain pressure on the material and thereby the liquid part will pass the filter. The filter cake is continuously removed as the belt rotates, so that the raw-slurry loading area and solid-fraction unloading area change over and are cleaned continuously. Often the belt separator is followed by a screw pressing unit, to increase the dry matter content in the fibre fraction.

Environmental effects

Effects on air (emissions):

- Performance of some systems implies a high exposition of manure/slurry to atmosphere, and thus, risk of gaseous emissions (COV) and odour problems. Nevertheless, this can be considered a closed system, consequently emissions are reduced as compared to other S/L separation techniques

Effects on water/soil (and management)

- As many of solid/liquid separation techniques, nutrients (N, P, K) can be concentrated in the solid fraction enhancing the capability of manure/slurry management. Solid fractions can be more easily exported to areas with low livestock density, reducing problems derived from nutrient surplus, whereas liquid fractions can be used or further processed in situ.

Other effects:-

Technical indicators	
Components conversion/efficiencies Considering use of polyelectrolyte they are attainable separation efficiencies of 30% TKN and 70% P in the solid fraction. Dry matter of the separated solid fraction is in the range of 25-35%.	**Energy consumption or production** ~ 0.5 kwh/m^3 of input manure (rotary press), (Vanotti et al., 2009) **Reagents:** Use of polyelectrolyte is normally considered in order to enhance separation efficiency.
Observations	

Economical indicators
Investment cost: 25,000-125,000 € depending on dimensions and type of separator (Levasseur, 2004; Foged, 2010)
Quantifiable incomes: NA
Non economically quantifiable benefits: Improvement of manure management capacity
Operational costs: 1.5 €/tonne of input manure (band filter) (Foged, 2010)

Selected literature references

- Foged H.L. (2010). Best Available Technologies for Manure Treatment: for Intensive Rearing of Pigs in Baltic Sea Region EU Member States. Baltic Sea 2020. Stockholm.
- Hjorth M., Christensen K.V., Christensen M.L., Sommer S.G. (2010). Solid-liquid separation of animal slurry in theory and practice. A review. *Agron. Sust. Devel.* 30, 153-180. DOI: 10.1051/agro/2009010.
- Levasseur P. (2004). Traitement des effluents porcins. Guide Practique des Procédés. ITP *(in French)*.
- Vanotti M.B.; Szogi A.A.; Millner P.D.; Loughrin, J.H. (2009). Development of a second-generation environmentally superior technology for treatment of swine manure in the USA. *Bioresour. Technol.* 100, 5406-5416. DOI: 10.1016/j.biortech.2009.02.019.

Real scale (commercial or pilot) references

-multiple

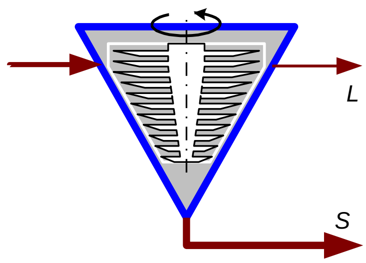
3.7: Separation by centrifuge

Objectives

Separation of solids from a (semi)liquid stream in two different fractions, one solid and the other liquid, by centrifugal force.

Level of complexity	Usual scale	Innovation stage
☐ low	☐on-farm	☐ laboratory/research
☒ medium	☐ medium	☐ pilot plant
☐ high complex	☒ large scale	☒ industrial/commercial

General diagram



Applied to

☐ Solid pig manure; ☐ Liquid pig manure; ☒ Pig slurry; ☐ Pig deep litter;

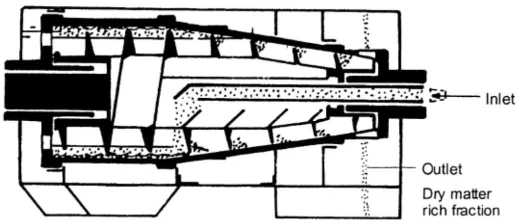
☐ Solid Cattle manure; ☐ Liquid Cattle manure; ☒Cattle slurry; ☐ Cattle deep litter;

☐ Poultry slurry; ☐ Poultry deep litter.

☒ Products of other processes. In this case, a possible combinations is:

10A-15 // 12 + 31A + 15 (see process codes in Annex A)

Pictures



Centrifuges at TRACJUSA pig manure treatment plant (Juneda, Spain), and a scheme of a centrifuge (Møller et al., 2000)

Theoretical fundamentals and process description

In decanter centrifuges a centrifugal force is generated to cause the separation of solids from the liquid. There are vertical and horizontal types of decanter centrifuges. The horizontal decanter centrifuge uses a closed cylinder with a continuous turning motion (3000-4000 rpm). The centrifugal force separates solids and liquids at the wall into an inner layer with a high dry matter concentration and an outer layer consisting of a liquid containing a suspension of colloids, organic components and salts. The solid and liquid phases are transported to either end of the centrifuge by rotating the entire centrifuge at high speed and by simultaneously rotating the conveyor at a speed that differs slightly from the speed of the bowl (outer conical shell). The solid particles are conveyed towards the conical end and let out through the solid discharge openings, whereas the supernatant flows towards the larger end of the cylinder formed by the bowl and the flights of the conveyor. During the transport of the slurry, the particles are separated from the liquid and the liquid phase is discharged through liquid-discharge openings at the wide end of the decanter centrifuge. Increasing the retention time by reducing the volumetric feed rate has been observed to increase the efficiency of the separation of slurry. The separation efficiency of dry matter increases at increasing dry matter content of the slurry.

Environmental effects

Effects on air (emissions):

- Performance of some systems implies a high exposition of manure/slurry to atmosphere, and thus, risk of gaseous emissions (COV) and odour problems. Nevertheless, a centrifuge can be considered a closed system than can reduce emissions compared to other S/L separation techniques.

Effects on water/soil (and management)

- As many of solid/liquid separation techniques, nutrients (N, P, K) can be concentrated in the solid fraction enhancing the capability of manure/slurry management. Solid fractions can be more easily exported to areas with low livestock density, reducing problems derived from nutrient surplus, whereas liquid fractions can be used or further processed in situ. Centrifugation is the technique that reports higher separation efficiencies.

Other effects:-

Technical indicators

Components conversion/efficiencies Average separation indexes at centrifugation were identified by Hjort *et al.* (2010) as: 14% volume; 61% dry matter; 28% Total-N; 16% NH4-N; 71% Total-P in the solid fraction.	**Energy consumption or production** 2.0-4.0 kWh/m^3 of input manure **Reagents:** Use of polyelectrolyte is normally considered in order to enhance separation efficiency.

Observations: It can be considered the most compact technology compared with other separation technologies.

Economical indicators

Investment cost:

40,000-60,000 € (1.5-2 m^3/h)

100,000 € (25 m^3/h) (Levasseur, 2004)

Quantifiable incomes: NA

Non economically quantifiable benefits: Improvement of manure management capacity

Operational costs: Treatment cost between 0.6-2.3 €/m^3 of input manure (Levasseur, 2004)

Selected literature references
▪ Hjorth M., Christensen K.V., Christensen M.L., Sommer S.G. (2010). Solid-liquid separation of animal slurry in theory and practice. A review. *Agron. Sust. Devel.* 30, 153-180. DOI: 10.1051/agro/2009010. ▪ Levasseur P. (2004). Traitement des effluents porcins. *Guide Practique des Procédés*. ITP *(in French)*. ▪ Møller H.B., Lund I., Sommer S.G. (2000). Solid-liquid separation of livestock slurry:efficiency and cost. *Bioresour. Technol.* 74, 223-229. DOI: 10.1016/S0960-8524(00)00016-X.
Real scale (commercial or pilot) references
• TRAJSUSA-VAG (Juneda, Spain) • SAVA (Miralcamp, Spain) • VALPUREN-BAÑUELO/VALPUREN POLAN (Toledo, Spain)

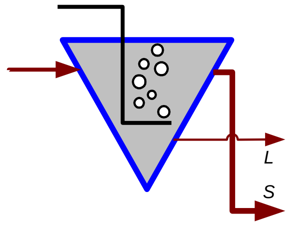
3.8: Air flotation

Objectives

Dissolved air flotation is a water treatment process that clarifies wastewaters (or other reject water/liquids) by the removal of suspended matter such as oil or solids. The removal is achieved by dissolving air in the water or wastewater under pressure and then releasing the air at atmospheric pressure in a flotation tank or basin. The released air forms tiny bubbles which adhere to the suspended matter causing the suspended matter to float to the surface of the liquid, where it may then be removed by a skimming device. An air flotation separator is able to separate livestock manure into a solid/fibre and a liquid fraction

Level of complexity	Usual scale	Innovation stage
☒low	☐on-farm	☐ laboratory/research
☐medium	☒ medium	☐ pilot plant
☐ high complex	☐large scale	☒ industrial/commercial

General diagram



Applied to

☐ Solid pig manure; ☒ Liquid pig manure; ☒Pig slurry; ☐ Pig deep litter;

☐ Solid Cattle manure; ☒Liquid Cattle manure; ☒Cattle slurry; ☐ Cattle deep litter;

☐ Poultry slurry; ☐ Poultry deep litter.

☒ products of other processes. In this case, a possible combinations is:

12 + 10A + 16 (see process codes in Annex A)

Pictures

Example of a dissolved air flotation unit. Illustration from Siltbuster Ltd (www.siltbuster.com)

Theoretical fundamentals and process description

Flotation is used extensively in food industry especially for the treatment of processed wastewater. By flotation, suspended material can be separated from the liquid phase and concentrated in a sludge phase, skimmed and handled separately. By flotation, water saturated with air under pressure is brought to the bottom of the flotation tank and releases microscopic bubbles to the reject/wastewater or liquid to be treated. In contrast to sedimentation, where heavy particles precipitates in a liquid, flotation forms large light particles brought to the surface of very fine small bubbles, which adhere to the suspended material. The suspended material can be scraped off the surface with a mechanical scraper and forms flotation sludge. A Danish company has applied the flotation in combination with ozone dosing for treatment of manure. Furthermore, there is installed a flotation plant to treat degassed biomass on a biogas plants in Denmark. Flotation has been used for treatment of manure on pig farms in USA and in Holland. Flotation is thus a process, which can further purify the liquid fraction after a mechanical separation and a flocculation process.

Environmental effects

Effects on air (emissions):

- Performance of some systems implies a high exposition of manure/slurry to atmosphere, and thus, risk of gaseous emissions (COV) and odour problems. By flotation a very high proportion of ammonia is discharged into the air (stripped), while the suspended material floats. It is therefore necessary to make a collection of exhaust air from flotation.

Effects on water/soil (and management)

- As the other solid/liquid separation techniques, particulate matter is concentrated in the solid fraction while concentrations of soluble compounds are almost uniformly distributed in the two fractions. While phosphorous and organic N are concentrated in the solid fraction, soluble nitrogen, such as ammonia or nitrates, and potassium mass flow rates are higher for the liquid fraction. Solid fractions can be more easily exported to areas with low livestock density, whereas liquid fractions can be used or further processed in situ.

Other effects:-

Technical indicators

Components conversion/efficiencies: NA Virtually all suspended material in the entering stream can be removed by this process.	**Energy consumption or production:** NA **Reagents:** NA

Observations: Flotation is often used in combination with chemical flocculation.

Economical indicators

Investment cost: NA

Quantifiable incomes: NA

Non economically quantifiable benefits: Improvement of manure management capacity

Operational costs: No valid data available. However, a plant in Holland (Kumac Mineralen), which used flotation in addition to flocculation, drum belt separation, reverse osmosis, and demineralization, claimed the operational costs for all processes were at a level of 5 €/m^3 slurry

Selected literature references

- Foged, Henning Lyngsø. 2009. Memorandum from visit to Holland 31 August to 4 September 2009. Not published.

Real scale (commercial or pilot) references
• Kumac Mineralen, Lupinenweg 8a 5753 SC Deurne Nederlands

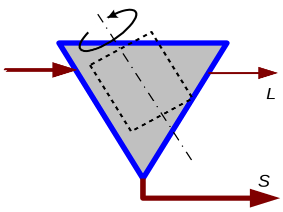
3.9: Separation by drum filters

Objectives

Separation of solids from a (semi)liquid stream in two different fractions, one solid and the other liquid, by drum filtration.

Level of complexity	Usual scale	Innovation stage
☒low	☐on-farm	☐ laboratory/research
☐medium	☒ medium	☐ pilot plant
☐ high complex	☐large scale	☒ industrial/commercial

General diagram



Applied to

☐ Solid pig manure; ☒ Liquid pig manure; ☒Pig slurry; ☐ Pig deep litter;

☐ Solid Cattle manure; ☒Liquid Cattle manure; ☒Cattle slurry; ☐ Cattle deep litter;

☐ Poultry slurry; ☐ Poultry deep litter.

☒ products of other processes. In this case, a possible combinations is:

10A + 17 (see process codes in Annex A)

Pictures

Illustration of Vredo separator (www.vredodanmark.com)

Theoretical fundamentals and process description

Drum sieve: The principle is a drum, where the material is flowing through inside and the liquid is passing through the drum. Eventually the drum can be mounted with a fibre cloth on the outside to optimize the separation. The drum sieve has often lower capacity compared to a centrifuge, but has fairly good separation efficiency in relation to a low investment.

Environmental effects

Effects on air (emissions):

- Performance of some systems implies a high exposition of manure/slurry to atmosphere, and thus, risk of gaseous emissions (COV) and odour problems. Nevertheless, drum filtration, can be considered a closed system, consequently emissions are reduced as compared to other S/L separation techniques.

Effects on water/soil (and management)

- As the other solid/liquid separation techniques, particulate matter is concentrated in the solid fraction while concentrations of soluble compounds are almost uniformly distributed in the two fractions. While phosphorous and organic N are concentrated in the solid fraction, soluble nitrogen, such as ammonia or nitrates, and potassium mass flow rates are higher for the liquid fraction. Solid fractions can be more easily exported to areas with low livestock density, whereas liquid fractions can be used or further processed in situ.

Other effects:-I

Technical indicators

Components conversion/efficiencies

Drum sieve	**Content in solid fraction**			
Capacity (t/h)	N	P	% of total volume	% DM
2-3	20 %	30 – 55 %	25 – 27 %	12 %

Drum separator in general (Nielsen, 2008)

	% DM	**Total N (kg/ton)**	**NH4-N (kg/ton)**	**P (kg/ton)**	**K (kg/ton)**
Untreated slurry	4.9	5.0	3.5	1.0	3.5
Fibre fraction	10.4	5.3	3.5	1.4	3.8
Liquid fraction (reject)	2.9	4.7	3.4	0.8	3.3

Data from Vredo drum separator applied to pig slurry treatment (Nielsen, 2007)

Energy consumption or production: Energy consumption: 1 kWh/m^3 slurry (Nielsen 2007)

Reagents: Drum filtration is often used in combination with chemical flocculation.

Observations: NA

Economical indicators

Investment cost: Basic investment of approx. 25,000 euro at a capacity of 2-3 m^3 slurry/hour

Quantifiable incomes: NA

Non economically quantifiable benefits: Improvement of manure management capacity

Operational costs: Approx. 0.35 euro/m^3 slurry

Selected literature references

- Nielsen, K.J. 2008. Plantekongres 2008. Session G2. Dansk Landbrugsrådgivning, Landscentret.
- Nielsen, K.J. 2007: *Gylleseparation med Vredo gylleseparator*. Farmtest nr. 36 Dansk Landbrugsrådgivning, Landscentret.

Real scale (commercial or pilot) references

NA

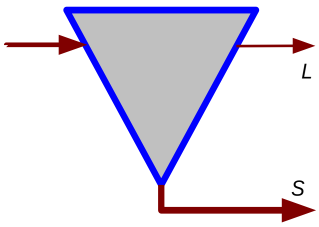
3.10: Natural settling separation

Objectives

Separation of solids from a (semi)liquid stream in two different fractions, one solid and the other liquid by natural settling in a thickener.

Level of complexity	Usual scale	Innovation stage
☒ low	☒on-farm	☐ laboratory/research
☐ medium	☒medium	☐ pilot plant
☐ high complex	☐large scale	☒ industrial/commercial

General diagram



Applied to

☐ Solid pig manure; ☒ Liquid pig manure; ☒ Pig slurry; ☐ Pig deep litter;

☐ Solid Cattle manure; ☒Liquid Cattle manure; ☒Cattle slurry; ☐ Cattle deep litter;

☐ Poultry slurry; ☐ Poultry deep litter.

☒products of other processes. In this case, a possible combinations is:

12-60-18 (see process codes in Annex A)

Pictures

Illustration of a thickener at the pig slurry NDN plant of Calldetenes (Spain)

Theoretical fundamentals and process description

Most thickeners consist of a container that is cylindrical at the top and conical at the bottom. In batch operation, slurry is added to the top of the thickener and the solids settle at the bottom of the conical part from where the solids can be removed. To encourage settling and increase the transfer of solids settled on the upper part of the conical section, small thickeners can be vibrated while, for larger thickeners, this can be achieved by using a rake. Thickeners can also be operated in continuous mode, where slurry is added continuously while solid and liquid phases are removed at the same rate as slurry is added. In this case, the slurry has to be added in the separating zone.

Environmental effects

Effects on air (emissions):

- Performance of some systems implies a high exposition of manure/slurry to atmosphere, and thus, risk of gaseous emissions (COV) and odour problems.

Effects on water/soil (and management)

- As the other solid/liquid separation techniques, particulate matter is concentrated in the solid fraction while concentrations of soluble compounds are almost uniformly distributed in the two fractions. While phosphorous and organic N are concentrated in the solid fraction, soluble nitrogen, such as ammonia or nitrates, and potassium mass flow rates are higher for the liquid fraction. Solid fractions can be more easily exported to areas with low livestock density, whereas liquid fractions can be used or further processed in situ.

Other effects:

Technical indicators

Components conversion/efficiencies:	Energy consumption or production:
Average separation indexes at sedimentation were identified by Hjort *et al.* (2010) as: 22% volume; 56% dry matter; 33% Total-N; 28% NH4-N; 52% Total-P in the solid fraction.	Consumption: 0.0-0.1 kWh/m^3 of input slurry for pumping **Reagents:** NA

Observations: The use of coagulation or flocculation agents may be considered to enhance separation.

Economical indicators

Investment cost:

17,000 € for a thickener volume of 350 m^3 (Levasseur, 2004)

Quantifiable incomes: NA

Non economically quantifiable benefits: Improvement of manure management capacity

Operational costs: NA

Selected literature references

- Converse J.C., Karthikeyan K.G. (2004). Nutrient and solids separation of flushed dairy manure by gravity settling. *Appl. Eng. Agr.* 20, 503-507.
- Hjorth M., Christensen K.V., Christensen M.L., Sommer S.G. (2010). Solid-liquid separation of animal slurry in theory and practice. A review. *Agron. Sust. Devel.* 30, 153-180. DOI: 10.1051/agro/2009010.
- Levasseur P. (2004). Traitement des effluents porcins. *Guide Practique des Procédés*. ITP *(in French)*.

Real scale (commercial or pilot) references

NA

4: ADDITIVES AND OTHER PRE/1ST TREATMENTS

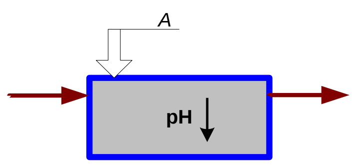
4.1: Acidification of liquid livestock manures

Objectives

The main objective of acidification of liquid manure is to lower the level of pH in the manure, and thereby increase the concentration of ammonium (NH_4^+-N) at the expense of ammonia – which will result in reduced free ammonia emission (NH_3).

Level of complexity	Usual scale	Innovation stage
☐ low	☒ on-farm	☐ laboratory/research
☒ medium	☐ medium	☐ pilot plant
☐ high complex	☐ large scale	☒ industrial/commercial

General diagram



Applied to

☐ Solid pig manure; ☒ Liquid pig manure; ☒ Pig slurry; ☐ Pig deep litter;

☐ Solid Cattle manure; ☒ Liquid Cattle manure; ☒Cattle slurry; ☐ Cattle deep litter;

☐ Poultry slurry; ☐ Poultry deep litter.

☐ products of other processes. In this case, a possible combinations is:

Pictures

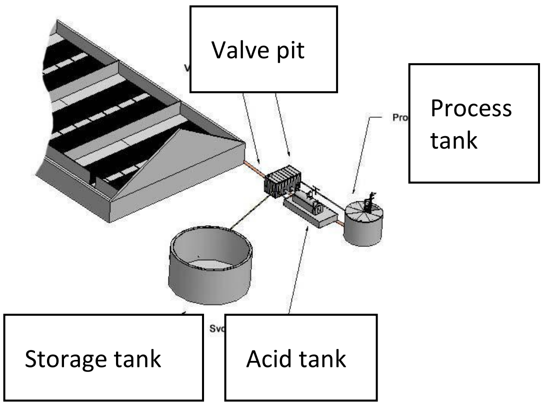


Illustration from In-farm acidification systems (www.infarm.dk)

Theoretical fundamentals and process description

Addition of acid to the slurry leads to a decrease of the slurry pH, whereby the amount of ammonia nitrogen increasingly is transformed into ammonium (NH_4^+) that does not evaporate. By adding 4-6 kg concentrated sulphuric acid (H_2SO_4) per 1,000 kg pig slurry reduces the slurry pH to between pH 5.5 and 6.0.

The acidification unit to treat the slurry, consists of the following main components: valve pit, process tank and acid tank.

When processed, the manure from a number of slurry basins in the stable is pumped to the process tank via the valve pit. In the process tank, sulphuric acid is added so that the slurry pH is decreased to 5.5 (target), during stirring and combined with aeration. After treatment, the main part of the slurry is pumped back to the basins in the stable, while the rest is pumped to the storage tank.

Treatment frequency depends on the slurry pH measured before each treatment, meaning the frequency increases with increasing initial pH. Normally, all the slurry in a herd will be treated 1-3 times daily. All processes are controlled and monitored automatically.

Environmental effects

Effects on air (emissions):

Acidification process can reduce risk of gaseous emissions (COV, CH_4, NH_3) and odour problems.

- A Danish study has shown that frequent adjustment of the pH of pig slurry in a pig house (fattening pigs) with 1/3 drained floor and 2/3 slats reduced ammonia volatilization by 70% (Pedersen, 2004). Acidification of slurry also results in reduced ammonia volatilization from the slurry storage. A single trial (Kai et al., 2008) estimated losses from acidified slurry being less than 20% of the emission from an untreated uncovered storage facility. Ammonia losses during storage of manure are expected to be reduced by 50% compared with untreated slurry with naturally established crust (floating layer). Acidification of slurry reduces ammonia volatilization during and after field application as well. An experiment has shown that the accumulated ammonia measured seven days after application with trailing hoses was about 67 % lower for acidified pig slurry compared to untreated slurry (Kai et al., 2008). A possible effect of adding more acid and thereby lowering pH further will be minimum, because nearly all ammonia will be as ammonium at pH 5.5.
- There have been conducted olfactometric odour measurements for the two trials of acidification of slurry in slaughter houses (Pedersen, 2004 and 2007). The experiments showed no statistically significant effect in terms of odour by acidification. There are examples, that increased odour problems have been discovered locally around the process tank of the acidification unit. Elimination of the problem by mounting a carbon filter at the process tank.
- A laboratory study has shown that emissions of methane from the sulphuric acid treated cattle slurry was 90% lower than the untreated control slurry by measurements over 100 days in a semi-field systems (Petersen and Eriksen, 2008). Another laboratory study showed that emissions of methane from cattle manure stored for seven weeks was 67% lower than the untreated slurry (Hansen, 2008). The experiments provide no basis for clarifying the effect of acidification of slurry, but it can be concluded that acidification has a markedly negative effect on methane production during storage. The effect on methane emissions from pig stables and storage of pig manure is not known but it is expected that there will be a significantly reducing effects due to the ongoing acidification and aeration of the slurry. There are not assumed any net effect of slurry acidification on nitrous oxide emissions. Only through the substitution of nitrogen in commercial fertilizers with saved ammonia volatilization in the field fertilizer level, you can expect a lower nitrous oxide emission (IPCC, 2006).

Effects on water/soil (and management)

- -

Other effects:

- Ammonia is concentrated in the manure/slurry. Consequently, if the target of the adopted treatment is concentrating nutrients in a fertilizing product (as pellets o concentrates obtained in evaporation or drying processes), acidification must be considered as a pre-requisite or pre-treatment for those process combinations.
- The acidic media can inhibit some pathogens or microorganisms growth. The impact of this process on pathogens and microorganisms survival must be evaluated.

Technical indicators

Components conversion/efficiencies

By adding 4-6 kg concentrated sulphuric acid (H_2SO_4) per 1,000 kg the pig slurry pH can be reduced up to pH value of 5.5-6.0.

The acidification process has proven to be able to reduce the ammonia emission from pig houses and slurry storage by 65-70 %.

Energy consumption or production

Pedersen (2004) calculated an increased consumption of approx. 3 kWh/m^3 slurry by using slurry acidification. The calculation is based on runtime and pump power and is therefore subject to some uncertainty. *For the Infarm plant located in Randers (Report 4. Annex B), treating 10000 m3/y, the estimated electricity consumption is 1.8 kWh/m^3*

Reagents

In the process there will be added approximately 4-6 kg concentrated sulphuric acid (H_2SO_4) per 1,000 kg pig slurry. The amount of reagent needed to attain a given pH is linked to the alkalinity of the manure. Treatments such as nitrification or CO_2 stripping may help in reducing such reagent requirements (possible volatilization must be considered).

Observations

Sulphuric acid addition to manure can have negative consequences for the sustainability of some types of concrete because of a sulphate reaction. Recommendations for selection of concrete should be followed. Also sulphuric acid manipulation should be performed under safety protocols.

Economical indicators

Investment cost: There is a basic investment in the range of 100,000 € at farm level (including storage tanks, pumps and controllers) but dependent on farm size and types of stables and other local parameters.

Quantifiable incomes

Acidification of slurry is a technology that reduces ammonia emissions from both stables, storage facilities and at land application. Based on standard figures for manure (2008) it can be estimated that net saving is 17-19 kg NH_3-N volatilization from stables, storage facilities and at application per. animal unit using acidification in pig houses. Acidification of manure means that the content of nitrogen in the manure at storage is 7-13% higher than in normal manure handling. By application with trail hoses of acidified slurry a 20-25% increase in fertilizer effect (bio-availability) is expected (Kai et al., 2008), while the nitrogen effect by injection of acidified slurry is not increased, because of the high nitrogen efficiency already expected from injected slurry (Sørensen and Eriksen, 2009).

Non economically quantifiable benefits: Improvement of manure management capacity **(**economic saving in chemical fertilizers)

Operational costs

	Total annual extra cost (excl. value of N)	Total extra cost per. produced pig incl. value of saved N (Ref. of production cost: 69 euro per produced pig)		Total extra cost per. kg N reduced incl. value of saved N
Animal units*	Euro	Euro	%	Euro
75	20,130	6.8	10	14.4
150	22,300	3.4	5	7.5
250	24,600	2.1	3	4.4
500	33,000	1.2	2	2.5
750	41,600	0.8	1	2.0

950	48,100	0.7	1	1.6

*1 animal unit = 36 produced slaughter pigs from 32 to 107 kg

(Reference: Technology Sheet: *Acidification of slurry* (2011), Environmental protection Agency, Danish Ministry of the Environment**)**

For the Infarm plant located in Randers (Report 4. Annex B), treating 10000 m3/y the estimated operational costs are:

	Euro/m^3
Energy consumption	0.17
Acid consumption	0.72
Maintenance and service contract	0.29
Total costs	1.18

Selected literature references

- Technology Sheet: *Acidification of slurry* (2011), Environmental protection Agency, Danish Ministry of the Environment.
- IPCC (2006): IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4 Agriculture, Forestry and Other Land Use.
- Kai, P., Pedersen, P., Jensen, J.E., Hansen, M.N., and Sommer, S.G. (2008): A whole-farm assessment of the efficacy of slurry acidification in reducing ammonia emissions. Eur. J. Agron. 28:148-154.
- Pedersen, P. (2004): Svovlsyrebehandling af gylle i slagtesvinestald med drænet gulv. Meddelelse nr. 683, Landsudvalget for Svin, pp. 12.
- Pedersen, P. (2007): Tilsætning af brintoverilte til forsuret gylle i slagtesvinestald med drænet gulv. Meddelelse nr. 792 fra Dansk Svineproduktion, Den rullende Afprøvning, pp. 14.
- Petersen og Eriksen (2008): Acidic slurry more climate-friendly. www.agrsci.dk.
- Sørensen, P, og J. Eriksen (2009): Effects of slurry acidification with sulfuric acid combined with aeration on the turnover and plant availability of nitrogen. Agriculture, Ecosystems and Environment 131, 240-246.

Real scale (commercial or pilot) references

- Pigfarmer, Mr. Mogens Sommer Jensen
Amstrupgårdsvej 40
8940 Randers SV
Tel. +45 86 44 71 59
Mob +45 2191 3575

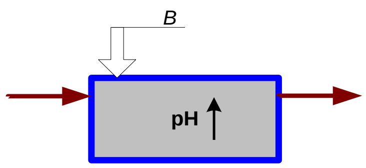
4.2: pH increasing (liming)

Objectives

To stabilize manure and reduce the contents on pathogens. Liming is also applied to increase the pH in view of the application of other treatment processes such as N-stripping or nutrient precipitation.

Level of complexity	Usual scale	Innovation stage
☐ low	☐ on-farm	☐ laboratory/research
☒ medium	☒ medium	☐ pilot plant
☐ high complex	☒ large scale	☒ industrial/commercial

General diagram



Applied to

☒ Solid pig manure; ☒ Liquid pig manure; ☐ Pig slurry; ☐ Pig deep litter;

☒ Solid Cattle manure; ☒ Liquid Cattle manure; ☐Cattle slurry; ☐ Cattle deep litter;

☐ Poultry slurry; ☐ Poultry deep litter.

☒ Products of other processes. In this case, a possible combination is:

14-60-22 (for subsequent calcium phosphate precipitation 62B) (see process codes in Annex A)

Pictures

Illustration of liming for phosphorous removal in Tyndall Farm (North Carolina, USA)

Theoretical fundamentals and process description

Slaked lime ($Ca(OH)_2$) is usually added to liquid streams in order to favour posterior treatments such as N-stripping or nutrient precipitation. When it is considered, a thorough mixing with liquid manures is needed. Buffering capacity of the system will determine lime requirements needed to regulate the pH, being highly dependent on the total content of inorganic carbon and the equilibrium HCO_3^-/CO_2. Reduction of such requirements may be achieved by removing CO_2 from the system by stripping or nitrification.

Quicklime (CaO) is normally used for the solidifying of dewatered materials. By mixing CaO with solid materials, the temperature rises exothermically to between 55ºC and 70ºC. Temperature and pH increase has a detrimental effect on the viability of pathogens. The reactive lime used in the process is serving as a source of energy for the drying, as a sterilizing agent for all bacteria and viruses (pathogens) present in the manure, and as a liming agent changing soil pH.

Environmental effects

Effects on air (emissions):

- If such process is not well controlled then it may result in an undesired volatilization of ammonia.

Effects on water/soil (and management)

- The increase of pH is a conditioning process applied when planning P-recovery by precipitation or N-recovery by stripping. Obtained products can enhance the capability of manure/slurry management. Solid fractions (struvite) or liquid by-products (ammonia salts) can be more easily exported to areas with low livestock density, reducing problems derived from nutrient surplus, whereas liquid fractions can be used or further processed in situ.,

Other effects:

- Temperature and pH increase has a detrimental effect on the viability of pathogens

Technical indicators

Components conversion/efficiencies	**Energy consumption or production**
NA	~ 0.4 kWh/m^3 of input slurry (Vanotti *et al.*, 2009)
	Reagents Lime unslaked (quicklime, calcium oxide, CaO) Lime slaked (calcium hydroxide, $Ca(OH)_2$) The amount of reagent needed to attain a given pH is linked to the alkalinity of the manure. Treatments such as nitrification or CO_2 stripping may help in reducing such reagent requirements.

Observations: Recommendations for selection of concrete should be followed. Also lime manipulation should be performed under safety protocols.

Economical indicators

Investment cost: NA

Quantifiable incomes: NA

Non economically quantifiable benefits:Hygienization is favoured by increasing pH. Combined with a nitrification-denitrification stage, the addition of $Ca(OH)_2$ to the treated effluent (pH 9.5) has been reported to result in an increase in the reduction of the number of pathogens from 2.6-log units to 4-log units (Vanotti *et al.*, 2009).

Operational costs: NA

Selected literature references

- Szogi A.A., Vanotti M.B. (2009). Removal of phosphorus from livestock effluents. *J. Environ. Qual.* 38, 576-586. DOI:10.2134/jeq2007.0641.
- Vanotti M.B., Szogi A.A., Millner P.D., Loughrin, J.H. (2009). Development of a second-generation environmentally superior technology for treatment of swine manure in the USA. *Bioresour. Technol.* 100, 5406-5416. DOI:10.1016/j.biortech.2009.02.019.

Real scale (commercial or pilot) references

- Tyndall farm

  Sampson Co., NC, USA

  Super Soil Systems

4.3: Temperature and pressure treatment

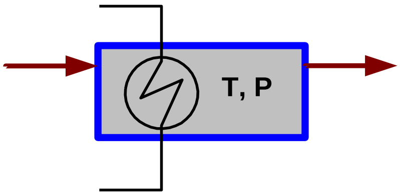
Objectives

The temperature and temperature/pressure pre-treatment have several objectives:

- Slurry/manure or other organic substrate hygienization
- To release or to increase bioavailability of the organic fraction contained in a waste, to improve a subsequent biological treatment (i.e. biogas production). The more affected fractions are the soluble organic, increased by particles disintegration, fibres or other slowly biodegradable fractions.
- To fit specific hygienic or veterinarian requirements as for example EU's Animal by-products regulations (Regulation 1069/2009 and its implementing regulation 142/2011)

Level of complexity	Usual scale	Innovation stage
☐ low	☐on-farm	☐ laboratory/research
☐ medium	☐ medium	☐ pilot plant
☒ high complex	☒ large scale	☒ industrial/commercial

General diagram



Applied to

☒ Solid pig manure; ☐Liquid pig manure; ☐ Pig slurry; ☐ Pig deep litter;

☒ Solid Cattle manure; ☐Liquid Cattle manure; ☒Cattle slurry; ☐ Cattle deep litter;

☐ Poultry slurry; ☐ Poultry deep litter.

☒ products of other processes. In this case, a possible combinations is:

Applied to anaerobic digestion co-substrates and/or anaerobic digestion products for sanitation purposes

Pictures

Lab equipment for T/P treatment (left) at GIRO (Spain) and integrated pasteurization unit (right) post-anaerobic digestion at Lemvig (Denmark)

Theoretical fundamentals and process description

The exposition to high temperature inactive microorganisms and enhance disintegration/hydrolysis of complex organic matter. The obtained effect is a function of temperature/time, and the disintegration can be improved by pressure or reagents (acid or base) addition. The subsequent biodegradability in an anerobic digestion process is also dependent of raw substrate characteristics. For pig slurry temperature (80ºC) pre-treatment, significant biogas increase was obtained with just produced and not previously stored manure (Bonmatí et al., 2001). For slaughterhouse solid waste, effects of pasteurization and sterilization on biogas production increase depends on the relative composition in proteins and carbohydrates (Rodríguez-Abalde at al., 2011). In the case of animal-by products treatment, depending on the by-product category (Cat. 1, 2 or 3) the EU specifications (CE No 142/2011) are:

Method	Methods specifications						Category		
	Size reduction (mm)	Temperature (ºC)	Time (min/h)	Pressure (bars)	Reagents	Other specifications	1	2	3
M1(pressure sterilization)	50 mm	133ºC	20min	3 bar		Batch or continuous			√
M2	150 mm	>100ºC	125min			Batch	√	√	√
M3	30 mm	>100ºC	95min			Batch or continuous	√	√	√
M4	30 mm	>100ºC	16min			Batch or continuous	√	√	√
M5	20 mm	>80ºC	120min			Batch or continuous	√	√	√
M6	50 mm	90ºC	24h		Acid pH<4.	Batch or cotinuous.			√
M7						Any other treatment that ensure a reported reduction *in Clostridium perfringens, Salmonella* or *Enterobacteriaceae*			√
Alternative methods									
Alkaline hydrolysis		150ºC	4 to 6h	4 bar	NaOH/KOH	Molar equivalency to the weight	√	√	√
High pressure/High temperature hydrolysis		180ºC	40 min	12 bar		Batch		√	√
High pressure hydrolysis Biogas production		220ºC	20 min	25 bar		Previously is needed M1. Batch or continuous. In Cat 1 material biogas must be combusted at 900 °C.	√	√	√
Biodiesel production process		72ºC 35 °C to 50 °C	2h		Acid pH<1. NaOH pH>14	Applied only to fat fraction. Esterification+TransesterificationPreviously M1 is needed.	√	√	√
Brookes' gasification process		950 °C	>2 s					√	√
Combustion		850-1.100ºC	15 min				√	√	√
Thermo-chemical biofuel production	<20 mm	100 ºC	2h						√

Environmental effects

Effects on air (emissions):

- Ammonia and volatiles can be discharged with the exhaust air and have to be collected and treated to prevent air pollution, using condensers or scrubbers (it must be considered in the operational cost)

Effects on water/soil (and management)

- Temperature, pressure or chemical introduction have a detrimental effect on the viability of pathogens, and allows the possibility of land application

Other effects:

- As a standalone treatment this form of treatment cannot be recommended (high energy consumption) but can be beneficial in some cases in combination with biogas plants. The treatment will, in case it is applied to plant fibres, make the anaerobic treatment more efficient because it opens the cell structures so the anaerobic bacteria can digest the substrate more efficiently. It is claimed that the biogas production in this way can be increased with 20- 60%.

Technical indicators

Components conversion/efficiencies

Can be measured as a soluble COD increase and pathogen inactivation, function of time/temperature/pressure. This effect is highly dependent on substrate characteristics (see listed references)

Energy consumption or production
It is function of time/temperature requirements. NA.

Reagents

It has been also used with added chemicals (NaOH) to produce the saponification of lipids (insoluble compounds) increasing the bio-availability and biodegradability rate of those components. The reagent consumption is usually a molar equivalency to the weight.

Observations

- The requirements of constructive materials (resistance to high temperature and pressure) will increase plant cost.
- Risk of accidents and requirement of workers training to work with high pressure and temperature equipments.
- The process design is not easy in continuous operation mode.

Economical indicators

Investment cost: NA

Quantifiable incomes: Related to biogas production, there is an increase due to increase on solubility and bioavailability of the substrate, depending of the ratio carbohydrates/proteins, when this technology is used as a pre-treatment to anaerobic digestion.

Non economically quantifiable benefits: Pathogens destruction and higienization

Operational costs: NA

Selected literature references

- Bonmatí, A., Flotats, X., Mateu, L., Campos, E. (2001). Study of thermal hydrolysis as a pretreatment to mesophilic anaerobic digestion of pig slurry. Water Science and Technology. 44(4): 109-116.
- COMMISSION REGULATION (EU) No 142/2011 of 25 February 2011 Implementing Regulation (EC) No 1069/2009 of the European Parliament and of the Council laying down health rules as regards animal by-products and derived products not intended for human consumption and implementing Council Directive 97/78/EC as regards certain samples and items exempt from veterinary checks at the border under that Directive.
- Ferrer, I., Palatsi, J., Campos, E., Flotats, X. (2010). Mesophilic and thermophilic anaerobic biodegradability of water hyacinth pre-treated at 80ºC. Waste Management 30(10): 1763-1767. DOI: http://dx.doi.org/10.1016/j.wasman.2009.09.020)
- Rodríguez-Abalde, A., Fernández, B., Silvestre, G., Flotats, X. (2011). Effects of thermal pre-treatments on solid slaughterhouse waste methane potential. Waste Management , 31(7): 1488–1493. DOI: http://dx.doi.org/10.1016/j.wasman.2011.02.014)

Real scale (commercial or pilot) references
NA

4.4: Applying other additives to manure

Objectives

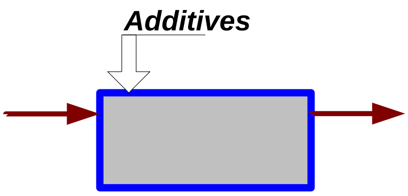
Under the generic denomination of manure additives are a group of products made up of different compounds that interact with the manure, changing its characteristics and properties. These products are applied to the manure in the pits or the storage tank, and the following effects are described to different degrees in the label of every product:

1. Reduction in the emission of several gaseous compounds (NH_3 and H_2S).
2. Reduction of unpleasant odours.
3. Change in the physical properties of the manure to improve its handling.
4. Increase in the fertilizing value of the manure.
5. Stabilization of pathogen micro-organisms.

Further description below.

Level of complexity	Usual scale	Innovation stage
☒ low	☒ on-farm	☐ laboratory/research
☐ medium	☒medium	☐ pilot plant
☐ high complex	☐ large scale	☒ industrial/commercial

General diagram



Applied to

☐ Solid pig manure; ☒ Liquid pig manure; ☒Pig slurry; ☐ Pig deep litter;

☐ Solid Cattle manure; ☒Liquid Cattle manure; ☒Cattle slurry; ☐ Cattle deep litter;

☐ Poultry slurry; ☐ Poultry deep litter.

☐ products of other processes. In this case, a possible combination is:

Pictures

Illustration NA

Theoretical fundamentals and process description

Usually, the effects 2 and 3 are the main reasons for the use of additives at farm level. The effects of the various additives are detailed as follows:

1. Additives for reducing the emission of several gaseous compounds: The decrease in gaseous emissions achieved through its use (mainly $NH_3$and H_2S) is one of the most interesting points. It has been well documented that up to 90 % of the N produced by the pigs is as urea. When the urease produced by faecal micro-organisms comes into contact with urea, the following reaction occurs:

   $CO(NH_2)_2 + 3\ H_2O \Rightarrow 2\ NH_4 + HCO_3 + OH$

   This reaction is highly influenced by temperature and pH, for example, under 10 °C or at a pH below 6.5 the reaction stops. Additives stop the reaction by reducing the pH.

2. Additives for reducing unpleasant odours: Odour results from the mix of different compounds under anaerobic conditions. More than 200 substances involved have been identified, such as:

   - volatile fatty acids
   - alcohols (indol, skatole, p-cresol, etc)
   - H_2S and derivatives
   - ammonia
   - other N compounds (amines and mercaptans).

   There is a huge variation in the proportion and concentration of every substance depending on the type of farm, nutrition and nutritional management, and climatic conditions. This could explain why in many instances the effectiveness of these compounds, such as ozone or iron sulphate, against odours could not be proven under farm conditions.

3. Additives for changing the physical properties of the manure: The objective of the additive is to make the manure easier to handle. These additives are probably the most used and their effects are well known. Their use results in an increase in manure flowing, an elimination of superficial crusts, a reduction of solved and suspended solids and a reduction in the stratification of the manure. However, these effects were not always demonstrated.

   Their application might make the cleaning of the manure pits easier, and thereby might shorten the cleaning time required and allow a saving in water and energy consumption. Moreover, since the manure is more homogeneous, it eases the manure's agricultural use (better dosing).

4. Additives for increasing the fertilising value of the manure: This effect is in fact derived from the reduction in NH3 emissions, thereby keeping this N retained in the manure (in many cases through the increased synthesis of the microbial cells, giving higher levels of organic N).

5. Additives for stabilising pathogens micro-organisms: There are many different microorganisms in manure, part of these contribute to the gaseous emissions and odours. It is also possible to find faecal coli forms and Salmonella and other pig pathogens, virus, eggs of flies and nematodes in the manure.

   Usually, the longer the storage period the higher the decrease in pathogens, because of the different requirements of temperature and pH. The pH decreases within the first month of storage (from 7.5 to 6.5 because the microbial synthesis of volatile fatty acids) which has a negative effect on pathogens survival. Some of the manure additives have been designed to control them, especially the eggs of flies.

The most common types of manure additives are as follows:

- Masking and neutralising agents: These are a mix of aromatic compounds (heliotropin, vanillin) that work by masking the manure odour. The agent is easily destroyed by manure microorganisms. Its actual efficacy is questionable.
- Adsorbers: There are a large number of substances that have demonstrated an ability to absorb ammonia. Some types of zeolites called clinoptilolites have shown the best effect on ammonia emission reduction, being added either to the manure or to feed. They are also able to improve soil structure and have the added benefit that they are not toxic or hazardous. Peat gives similar results and is also sometimes used.
- Urease inhibitors: These compounds stop the reaction described earlier preventing urea from being

transformed into ammonia. There are three main types of urease inhibitor:

a. phosphoramides: applied directly to the soil. Show a good effect. They work better in acid soils, but could affect soil micro-organisms

b. yucca extracts (*Y. schidigera*): many trials have been done to assess its potential but the available information is controversial, showing good results in some cases, but no effect at all in other cases

c. straw: considered as an adsorbant in many references. However besides the absorbing effect, it also increases the C:N ratio. Its use is controversial because in many other works it shows an increase in ammonia emissions.

- pH regulators: there are two main types:

  a. acid regulators: see acidification at 4.1 and pH increasing at 4.2

  b. Ca and Mg salts: these salts interact with manure carbonate, decreasing the pH. They could increase the fertilising value of the manure but could also increase the salinity of the soil (chlorides). They are used sometimes, but mainly in combination with other additives.

- Oxidising agents: Their effects are through:

  - oxidation of the odour compounds
  - providing oxygen to aerobic bacteria
  - inactivating the anaerobic bacteria that generate odorous compounds.

  The most active are strong oxidising agents such as hydrogen peroxide, potassium permanganate or sodium hypochloride. They are hazardous and not recommended for farm use.

  Some of them (formaldehyde) could be carcinogens. Ozone application has demonstrated its efficacy but operational costs are very high.

- Flocculants: are mineral compounds (ferric or ferrous chloride and others) or organic polymers. P is highly decreased but their use generates waste that is difficult to manage (see also above)

- Disinfectants and antimicrobials: chemical compounds that inhibit the activity of the microorganisms involved in odour generation. They are expensive to use and with sustained use an increase in dosing is needed because of habituation processes

- Biological agents: these can be divided into:

  a. enzymes: their use is to liquefy solids. They are not hazardous. The actual effect depends strongly on the type of enzyme, the substrate and a proper mixing bacteria:

     a. Exogenous strains: they have to compete with natural strains which makes getting good results more difficult. Their use is better in anaerobic pits or lagoons to reduce the organic matter producing CH4 (sowing of methanogens bacteria is more efficient and sensitive to pH and temperature). High effectiveness but frequent re-sowing has to be carried out

     b. promote natural strains: this is based on adding carbonate substrates (increased C:N ratio). Its effect is based on the use of ammonia as a nutrient, but they need a sufficient source of C to develop an efficient synthesis process, changing ammonia on the organic N of cell tissue. Re-sowing has to be carried out too, to avoid reverting to the starting point. They are not hazardous and no significant cross-media effects have been reported.

Overall effectiveness of manure additives and farm use:

Nowadays there are many manure additives in the market, but the effectiveness has not been demonstrated in every case. One of the main problems is the lack of standard techniques to test and analyze the results. Another problem with their use is that many trials have only been developed under experimental conditions in laboratories and not on-farm, where big variations in nutrition, management of nutrition, pH and temperature can be found. Besides this, there is also sometimes a huge volume of manure to be mixed with the additive in a pit or lagoon, and the results achieved often depend a lot more on the mixing efficiency than on the lack of effectiveness of the additive. Improving the flow characteristics seems to be strongly related with a good mixing.

The effectiveness of every compound is highly dependent on the correct dosing, right timing and a good mixing. In some cases a small effect has been observed of an increase in the fertilizing value, but this effect is related to the type of crop, the time of application and dosing.

It has to be highlighted that in many cases the effects on human or animal health or other environmental effects by using additives are not known and this, of course, limits their applicability.

Environmental effects

Effects on air (emissions):

- Ammonia emissions are reduced: Some additives, such as acids (phosphoric, hydrochloric and sulphuric) have good documentation for high effects on reducing ammonia emissions, due to lowering pH. Other additives, such as Ca and Mg salts, also lower pH due to their interaction with manure carbonate.

Effects on water/soil (and management)

- The effects on N leaching are related to the reduced ammonia emissions and to the better utilization of other N compounds. Less emission of ammonia means that less N could return as atmospheric deposition and that more N is re-circulated in the agricultural production rather than ending in the environment, under the assumption of good management.
- The effect on P leaching is associated with the use of additives in processes to separate the manure in fractions, allowing the solid fraction with a high content of P to be exported to areas with a low livestock density.

Other effects:

- Pathogen reduction and hygienisation

Technical indicators

Components conversion/efficiencies

In general for all mentioned additives, the documented effects by scientific trials or similar are very poor. Often, companies behind can only show own-made documentation, which makes difficult to get valid data for evaluation of effects and costs. Grønkjær Hansen at al. (2008) states that:

- In an American study were tested 35 slurry additives including biological stimulants. The study did not show a significant reduction of odour emissions. Some of these additives gave a limited reduction of ammonia (under 15%) while others appeared to reduce hydrogen sulphide emissions. A product of Alkan Clean-Flo based on specially Adapted microorganisms distinguished by reducing hydrogen sulfide emissions by 47% (Heber et al, 2001).
- Terra Biosa from Biosa Denmark Aps consists of a variety of herbs that are fermented by lactic acid bacteria culture. This product is the same as Siolit Plus has been tested in laboratory experiments on pig manure. They found no effect on either the odour of hydrogen sulphide or ammonia emissions with the addition of Terra Biosa.

Energy consumption or production: NA

Reagents: No valid data available.

Observations: NA

Economical indicators
Investment cost: No valid data available, however, normally there are only marginal investment costs, if any.
Quantifiable incomes: NA
Non economically quantifiable benefits: NA
Operational costs No valid data available, however, the operational costs are typically equal to the price of the additive, wherefore it is easy to calculate in the individual case.

Selected literature references

- European Commission. Reference Document on Best Available Techniques for Intensive Rearing of Poultry and Pigs. July 2003. 383 pp.
- Foged, Henning Lyngsø. 2010. Best Available Technologies for Manure Treatment – for Intensive Rearing of Pigs in Baltic Sea Region EU Member States. Published by Baltic Sea 2020, Stockholm. 102 pp
- Grønkjær Hansen, Arne, et al. 2008. Forarbejde til Teknologiudvalget. Miljøstyrelsen. 75 pp.
- Schelde, Karl Martin (2011): personal information, Agro Business Park, DK 8830 Tjele

Real scale (commercial or pilot) references

NA

5: ANAEROBIC TREATMENT

5.1: Mesophilic / thermophilic anaerobic digestion

Objectives

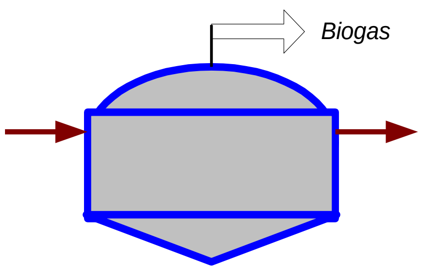
The main objective of anaerobic digestion of liquid livestock manure is to produce renewable energy (bio-methane) via biological degradation of organic matter. Other important effects include the reduction of emissions of ammonia after digestate spreading, methane and nitrous oxide, reduced odour and nuisances, increased bio-availability of nitrogen, and sanitation.

Mesophilic plants operate at temperature levels of approximately 37°C, with up to 2°C variation, while thermophilic plants operate at temperature levels of approximately 52°C, but with accepted temperature variation of only ½°C.

Mesophilic plants are therefore easier to run, and most farm scale plants and many regional plants are mesophilic. The advantages of thermophilic plants are a higher contribution to hygienization and to lower viscosity during the process, facilitating mixing.

Level of complexity	Usual scale	Innovation stage
☐ low	☒ on-farm	☐ laboratory/research
☒ medium	☒ medium	☐ pilot plant
☐ high complex	☒ large scale	☒ industrial/commercial

General diagram



Applied to

☐ Solid pig manure; ☒ Liquid pig manure; ☒Pig slurry; ☐ Pig deep litter;

☐ Solid Cattle manure; ☒Liquid Cattle manure; ☒Cattle slurry; ☐ Cattle deep litter;

☐ Poultry slurry; ☐ Poultry deep litter.

☐ products of other processes. In this case, a possible combinations is:

Pictures

Illustration from Morsø Bioenergi, Denmark. (http://www.bigadan.dk/da/cases/biogas-cases/page/morsoe-bioenergi)

Theoretical fundamentals and process description

Anaerobic digestion is a biological decomposition process following several steps (disintegration, hydrolysis, acidogenesis, acetogenesis, methanogenesis) and with a final conversion of organic matter to biogas, which typically has a methane content of 60-65%. Usual digesters (reactors where the process is controlled) operates with a maximal dry matter content of 12.5% , and at constant temperature of 30-45°C (mesophile) or 55°C (thermophile). The hydraulic retention time is normally from 15-40 days, and the process happens in one or two stages/reactors, where the first is intended to maximize hydrolysis process and the second the methanogenesis process, giving a slightly higher biogas production in the second. Propellers are normally installed in the digestion tanks to ensure the digestate remains homogenous and gives a maximal release of biogas. The biogas production depend much of the type of biomass.

Typically 15% (mesophile process) to 25% (thermophile process) of the energy production from a biogas plant is used to heat up the digester. About 3-4% of the energy is used as electricity consumption for pumping, mixing, transport and other. The remaining energy production can be used for farm purposes or sold.

The regional plants also serve as centres for re-distribution of manure in the region. Both at centralized scale or on-farm scale, often a co-substrate is required to increase biogas production, being easier to manage at large scale. Many examples can be found in Germany, Denmark or Sweden.

Anaerobic digestion does not change the overall N/P ratio, and it has only effect on the N availability.

Environmental effects

Effects on air (emissions):

- The biogas process contributes positively to the reduction of greenhouse gas emissions in two ways: decreasing methane natural emissions to the atmosphere and decreasing fossil fuels consumption if this is substituted by biogas. Calculations show that the CO_2 neutral energy produced by the biogas process saves 2 kg CO_2-eqv per m3 biogas, if it replaces fossil fuels.
- Furthermore model calculations show a reduction of naturally developed greenhouse gases (methane and nitrous oxide) of approx. 1.2 kg CO_2-eqv per m3 biogas. So, all in all a potential of 3.2 kg CO2-eqv reduction in greenhouse gases/ m^3 biogas.
- A number of odour compounds in the slurry are broken down in the biogas process, but others are formed in their place. The number of odour units (OU) is therefore often just as high above digested slurry as it is above untreated slurry. There is, nevertheless, a marked difference when the slurry is applied. The odour is not as strong and pungent from digested slurry as from raw slurry, and it also disappears faster from a fertilised field, partly because the digested slurry percolates faster into the soil due to its lower DM content, lower particles size and viscosity.

Effects on water/soil (and management)

- The digestate is more homogenous, e.g. less lumpy, nutrients more evenly spread out, making the digestate easier to seep evenly into the crop root area, enabling better nutrient uptake from field crop
- Anaerobic digestion does not change the overall N/P ratio, and it has only effect on the N availability.

Field trials performed by Danish Agricultural Advisory Service have proven 17-30% higher field effect (bio-availability) of nitrogen in digested slurry, compared to non-digested slurry; the increase of the field effect is higher for cattle slurry than for pig slurry.

Other effects:

- Pathogen reduction and higienization (higher in thermophilic range).

Technical indicators

Components conversion/efficiencies

Calculations for Danish biogas plants shows that these plants in average produces 22 m3 biogas per tonnes of slurry (containing in average 6 % DM)

The anaerobic digestion process converts the main part of the organic bounded nitrogen into ammonium, and thereby the concentration of ammonium in digested slurry is increased up to 20 % compared to undigested slurry.

The digestate is more homogenous, e.g. less lumpy, nutrients more evenly spread out, making the digestate easier to seep evenly into the crop root area, enabling better nutrient uptake from crops.

Energy consumption or production

Biogas heat and power production:

Power production*: 2.5 kWh per m3 biogas

Heat production*: 2.0 kWh per m3 biogas

*left after own use of heat and power in the process

Reagents

Often no reagents are used for biogas production. Possible reagents/additives are described under process 4.4 (num. 24).

Observations: -

Economical indicators

Investment cost

There are different ways to estimate the investment costs.

Flotats and Sarquella (2008) propose to use the following equation for the estimation of investment costs for biogas plants, where the biogas is converted to electricity:

$$Unitary\ Investment\ [€/kW] = 16272 * (Electrical\ \ power\ [kW])^{-0.2114}$$

The equation shows good correlation to investment prices, and the economy of scale.

Foged (2010) proposed using the formula:

Investment cost, € = 75,000 € + 50 €/ton annual capacity

This equation also express an economy of scale, and is independent of the use of the biogas. The equation may be most applicable for plant sizes up to medium-size regional plants.

Gregersen (2002) has made, on basis of regional plants in Denmark, working under co-digestion conditions, the following indications of investment sizes and operational costs:

	Size of plant		
Capacity/day	300 m^3	550 m^3	800 m^3
Capacity/year	109,500 m^3	200,750 m^3	292,000 m^3
Total investment, mill. euro	5.9	8.4	10.5
Investment, euro/m3 treated biomass/year	54	43	36
Operational costs, euro/m3			
Gas production:	2.1	2.1	2.4
Transport:	7	5.5	4.7
Total:	9.1	7.6	7.1

Quantifiable incomes

Rosager (2010) indicates the following tariffs for biogas-based electricity production in a number of European countries:

	Type	Tariff €c/kWh	Dura-tion years	Grant	Biomasses	Market status 2010
Denmark	Feed-in	**10-12**	?	Short time 20% 2011	M+IW	Awaiting
Germany	Feed-in	**10-20 <500 kW N-gas I**	20		E+M+AW	Still growing f
Austria	Feed-in	**14-18**	10	-	E+M	Growing slowly
Netherlands	Certificate 2007 + feed-in 2008	**16-18 12**	10	Tax deduction 140%	M+IW+SW+E	Stopped
Belgium	Certificate + feed-in	**18-22**	10	-	M+IW+SW	Nearly stopped
Italy	Green certificate	**27>1 MW**	15	-	E+M	Fast growing
UK	Certificate + feed-in from 2011	**16**	1 15	Short time 30%	SW+HW+AW+ M+E	Growing
France	Feed-in	**11-14**	15	Feasibility 50% Investment 10%	M+AW+SW	Awaiting
Poland	Certificate	**9-12**	-	0-40%	IW+M+SW+?	Starting to grow
Greece	Feed-in	**20-25**	10	-	IW+M+E	Starting to grow
Spain	Feed-in	**12-16**	15	-	M+?	Growing very slowly

M=Manure+deep litter, SW=Super market waste, IW=Industrial waste, HW=Household waste, E=Energy crops

Non economically quantifiable benefits

- Reduction of odour and nuisances, especially during spreading of the digestate as fertiliser on the fields.
- Sanitation of the slurry.

Operational costs

See above

Selected literature references

- Flotats and Sarquella (2008). Producció de biogàs per codigestió anaeròbia. Quadern pràctic núm. 1. ICAEN, Spain (www.icaen.net).
- Foged, Henning Lyngsø (2010). Best Available Technologies for Manure Treatment – for Intensive Rearing of Pigs in Baltic Sea Region EU Member States. Published by Baltic Sea 2020, Stockholm. 102 pp
- Jørgensen, Peter Jacob (2009): *Biogas – green energy*, PlanEnergi and Researcher for a Day – Faculty of Agricultural Sciences, Aarhus University, 2nd edition.
- Hjorth-Gregersen, Kurt (2002): *Status for økonomien i biogasfællesanlæg*, abstract from report 136, Institute of Food and Resource Economics, Faculty of Life Sciences, University of Copenhagen, DK
- Rosager, Frank (2010). Etablering af biogasanlæg I udlandet. PowerPoint. Energinet.dk biogas seminar 8. september 2010.

Real scale (commercial or pilot) references

Many plants treating manure across Europe. As example:

- Morsø Bioenergi
  Næssundvej 234
  7970 Redsted Mors

6: TREATMENT OF THE FIBRE/SOLID FRACTION

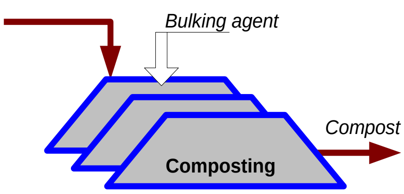
6.1: Composting of solid livestock manure or fibre fractions of slurries

Objectives

The main objective is to obtain a stable product with low moisture content and most of the initial nutrients, free of pathogens and seeds, called compost. The significant reduction of mass (water evaporation) reduces substantially transport costs.

Level of complexity	Usual scale	Innovation stage
☒ low	☒ on-farm	☐ laboratory/research
☒ medium	☒ medium	☐ pilot plant
☐ high complex	☒ large scale	☒ industrial/commercial

General diagram



Applied to

☒ Solid pig manure; ☐Liquid pig manure; ☐ Pig slurry; ☒ Pig deep litter;

☒ Solid Cattle manure; ☐ Liquid Cattle manure; ☐Cattle slurry; ☒ Cattle deep litter;

☐ Poultry slurry; ☒ Poultry deep litter.

☒ products of other processes. In this case, a possible combinations is:

24 (addition of bulking agent) + 41 // (10-18, solid fraction from separation unit) + 24 + 41 //

(30-31)+ (10-18) + 24 + 41 (see Annex A)

Liquid manures can be composted if enough bulking agent is added in order to obtain a solid mixture.

Pictures

Illustration of on farm composting (first to third columns) and centralized composting of solid cattle manure, Juncosa, Spain (fourth column)

Theoretical fundamentals and process description

Compost is obtained through a thermophilic aerobic degradation process of the organic matter, followed by a curing phase where temperature slowly decreases and complex organic macromolecules are produced (fulvic and humic acids).

In the first stage (decomposition), exothermic reactions produce an increase of temperature of the composting matrix above 50ºC (55-70ºC). Aerobic conditions must be assured in order to enable the reaction. Mechanical turning of the piles, as well as forced aeration are commonly used. The high temperatures, together with aeration, leads to a high rate of water evaporation. Water must be provided and maintained to a certain level to avoid microbes inhibition. In a second stage, curing is produced. Complex organic matter is degraded and humic and fulvic acids are produced. Temperature slowly decreases till room temperature. The whole process lasted between 8 to 16 weeks.

Adequate initial conditions of the composting matrix: Moisture content: 40-65%, C/N ratio: 25-35. Porosity (AFP: Air Filled Porosity): 30-60%.

Solid manures usually need the addition of bulking agent (e.g. well-chopped straw) in order to have appropriate C/N ratio, structure and porosity. When applied to slurries a previous mechanical separation is necessary,

Composting of liquid manures requires abundant bulking agent, in order to absorb the water and reach an adequate C/N ratio.

Environmental effects

Effects on air (emissions):

- Possible emissions of NH_3, COVs and CH_4
- CH_4 is produced when the composting matrix has anaerobic zones
- The use of close systems (tunnels), or semi-permeable membranes, as well as efficient aeration, can reduce emissions.

Expected emissions	**CH_4- C**	**N_2O-N**
g/kg VS degraded	8.1 - 13	0.047 - 0.176
CO_2-Eq (g/kg VS degraded)	271 - 418	22 - 83

Effects on water/soil (and management)

- Production of an organic fertilizer (compost) with part of the original nitrogen and most of the P, K, etc. Its application to soil makes nutrients recycling possible to soil and field crops. When the system is open, up to 30-50% N is lost during composting of pig manure and straw

Other effects:

- Organic matter stabilization, pathogens and seeds removal, and odour abatement (during the thermophilic phase)

Technical indicators

Components conversion/efficiencies

- Volume and weigh reduction: 40-50%
- Conversion of ammonia to NO_3 and organic nitrogen (40 – 70%)
- Concentration of nutrients and heavy metals (due to water evaporation)
- Organic matter stabilization, pathogens and seeds removal, and odour abatement.

Energy consumption or production

The guidance consumptions of the possible machineries used in a composting plant are:

	Energy consumption (KWh_{el}/t)
Trommel	3.0
Magnet separator	0.5
Shredding and crushing	2.6
Container composting (11 days)	10
Waste gas purification of 11 days intensive composting	8.1
Conversion of the secondary maturing stage windrows in door composting, every 14 days for 8 weeks	10
Waste gas purification (8 weeks)	19.3

Reagents

- Bulking agent in different proportions
- Water: 250-650 L/t manure
- Possible use of inoculum to start up the process, or chemical agents to reduce odour emission

Observations

Composting can be applied at farm scale (exists many experiences), but composting in centralized plants could benefit of scale economy.

Economical indicators

Investment cost

Equipment:

Turner machinery (windrow composting): 30 000 € (100 m3/h) / 100 000 € (1000 – 1500 m3/h)/ 180 000 (2500 m3/h)

Tractor: 50 000 €

Mixers: 20 000- 50 000 € (10-100 m3/h)

Drum sieve: 70 000 (100 m3/h)

Full plant (investment cost):

Turned windrow composting plant (2000 t/y manure + 1360 t/y sawdust): 35 000 – 100 000 € (depending on the buildings or covers constructed)

Quantifiable incomes: Sales of compost (guidance price):15 - 30 € /t

Non economically quantifiable benefits: Favours closing the nutrient cycle, consequently the consumption of fossil fuels used to synthesize chemical fertilizers is reduced

Operational costs: Operational costs (guidance): 20 € /t (per ton produced)

Selected literature references

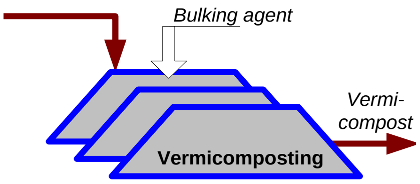
- Ahn, H.K., Mulbry, W., White, JH.W., Kondrar, S.L. (2011) Pile mixing increases greenhouse gas emissions during composting of dairy manure. Bioresource Technology 102: 2904-2909.
- Barrington, S. Choinière, D., Trigui, M., Knight, W. (2002). Effect of carbon source on compost nitrogen and carbon losses. Bioresource Technology 83: 189-194.
- CBMI (2010). Best available Technologies for manure treatment- For intensive rearing of pigs in batic sea region EU member states. Baltic Sea 2020. pp. 103
- de Guardia, A., Mallard, P., Teglia, C., Marin, A., Le Pape, C., Launay, M., Benoist, J.C., Petiot, C. (2010). Comparison of five organic wastes regarding their behaviour during composting: Part 2, nitrogen dynamic. Waste Management 30: 415 – 425
- Hao, X., Chang, C., Larney, F. J., Travis, G.R. (2001) Greenhouse gas emissions during cattle feedlot manure composting. J. Environ. Qual. 30: 376-386
- Levasseur P. (2004) Traitement des effluents porcins. Guide Pratique des Procédés. Institut Technique du Porc. pp.36
- Zhu, N. (2007). Effect of low initial C/N ratio on aerobic composting of swine manure with rice straw. Bioresource Technology 98: 9-13

Real scale (commercial or pilot) references

Many full scale plants at farm level as well as centralized plants. E.g.:

- Composting Plant Juncosa de les Garrigues (Catalunya, Spain)

6.2: Vermicomposting

Objectives			
The main objective is to produce a stable product (vermicompost) utilizing various species of worms. Vermicompost is a heterogeneous mixture of decomposing vegetable or food waste, bedding material and vermicast (also known as worm castings, worm humus or worm manure).			
Level of complexity	**Usual scale**	**Innovation stage**	**General diagram**
☐ low ☒ medium ☐ high complex	☒ on-farm ☒ medium ☐ large scale	☐ laboratory/research ☒ pilot plant ☒ industrial/commercial	
Applied to			
☒ Solid pig manure; ☐Liquid pig manure; ☐ Pig slurry; ☒ Pig deep litter; ☒ Solid Cattle manure; ☐ Liquid Cattle manure; ☐Cattle slurry; ☒ Cattle deep litter; ☐ Poultry slurry; ☒ Poultry deep litter. ☒ products of other processes. In this case, a possible combinations is: (10-18, solid fraction from separation unit) + 24 + 41A // 41-41A (see Annex A)			

Pictures

Vermicomposting units at Ecocelta company, Spain (www.ecocelta.es)

Theoretical fundamentals and process description
Vermicomposting is a biological waste management technology by which organic fraction of the waste stream is decomposed by microorganisms and earthworms in controlled environmental conditions to a level in which it can be handled, stored, and applied in the agricultural fields without adverse impacts on the environment. In vermicomposting process microbes are responsible for biochemical degradation of organic matter and earthworm acts as mechanical blenders; they modify its biological, physical and chemical state, gradually reducing its C:N ratio and increasing the surface area exposed to microorganisms. Earthworm species most often used are Red Wigglers (*Eisenia foetida* o *Eisenia Andrei*), though European nigtcrawlers (*Eisenia Hortensis*) could also be used. Vermicompost is an excellent soil conditioner, it is homogeneous, has low levels of toxic substances, contains important plant nutrients (N, P & K), and these nutrients have higher availability for plant growth. When applying to high biodegradable substrates (eg. pig manure) a previous composting process (decomposition phase) is recommended to avoid high temperature (thermophilic) that can kill worms. In some cases, water washing before feeding is necessary to remove toxic substances to worms (NH_4^+-N, VFA, etc.).

Environmental effects
Effects on air (emissions): • Possible emissions of NH_3, COVs and CH_4 during the previous degradation phase (composting thermophilic phase), applied when substrate is highly biodegradable. *Effects on water/soil (and management)* • As nutrient content and availability in vermicompost are higher, this product could lead to higher N leaching, if not managed properly. *Other effects:* • Organic matter stabilization, pathogens and seeds removal, and odour abatement.

Technical indicators	
Components conversion/efficiencies High reduction of C/N ratio (60-80%).	**Energy consumption or production** No energy requirements **Reagents** Bedding material
Observations The care of earthworms requires attention, high temperature and toxic substances can produce devastating effects.	

Economical indicators
Investment cost: NA
Quantifiable incomes: Production of high quality organic fertilizer**.** Sales of vermicompost (guidance price):150 - 350 €/t
Non economically quantifiable benefits: Closing of nutrients cycles
Operational costs: NA

Selected literature references

- Aira, M., Monroy, M., Domínguez, J., Mato, S. (2002). How earthworm density affects microbial biomas and activity in pig manure. European Journal of Soil Biology, 38: 7–10.
- Bansal, S., Kapoor, K.K. (2000). Vermicomposting of crop residus and cattle dung with Eisenia Foetida. Bioresource Technology, 73: 95-98
- Chan, P.L.S., Griffiths, D.A. (1988). The vermicomposting of pre-treated pig manure. Biological Wastes, 24:57-69
- Yadev, A., Garg, V.D. (2011). Recycling of organic wastes by employing Eisenia fetida. Bioresource Technology 102:2874-2880

Real scale (commercial or pilot) references

Pilot experiences with manure at

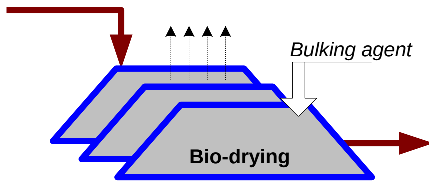
- ECOCELTA

  Carretera Pazos de Borbén (PO-253) Km-1

  Pontacons, Pías, Pontevedra (Spain)

  Tel.: +34 986 645 487

6.3: Bio drying

Objectives			
To remove moisture from a waste stream and hence reduce its overall weight, by means of the heat produced during the initial stages of composting (decomposition of organic matter). The main difference with composting is that biodrying aims at removing as much moisture as possible in the shortest time, by controlling process parameters (different aeration and moisture content compared with composting).			
Level of complexity	**Usual scale**	**Innovation stage**	**General diagram**
☐ low	☒ on-farm	☐ laboratory/research	
☒ medium	☒ medium	☒ pilot plant	
☒ high complex	☐ large scale	☐ industrial/commercial	
Applied to			
☐Solid pig manure; ☒Liquid pig manure; ☒ Pig slurry; ☐Pig deep litter; ☐Solid Cattle manure; ☒Liquid Cattle manure; ☒Cattle slurry; ☐Cattle deep litter; ☒ Poultry slurry; ☐Poultry deep litter. ☒ products of other processes. In this case, a possible combinations is: 24 (addition of bulking agent) + 42 // (30-31)+ (10-18) + 24 + 42 // (30-31)+ (10-18) +55+ 24 + 42 (see Annex A)			

Pictures

Illustration of pig farm-scale bio drying: at Les Garrigues county (upper row) and at Torelló (lower row), Catalonia, Spain. These examples are pilot experiences.

Theoretical fundamentals and process description

It is a drying technique that relies on biological activities of microorganisms, bacteria and fungi, to reduce the moisture content of wet biomaterial. As the microorganisms feed on the nutrients, carbon, nitrogen and other elements available in the waste, heat is produced as part of the metabolic activities. This head, assisted by air, is used to evaporate the excess of moisture.

The process duration varies with the material type and the system setup, but it typically last between two to three weeks. A biodried pile requires mixing at least once a week for moisture redistribution.

As biodrying is both a biological and a physical process, it is affected by a number of factors. The biological factors that directly influence the microorganisms include material composition, C/N ratio, moisture content and pH. The relevant physical factors are pile geometry, void ratio, airflow and mixing intervals

Initial moisture content should be 60-65%. If manure has higher moisture content (MC) a bulking agent with significant lower moisture content should be added. When liquid manure (slurry) is biodryied, the bulking agent to manure ration varies a lot and depends on the number of addition, the mixing procedures and the moisture content of manure and bulking material (eg. Sawdust:manure (2.5:1), yard trimming:pig slurry (1:1), pig slurry:straw in multiple dosses (1:10))

Airflow is also a critical factor that should be controlled during the biodrying process. Low aeration result in decomposition without significant moisture removal, but excess aeration rates and frequent turnings will cool down the material and stop microbial activity, and pathogens killing. Usual aeration rates are 0.2-0.6 m^3/min.

A previous stage to remove or recover ammonia (NDN or ammonia stripping) is necessary to avoid high NH_3 emissions. If nitrification is performed but not denitrification, the dried product will contain higher amount of nitrogen, no NH_3 emissions could be expected but the risk of NO_x emissions would be higher.

Environmental effects

Effects on air (emissions):

- A previous stage to remove or recover ammonia (NDN or ammonia stripping) is necessary to avoid high NH_3 emissions. If nitrification is performed but not denitrification, the dried product will contain higher amount of nitrogen, no NH_3 emissions could be expected, but the risk of NO_x emissions could be higher.

Effects on water/soil (and management)

- Production of a dried product (MC: 20-30%) easily handled for field crops fertilization. Consequently, risk for N leaching could decrease, if products are appropriately managed.

Other effects:

- Organic matter stabilization, pathogens and seeds removal.

Technical indicators

Components conversion/efficiencies	Energy consumption or production
50-56% VS reduction 40-60% MC reduction 0.46- 0.78 $kg_{H2Oremoval}$/kg TS day	NA. Aeration and mixing requirements are higher compared to composting **Reagents** Bulking material (porosity and carbon source) with low moisture content, with proportions depending of characteristics of liquid manure.

Observations

The reduction of moisture reduces the weight of the material and can significantly change its handling characteristics. This reduction of weight reduces the cost of transporting material from its source to end users.

Additional benefits include the reduction of potential emissions of odours, and the material is more suitable for energy production by thermochemical process such as combustion, pyrolysis or gasification.

Economical indicators
Investment cost NA
Quantifiable incomes Sales of dried product (no data available)
Non economically quantifiable benefits Closing of nutrients cycles
Operational costs NA

Selected literature references

- Fugère, M., Farand, P., Chabot, R., Stuart, P. (2007) Design and techno-economic analysis of a process for transforming pig manure into a value-added product. The Canadian Jouirnal of Chemical Enginering, 85: 360-368)
- Levasseur P. (2004) Traitement des effluents porcins. Guide Pratique des Procédés. Institut Technique du Porc. pp.36
- Sadaka, S., VanDEvender, K., Costello, T., Sharara, M. (2011). Partial composting for biodrying organic materials Agriculture and Natural Resources FSA1055. University of Arkansas (USA)
- Choi, HJ.L., Richard, T.I., Ahn, H.K. (2001) Compost Science & Utilization, 90 (4): 303-311
- Collick, A.S., Inglis, S., Wright, P., Steenhuis, T.S., Bowman, D.D. (2007) Inactivation of Ascaris suum in a biodrying compost system. J. Environ. Qual. 36:1528-1533.

Real scale (commercial or pilot) references

Pilot plants:

- Inman Farm, Bovina Center (Delaware County, New York City Watershed (USA)
- Cooperativa de Torrelló (Catalunya, Spain)

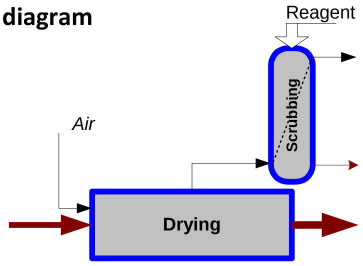
6.4: Thermal drying

Objectives

The aim of this treatment is to obtain a dried product from manure/slurry (solid fraction, raw or digested) with most of the nutrients, easier and cheaper to transport and land spreading. Depending of the moisture content of the product (slurry) a previous evaporation process is required.

Level of complexity	Usual scale	Innovation stage
☐ low	☐on-farm	☐ laboratory/research
☐ medium	☐ medium	☐pilot plant
☒ high complex	☒ large scale	☒ industrial/commercial

General diagram



Applied to

☒Solid pig manure; ☐Liquid pig manure; ☐ Pig slurry; ☐Pig deep litter;

☒Solid Cattle manure; ☐Liquid Cattle manure; ☐Cattle slurry; ☐Cattle deep litter;

☐ Poultry slurry; ☒Poultry deep litter.

☒ products of other processes. In this case, a possible combinations is:

(10-18) + 43 (when only solid fraction is dried) + 101 // (30-31) + (10-18) + 43 (when only solid fraction is dried) +101 // (10 -18) + (60-61) + (54A-54B) + 43 + 101 // (30-31) +(10-18) + 21 + 54A+43+101 (see Annex A)

Pictures

Illustration of a dryer (left) and image of the dried product (right) at the TRACJUSA pig manure treatment plant (Juneda, Spain).

Theoretical fundamentals and process description

Water from previously centrifuged slurry and/or the concentrate of an evaporation process is removed (vaporized) applying heat. Thermal energy is usually recovered from a combined heat and power (CHP) engines or other heat residual streams.

The aim of the drying process is to obtain a product easily to handle, that conserve most of the nutrients of the original material (N:P:K). The dried product can be stored in a silo and transported pneumatically or by belt conveyor systems.

The gaseous emissions from the dryer must be recovered (by filtration or scrubbing) to avoid ammonia (NH_3) or organic volatiles (VOC) emissions. If the product comes from anaerobic digestion process, this reduces VOC emissions, and the biogas produced covers part of the thermal energy needs (10-20%). Acidification of the input product, in order to control ammonia emissions, is also necessary.

When combined with nitrification-denitrification process, VOC and ammonia emission can be controlled, but poor nitrogen recovery is expected. If nitrification is applied but not denitrification, nitrogen recovery can be improved.

Environmental effects

Effects on air (emissions):

- Potential risk of air pollutant emissions. Previous nitrification-denitrification process, acidification or anaerobic digestion and recovery of emissions from the drier (by filtration or scrubbing) to avoid ammonia (NH_3) or organic volatiles (VOC) emissions are necessary.

Effects on water/soil (and management)

- Cu, Zn and other heavy metals are present in the dried product (depending of their concentration in the raw manures). This fact could limit their use on field crops,
- Need of special machinery for land spreading if pelletizing is not applied (dust product)

Other effects:

- Production of a dried product easily to handle, with moderate-high concentration of nutrient (N and P)
- Organic matter stabilization, pathogens and seeds removal. The dried product could be considered sterilized (according to the operation time/temperature)

Technical indicators

Components conversion/efficiencies

High efficiency. More than 85% of the water is removed and 95% of the N (if previously acidified), and almost all P and K of the inflow could be conserved in the dried product.

Energy consumption or production

High energy consumption (high temperature is required). For and industrial scale facility the thermal requirements can be estimated in 15-18 KW/m^3 for S/L acidified-digested slurry entering at 25-30% TS. Subsidies (eg. to power production) are usually necessaries to make economical feasible these kind of treatment facilities

Reagents

- No reagents.
- Sulphuric acid could be used in a previous acidification step to control NH_3 emissions

Observations

- No specific equipment to dry slurries/manures is available. It is necessary to adapt equipment from other technologies (mainly animal feed production)
- It is of high relevance the selection of the constructive materials (resistance to high temperature and corrosion). It requires stainless steel quality >316L.

Economical indicators

Investment cost

NA

Quantifiable incomes

The marked prices of the pellet from pig slurry (the dried product is usually pelletized) are between 30 and 55 €/t. If the dried product is not pelletized, its price is lower (25-30 €/t)

Non economically quantifiable benefits

Favours closing the nutrient cycle, consequently the consumption of fossil fuels used to synthesize chemical fertilizers is reduced. Transporting end-products nutrients concentrate to high distances

Operational costs

NA

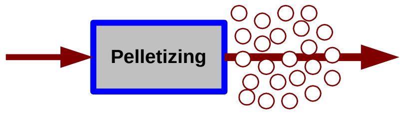
Selected literature references

- Bonmatí, A., Campos, E., Flotats, X. (2003). Concentration of pig slurry by evaporation: anaerobic digestion as the key process. Water Sci. Technol. 48: 189-194.
- Bonmatí, A., Flotats, X. (2003). Pig slurry concentration by vacuum evaporation: influence of previous mesophilic anaerobic digestion process. J. Air Waste Manage. Assoc. 53: 21-31.
- Burton, C.H., Turner, C. (Eds) (2003). Manure Management. Treatment strategies for sustainable agriculture. Silsoe Research Institute, 490 pps. ISBN: 0-9531282-6-1.
- Martens, W. Böhm, R. (2009). Overview of the ability of different treatment methods for liquid and solid manure to inactivate pathogens. Bioresource Technology, 100(22): 5374-5378.

Real scale (commercial or pilot) references

- TRACJUSA and VAG (Juneda, Spain)
- SAVA (Miralcamp, Spain)
- VALPUREN-BAÑUELO/VALPUREN POLAN (Toledo, Spain)

6.5: Pelletizing

Objectives			
Moulding a dried slurry/manure into a pellet to obtain a product easier to transport and to spread on land. Pellets are small particles typically created by compressing of the original material at high pressure/temperature.			
Level of complexity	**Usual scale**	**Innovation stage**	**General diagram**
☐ low ☐ medium ☒ high complex	☐on-farm ☐ medium ☒ large scale	☐ laboratory/research ☐pilot plant ☒ industrial/commercial	
Applied to			
☐Solid pig manure; ☐Liquid pig manure; ☐ Pig slurry; ☐Pig deep litter; ☐Solid Cattle manure; ☐Liquid Cattle manure; ☐Cattle slurry; ☐Cattle deep litter; ☐ Poultry slurry; ☐Poultry deep litter. ☒ products of other processes. In this case, a possible combinations is: 43 + 44 (with different combinations previous to drying (43) (see Annex A)			

Pictures


Illustration of a pelletizing facility (left) and view of the pellets produced (right) at Tracjusa pig manure treatment plant (Juneda, Spain)

Theoretical fundamentals and process description

Pelletizing is the process of moulding a material into the shape of a pellet. Compression and temperature, as well as composition of the raw material are the major factors affecting the process.

The dried slurry/manure is pushed through the holes of the matrix, of the desired shape/size, and the material exits the pellet-mill as a pellet shaped end product.

The goal of pelletizing is to produce an easily manageable product for land crop fertilization, that conserves all the properties of the original material (nutrient content), and with better storage and handling properties as compared to a dusty product.

Environmental effects

Effects on air (emissions):

- Potential risk of dust emissions (cyclers to recover dust are recommended)

Effects on water/soil (and management)

- Cu, Zn and other heavy metals are present in the dried product (depending of their concentration in the raw manures). This fact could limit their use on field crops

Other effects:

- Production of a dried product easily to handle, with moderate-high concentration of nutrient (N and P)
- Land spreading could be performed with usual agricultural machineries

Technical indicators

Components conversion/efficiencies

- High efficiency,
- Dust leakage from the system can be re-circulated in the inflow.

Energy consumption or production

NA

Reagents

- No reagents. In some cases addition of water is required,
- Addition of nutrients can be done easily at this step, If required for improving nutrients balance of the final product (NPK fertilizer)

Observations

- No specific equipment for slurries/manures pelletizing is available. It is necessary to adapt equipment from other technologies (mainly animal feed production)
- In some cases, depending on the previous drying operation, is necessary to add some water to improve the performance of the pelletizing process. The obtained product have a solids content over >85%.
- Frequent matrix replacement due to erosion. It is important the choice of constructive materials,

Economical indicators

Investment cost: NA

Quantifiable incomes: The marked prices of the pellet from pig slurry are between 30 - 55 €/t

Non economically quantifiable benefits

Lab/land experiments with the obtained product show that its performance on the soil is better than from the raw material (slowly N release in soil). Data from TRACJUSA-LEA_LAF, 2004

Operational costs: NA

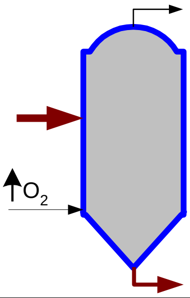
Selected literature references

- Burton, C.H., Turner, C. (Eds) (2003). Manure Management. Treatment strategies for sustainable agriculture. Silsoe Research Institute, 490 pps. ISBN: 0-9531282-6-1.

Real scale (commercial or pilot) references

- TRACJUSA and VAG (Juneda, Spain)
- SAVA (Miralcamp, Spain)
- VALPUREN-BAÑUELO/VALPUREN POLAN (Toledo, Spain)

6.6: Combustion

Objectives			
Transformation of organic materials into energy by thermal oxidative process, resulting in a substantial reduction of volume and mass. Thermal energy should be recovered and it is usually transformed into electricity.			
Level of complexity	**Usual scale**	**Innovation stage**	**General diagram** 
☐ low ☐ medium ☒ high complex	☐on-farm ☐ medium ☒ large scale	☐ laboratory/research ☐pilot plant ☒ industrial/commercial	
Applied to			
☒Solid pig manure; ☐Liquid pig manure; ☐ Pig slurry; ☒Pig deep litter; ☒Solid Cattle manure; ☐Liquid Cattle manure; ☐Cattle slurry; ☒Cattle deep litter; ☐ Poultry slurry; ☒Poultry deep litter. ☒ products of other processes. In this case, a possible combinations is: (10-18) + 45 // (10-18) + 43 + 45 (see Annex A)			

Pictures

Illustration BMC Moerdijk power plant (The Netherlands). The plant is designed to turn more than 400,000 tonnes/year of poultry litter into electricity (36 MW) and reusable minerals for agriculture. (http://www.bmcmoerdijk.nl/index.php)

Theoretical fundamentals and process description

Carbon, hydrogen, and sulphur contained in manure is oxidised at high temperature (>900ºC) in an oxidative ambient. Air (oxygen) is introduced in excess (greater than the stoichiometric requirement). If a complete combustion is done, all volatile solids are transformed to gases; in this case, ashes will contain only inorganic material. If combustion is not complete (insufficient oxygen or low degree of turbulence) volatile solids (VS) can be found in the ashes and CO in the exhaust gasses.

In order to recover thermal energy it is necessary a steam generator. The steam generated, in turn, can be transformed to electricity in a steam turbine. EU Waste Directive (2008/98/CE) requires a 65% of energy efficiency for a plant to be considered a plant recovering energy. If manure has high moisture content, it is not possible to reach this efficiency. In this case, a previous drying process (and pelletizing) could be appropriate.

Different furnaces can be used, commonly, rotator drum, grilled bed, and fluidised bed reactor. Equipment to control emission is required in all cases. Gas emissions should accomplish the EU Waste Incineration Directive (2000/76/EC). This requires detailed measurements and high investment on control equipment devices, not applicable for farm scale uses.

During combustion, most of the N will be converted to N_2, and some into NO_x, that should be minimized with the appropriate devices. On the other hand, P is concentrated in the ashes, but field crops availability of this P is still under study. Ashes removed in the emission control devices must be disposed in controlled landfills.

Environmental effects

Effects on air (emissions):

- Potential risk of emissions (eg. NO_x, SO_x, H_2S, HCl, dioxines, etc.)

Effects on water/soil (and management)

- -

Other effects:

- Sanitation and destruction of pathogens and also pharmaceutically activated compounds.
- High reduction of volume and mass of manure/slurry,
- P can be reused for crop fertilization if appropriate treatment of the ashes is done

Technical indicators

Components conversion/efficiencies	Energy consumption or production
70-80% of mass reduction 76-81% carbon combustion efficiency (Zhu et Lee, 2005)	Energy production can be calculated with the Higher Heating Value (HHV) of the manure. Estimate can be done with elemental analysis or by means of COD (1kgCOD equivalent to 14MJ). The principal factor affecting energy recovery is the water content of the manure (latent heat of vaporization)
	Reagents Air (oxygen) is required to oxidise and maintain adequate turbulence degree

Observations

Several experiences at farm scale in poultry breeding farms in the past, for heating uses, with good economical balance but with strong environmental problems due to bad combustion control.

Economical indicators

Investment cost:

Economic feasibility studies should be performed in each location/country

Indicating costs for a generic poultry power plant (Florin et al., 2009)

	Plant Capacity	
	2 (t/h)	8 (t/h)
Electrical output (MWe)	1.5	6
Equipment cost (€)	6,267,620	20,737,090

Quantifiable incomes: Sales of energy (combustion or electricity generation), depending on individual EU State regulations and market price.

Non economically quantifiable benefits: Sanitation and destruction of pathogens and also pharmaceutically activated compounds.

Operational costs: NA

Selected literature references

- Florin, N.H., Maddocks, A.R., Wood, S., Harris, A.T. (2009) High-temperature thermal destruction of poultry derived wastes for energy recovery in Australia. Waste Management, 29: 1399-1408
- Henihan, A.M., Kelleher, C.P., Leahy, M.J., Cummins, E., Leahy, J.J. (2003). Monitoring and dispersion modelling of emissions from the fluidised bed combustion of poultry litter. Environmental Monitoring and Assessment, 85: 239-255
- Zhu, S., Lee, S.W. (2005) Co-combustion performance of poultry wastes and natural gas in the advanced Swirling Fluidized Bed Combustor (SFBC). Waste Management, 25: 511-518

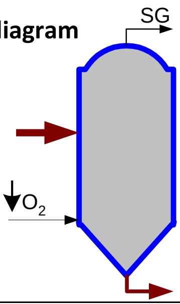
Real scale (commercial or pilot) references

- BMC Moerdijk power plant (http://www.bmcmoerdijk.nl/index.php) Middenweg 36a
  4782 PM Moerdijk
  The Netherlands
  T +31 (0) 168 - 331 433
  F +31 (0) 168 - 331 439

6.7: Thermal gasification

Objectives
Production of a fuel gas (syngas) from partial oxidations of organic wastes.

Level of complexity	Usual scale	Innovation stage	General diagram
☐ low	☐on-farm	☒ laboratory/research	
☐ medium	☐ medium	☒ pilot plant	
☒ high complex	☒ large scale	☐ industrial/commercial	



Applied to
☒Solid pig manure; ☐Liquid pig manure; ☐ Pig slurry; ☒Pig deep litter;
☒Solid Cattle manure; ☐Liquid Cattle manure; ☐Cattle slurry; ☒Cattle deep litter;
☐ Poultry slurry; ☒Poultry deep litter.
☒ products of other processes. In this case, a possible combinations is:
(10-18) + 46 // (10-18) + 43 + 46 // (10-18) + 43 + 44 + 46 (see Annex A)

Pictures

Illustration of a gasification pilot plant of the CEPIMA research group at UPC-BARCELONATECH (http://www.upc.edu/pct/es/equip/297/planta-piloto-gasificacion-limpieza-gases-calientes.html)

Theoretical fundamentals and process description

Gasification is a process that converts organic carbonaceous materials into carbon monoxide, hydrogen, carbon dioxide and methane. The resulting gas mixture is called *syngas* (synthetic gas). The process is performed at high temperature (>800ºC), with a controlled amount of oxygen or steam (25-30% of the required O_2 for a complete combustion).

Gasification can be performed with air, pure O_2, steam and H_2, resulting a *syngas* with different characteristics and heating values. The advantage of gasification is that syngas combustion can potentially reduce emissions compared with direct combustion of the original fuel (manure). The higher temperature of combustion refines out corrosive ash elements, furthermore *syngas* could be depurated, and thus, fewer emissions could be expected.

Usually gasification is divided in four steps: drying, pyrolysis, reduction and oxidation. The combustion steep delivers the necessary thermal energy to be a self-heating process.

It could be useful for organic material with slow biodegradability and with low moister content. Composition should be constant in order to control the process.

The resulting solid/char derived from gasification will be significantly smaller in volume and mass than the starting waste and can be sold as fertilizer (most of the P will be in this fraction) or used in cement or concrete manufacturing.

Pig and dairy slurry can directly used as fuel in wet oxidation, the excess water can serve as the carrier fluid and reaction medium for direct aqueous-phase gasification. Nevertheless this option is only a remote possibility.

Environmental effects

Effects on air (emissions):

- Potential risk of emissions (eg. NO_x, SO_x, H_2S, HCl, dioxines, etc.) but lower than for combustion.

Effects on water/soil (and management)

- -

Other effects:

- Sanitation and destruction of pathogens and also pharmaceutically activated compounds.
- High reduction of volume and mass of manure/slurry. Production of a clean fuel gas.
- P can be reused for crop fertilization (P availability for field crops is higher than ashes coming from combustion)

Technical indicators

Components conversion/efficiencies: NA

Energy consumption or production

Depending of the oxidant, different composition and Low Heating Value (LHV) of the *syngas* can be expected

Oxidant	*Syngas* composition	LHV (MJ/m^3)
Air	CO, H_2, N_2	6
O_2	CO, H_2, N_2	10-20
Steam + O_2	Enriched with CO and H_2	-
H_2	Enriched with CH_4 and long-chain hydrocarbons	>30

LHV is determined by subtracting the heat of vaporization of the water vapour from the higher heating value (HHV) or gross energy

Reagents : Air, O_2, Steam or H_2. Catalyst (Ni or K) could promote greater gas production.

Observations

Moisture content and heterogeneity of manures is the main limiting factor

Economical indicators

Investment cost:

Economic feasibility studies should be performed in each location/country

Indicative costs for a generic thermal gasification poultry facility (Sheth and English, 2005)

Plant Capacity (t/day)	Capital investment ($)	Equipment cost ($)	Operational Cost ($)
100	3 066 550	1 005 712	1 984 037
500	nd	2 627 289	8 100 593
1000	nd	3 978 333	15 226 037

nd: no data available

Quantifiable incomes:

- Sales of electricity or *syngas*
- Sales of char/residue

Non economically quantifiable benefits:

- Sanitation and destruction of pathogens and also pharmaceutically activated compounds.

Operational costs: NA

Selected literature references

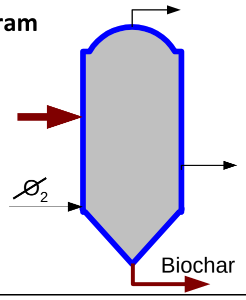
- Cantrell, K., Ro, K., Mahajan, D., Anjom, M., Hunt, P.G. (2007). Role of thermochemical conversion in livestock waste-to-energy treatments: obstacles and opportunities. Ind. Eng. Chem. Res., 46: 8918-8927.
- Sheth, A. C., and English, J. (2005). Preliminary Economics Analysis of Poultry Litter Gasification Option with a Simple Transportation Model. Air & Waste Manage. Assoc., 55: 510- 522.

Real scale (commercial or pilot) references

NA

6.8: Pyrolysis

Objectives
Thermochemical decomposition of organic matter at high temperature in the absence of oxygen, aiming to produce energy-dense alternative fuels: fuel-gas (*syngas*), long-chain condensable hydrocarbons (*biocrude oil)* and a carbonaceous residue (*biochar)*.

Level of complexity	Usual scale	Innovation stage	General diagram
☐ low ☐ medium ☒ high complex	☐on-farm ☐ medium ☒ large scale	☒ laboratory/research ☒ pilot plant ☐ industrial/commercial	

Applied to
☒Solid pig manure; ☐Liquid pig manure; ☐ Pig slurry; ☒Pig deep litter; ☒Solid Cattle manure; ☐Liquid Cattle manure; ☐Cattle slurry; ☒Cattle deep litter; ☐ Poultry slurry; ☒Poultry deep litter. ☒ products of other processes. In this case, a possible combinations is: (10-18) + 47 // (10-18) + 43 + 47 // (10-18) + 43 + 44 + 47 (see Annex A)

Pictures

Illustration NA

Theoretical fundamentals and process description

Thermochemical decomposition is produced at high temperatures (>450ºC) in the absence of oxygen and usually under pressure; vacuum pyrolysis is also possible. Since pyrolysis is an endothermic process various methods to provide heat have been proposed: partial combustion, direct or indirect heat transfer, or solids recirculation. Fixed beds as well as fluidized beds reactors are usually used.

Pyrolylsis products (*syngs, biocrude oil, and biochar*) can be used as energy intermediates for combined heat and power generation (CHP) or feedstock for downstream catalytic conversion processes to produce higher value products such as liquid transportation fuels. Its characteristics and proportion depends on the composition of manure and the reactor design and process parameters (temperature, heating rate, retention time). With slow pyrolysis, low reactor temperatures and long vapour residence time, char production is promoted. When higher temperature and short residence times are used, fast pyrolysis convert biomass mainly to biocrude oil.

The *biochar* produced has a high content of carbon (30 – 52 $\%_{db}$) and ashes (36 - $53\%_{db}$) with a C recovered ratio between 48-56%. It retains about 50% of the feedstock energy, with a high heating value (HHV) between 14- 25 MJ/m^3. It can be used for Activated Carbon production, burned for energy production or recycled as fertilizer. Manure *biochar* contained higher concentrations of P and K than the original manure or substrate. Consequently, these could be used as low-release fertilizer to improve soil fertility and crop yields.

The *syngas* produced is a mixture of CO_2, CO, CH_4 and H_2, as well as S-containing gases (dimethyl suffice, methyl mecaptan, has been detected). Its HHV varies from 15 to 30 MH/m^3 and retains around 25% of the energy of the raw material.

Crude bio-oil had relatively high nitrogen content, but very low sulphur and high viscosity. Its HHV is between 22 and 30 MJ/m^3.

Extremely high energy is required to make *biochar* from wet swine manure (eg. 1 kg of *biochar* coming from pig slurry with a MC: 97% requires 232. MJ/kg) (Ro et al. 2010). Dewatering, is recommended as substantially reduces the external energy requirement.

Environmental effects

Effects on air (emissions):

- Potential risk of emissions (eg. NO_x, SO_x, H_2S, HCl, Dioxines, etc.) but lower than for combustion.

Effects on water/soil (and management)

- -

Other effects:

- Sanitation and destruction of pathogens and also pharmaceutically activated compounds.
- High reduction of volume and mass of manure/slurry. Production of a clean fuel gas and bio-oil that can be used as energy intermediates.
- P and K (contained in the biochar) can be reused for field crop fertilization

Technical indicators

Components conversion/efficiencies:

Products yield (%):

- Bio-oil: 37 – 50%
- BioChar: 27 – 40%
- Syngas: 14 – 24%

Energy consumption or production

Energy is required to dry, increase and maintain temperature. Energy contained in the syngas can be used, but it is not always sufficient. Biochar and biocrude oil can be also used to run the process but other valuable uses are preferable.

Depending of the manure composition the energetic requirements can largely be different (Ro et al. 2010).

Parameters (Units: MJ/kg biochar)	Chicken litter (MC%= 10.2)	Swine solid (MC%= 12.8)	Swine slurry (MC%= 97.0)	Blended* (MC%= 10.9)
Heat for drying	+6.9	+22.9	242.6	+10.0
Sensible heat (100ºc-620oC)	+1.8	+2.1	2.1	+2.1
Heat loss by carbonizer	+0.1	+0.1	0.1	+0.1
Heat of reaction	-0.8	-1.1	-1.1	-1.2
Energy in produced gas	-4.9	-11.4	-11.4	-10.6
Balance	+3.1	+12.5	+232.3	+0.5

*Blended: 2.9/7.1 (kg/kg) rye grass/swine solids / MC: Moisture content

Reagents

Observations

Nowadays, no full scale pyrolysis plant exists and its high complexity suggested that large plant will be the optimum size, but some authors think that may be suitable for small farms if a modular plant can be constructed at a moderate price. The liquid fuel produced could then be used for on-farm heating. In addition, the pyrolysis biochars which will normally trap most of the inorganic residue could be used as a slow-release fertilizer.

Economical indicators

Investment cost:

Economic feasibility studies should be performed in each location/country

Indicating costing for a pyrolisy poultry facility producing Active Carbon (Lima et al. 2008)

Plant capacity (t/day)	20
Equipment purchase cost ($)	1 776 000
Installation ($)	3 551 000
Total plant direct cost ($)	5 327 000
Operatin cost ($/yr)	1 599 000
Production rate ($kg_{Activated\ C}$ /yr)	1 108 356
Unit production coast ($/$kg_{Activated\ C}$)	1.44

Quantifiable incomes:

Sales of syngas, biocrude oil and biochar

Non economically quantifiable benefits:

Sanitation

Operational costs: NA

Selected literature references

- Agblevor, F.A., Beis, S., Kim, S.S., Tarrant, R., Mante, N.O. (2010). Biocrude oils from the fast pyrolysis of poultry litter and hardwood. Waste Management, 30: 298- 307.
- Cantrell, K., Ro, K., Mahajan, D., Anjom, M., Hunt, P.G. (2007). Role of thermochemical conversion in livestock waste-to-energy treatments: obstacles and opportunities. Ind. Eng. Chem. Res., 46: 8918-8927.
- Koutcheiko, S., Monreal, C.M., Kodama, H., McCracken, T., Kotlyar, L. (2007). Preparation and characterization of activated carbon derived from the thermo-chemical conversion of chiken manure. Bioresource Techonology, 98: 2459-2464.
- Lima, I.M., McAloon, A., Boateng, A.A. (2008). Activated carbon from broiler litter: Process description and cost of production. Biomass and bioenergy, 32: 568-572.
- Mante, O.D., Agblevor, F.A. (2010). Influnece of pin Wood shavings on the pyrolysis o poutry litter. Waste Management, 30:2537-2547.
- Ro, K. S., Cantrell, K. B., Hunt, P.G. (2010). High-temperature pyrolysis of blended animal manures for producing renewable energy and value-added biochar. Ind. Eng. Chem. Res., 49: 10125-10131.

Real scale (commercial or pilot) references

NA

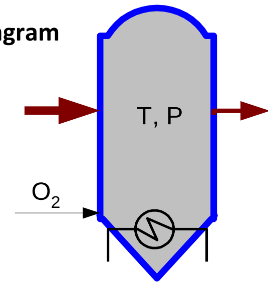
6.9: Wet oxidation

Objectives

Oxidation of dissolved and suspended organic components using oxygen, at high temperature and under pressure. Compounds that would not oxidize under dry conditions at same temperature and pressure can oxidize under wet oxidation conditions

Level of complexity	Usual scale	Innovation stage
☐ low	☐on-farm	☒ laboratory/research
☐ medium	☐ medium	☐ pilot plant
☒ high complex	☒ large scale	☐ industrial/commercial

General diagram



Applied to

☐Solid pig manure; ☒Liquid pig manure; ☒Pig slurry; ☐Pig deep litter;

☐Solid Cattle manure; ☒Liquid Cattle manure; ☒Cattle slurry; ☐Cattle deep litter;

☒ Poultry slurry; ☐Poultry deep litter.

☒ products of other processes. In this case, a possible combinations is:

48 + (30 – 31) (applied to other co-substrates than manures) // (30 – 31) + 48 + Ethanol production (see Annex A)

Conditioning the effluent from anaerobic digestion to water and nutrient source to ethanol production

Pictures

Illustration NA

Theoretical fundamentals and process description

The oxidation reactions occur in superheated waters at a temperature above water boiling point (100ºC), but below the critical point (374ºC), usually between 125ºC to 350ºC. The system must be maintained under pressure (0.5 – 20 MPa) to avoid water evaporation. O_2 or H_2O_2 can be used as oxidant agent. Cost can be significantly reduced using suitable catalysts capable of promoting the process under milder operating conditions and shorter retention time.

Commercial systems typically use a bubble column reactor, where air is bubbled through a vertical column that is full of liquid (slurry) at high temperature and pressurized.

Complex organic compounds are oxidized, mostly to carbon dioxide and water, with the presence of refractory compounds like short-chain carboxylic acids (e.g. acetic acid) and ammonia.

Wet Oxidation could be used as pre-treatment to anaerobic process, but depending on manure characteristics anaerobic biodegradability is not enhanced (Strong et al. 2011). Alternatively, it can be used as a post-treatment of anaerobic digestion, to condition anaerobic effluents as a water and mineral source in the ethanol-fermentation and to reduce cost in the simultaneous saccharification and fermentation (SSF) step (Oleskowicz-Popiel, 2008). But the most frequent use is to treat wastewater containing complex/recalcitrant organic compounds.

Environmental effects

Effects on air (emissions):

- Potential risk of emissions (eg. NO_x, SO_x, H_2S, HCl, dioxines, etc.) but lower than in other oxidative process, because of the liquid media conditions.

Effects on water/soil (and management)

- -

Other effects:

- Sanitation and destruction of pathogens and also pharmaceutically activated compounds,, which are not degraded in other treatments conditions,
- Organic N mineralization (N conversion to N-NH_4^+-N)
- High reduction of recalcitrant organic matter.
- It enables the reuse of nutrients and reduces fossil fuels input in certain processes (e.g. ethanol production).

Technical indicators

Components conversion/efficiencies:

COD removal = 75-90%
Organic N conversion to N-NH_4^+-N = 78 – 86%

Energy consumption or production High energetic input is required (high temperature and pressure). NA

Reagents

- O_2 or H_2O_2 can be used as oxidant agent.
- Catalyst can be used to optimize the process: Copper (Cu), Iron (Fe), etc.

Observations

Economical indicators
Investment cost: NA
Quantifiable incomes: Cost reduction of the subsequent treatment
Non economically quantifiable benefits: NA
Operational costs: NA

Selected literature references

- Anglada, A., Urtiaga, A., Ortiz, I., Mantzavinos, D., Diamadopoulos, E. (2011). Treatment of municipal landfill leachate by catalytic wet air oxidation: Assessment of the role of operating parameters by factorial design. Waste Management, 31: 1833- 1840
- Fontanier, V., Zalouk, S., Barbati, S. (2011). Conversion of the refractory ammonia and acetic in catalytic wet air oxidation of animal byproducts. Journal of environmental sciences, 23:520-528
- Oleskowicz-Ppiel, P., Lisiecki, P., Holm-Nielsen, J.B., Thomsen, A.B., Thomsen, M. H. (2008). Ethanol production from maize silage as lingocellulosic biomass in anaerobically digested and we-oxidation manure. Bioresource Technology, 99: 5327-5334
- Strong, P.J., McDonald, B., Gapes, D.J. (2011). Combined thermochemical and fermentative destruction of municipal biosolids: A comparison between thermal hydrolysis and wet oxidative pre-treatment. Bioresource Technology, 102: 5520 – 5527
- Zalouk, S., Barbati, S., Sergent M., Ambrosio, M. (2009). Disposal of animal by-products by wet air oxidation: Performance optimization and kinetics. Chemosphere, 74: 193- 199

Real scale (commercial or pilot) references

NA

7: TREATMENT OF THE LIQUID FRACTION

7.1: Membrane filtration (MF, UF, RO)

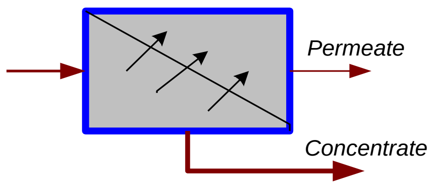
Objectives

Micro filtration (MF) is often used on the liquid fraction, to separate or remove suspended solids, bacteria and virus. Often micro filtration is a type of pre-treatment for the reverse osmosis treatment (RO). Microfiltration is a low-pressure cross-flow membrane process for separating colloidal and suspended particles in the range of 0.05-10 microns.

Ultra filtration (UF) concentrates suspended solids and solutes of molecular weight greater than 1,000. The permeate has low-molecular-weight organic solutes and salts. Small dissolved molecules pass the filtration and can be removed by reverse osmosis (RO).

Level of complexity	Usual scale	Innovation stage
☐ low	☐ on-farm	☐ laboratory/research
☐ medium	☒ medium	☐ pilot plant
☒ high complex	☒ large-scale	☒industrial/commercial

General diagram



Applied to

☐ Solid pig manure; ☐ Liquid pig manure; ☐ Pig slurry; ☐ Pig deep litter;

☐ Solid Cattle manure; ☐ Liquid Cattle manure; ☐ Cattle slurry; ☐ Cattle deep litter;

☐ Poultry slurry; ☐ Poultry deep litter.

☒ products of other processes. In this case, a possible combination is:

10A or 15 + 51 + 53 (see process codes in Annex A)

Pictures

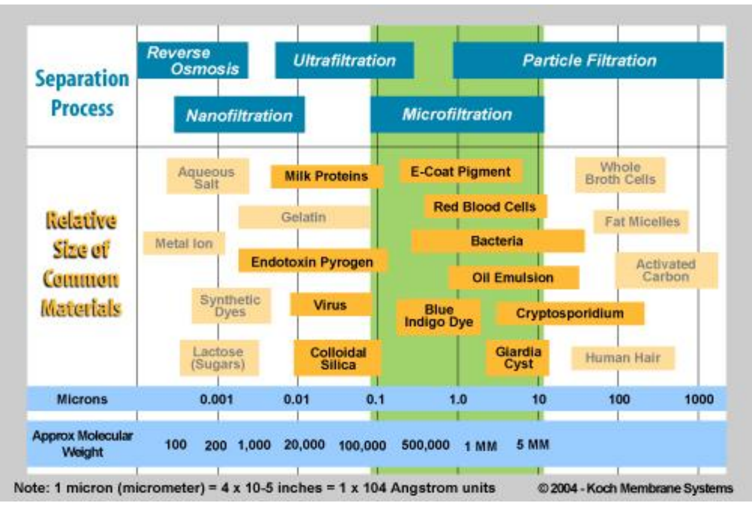


Illustration from Koch membrane systems (www.kochmembrane.com), left, and Illustration from AstroPure (www.astropure.com), right.

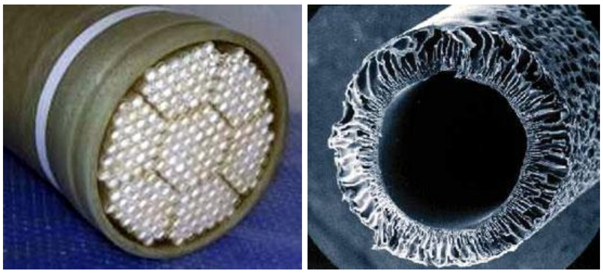


Illustration of membrane unit, UF area (Hinge, 2005)

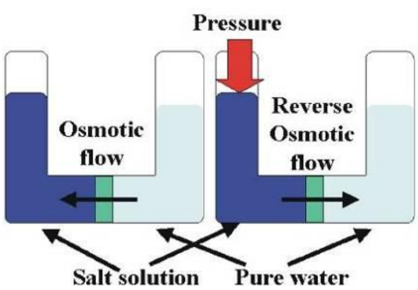
Theoretical fundamentals and process description

There are several different techniques of membrane filtration, and those are categorized according to pore size in the membrane. The size of the particles retained by the membranes, thus decreasing with decreasing pore size. All the four membrane techniques listed in the following table and Figure (www.kochmembrane.com) have the pressure difference across the membrane as the driving force for the process. The smaller pore sizes, the higher the needed pressure.

Membrane type	Size of pores	Pressure (bar)	Flux (l m^{-2} h^{-1} bar^{-1})
Micro filtration (MF)	0,03 - 10 µm	0,1 - 2,0	> 50
Ultra filtration (UF)	0,002 - 0,1 µm	1,0 - 5,0	10 - 50
Nano filtration (NF)	0,001 - 0,01 µm	5,0 - 20	1,4 - 12
Reverse osmosis (RO)	0,0001 - 0,001 µm	10 - 100	0,05 - 1,4

Membrane processes such as micro filtration (MF) has long been used to provide clean drinking water in areas with poor water resources, but these are relatively new for slurry separation.

Ultra filtration (UF) is made on the liquid separation fraction. It is a type of pre-treatment for the reverse osmosis treatment (RO), both technologies being part of a high tech manure treatment facility where the liquid part is purified up to (or near to) clean water. The ultra filtration process will remove suspended solids as well as bacteria and virus, while small dissolved molecules passes the filtration and can be removed by reverse osmosis, where the pore size of the membranes is smaller.



Schematics of the reverse osmosis process (left) and illustration of a cleaning unit with reverse osmosis (www.kruger.dk)

Microfiltration and ultra filtration is fundamentally different from reverse osmosis and nano filtration because those systems use pressure as a means of forcing water to go from low pressure to high pressure (to control the reverse diffusion through the membrane). MF and UF can use a pressurized system but it does not need to include pressure. The compounds retained in the MF and UF are mainly molecules and colloids, which form a "cake" at the membrane surface.

NF and RO detain mostly ions and the osmotic pressure is the governing parameter for the diffusion of water across the membrane. During NF and RO, it is important to avoid precipitation of solids in the membrane (scaling), as this will cause a pressure drop across the membrane. Therefore, the substance concentration and solubility are limiting factors for membrane plant utilization.

In many membrane plants a flow longitudinally along the membrane (crossflow) is often maintained, to reduce the concentration of substances by the membrane surface. This leads to a reduction of the concentration of retained material, and thereby risk of scaling / fouling decreases.

If the slurry is pressurized on one side of such a membrane, its water content is pushed through the membrane. It is thus possible by the use of membrane filtration to remove ammonia and potassium from the slurry liquid phase.

There are many materials that can be used to manufacture membranes, for example cellulose acetate, polyamide and polysulfone. These materials are distinguished by specific characteristics in relation to porosity, pore size and resistance to various substances and environments.

The geometric shape of the membrane is important for internal hydraulic conditions. Moreover, the geometric shape of the membrane affects the physical plant design, and affects how easy the membrane is to be cleaned or recovered.

Environmental effects

Effects on air (emissions):

- The filtration process has no negative effects in it, concerning emissions or odours.

Effects on water/soil (and management)

- As regards leaching of N and P, it can have a positive effect, assumed that the products of the process (fibre fraction, concentrate and permeate) are being used in the most optimal way; field crops can be fertilized with more precision according to their demands. High reduction of recalcitrant organic matter.

Other effects:

- Sanitation and retention of pathogens.

Technical indicators

Components conversion/efficiencies

The process can remove 99% of the organic matter and up to 99.5% of the salts. For manure treatment the K ion still remain in the water fraction and might be the limiting factor for the use of this water as irrigation water.

The input in the process is a liquid fraction, for instance coming from ultra filtration.

Energy consumption or production

Energy consumption by membrane filtration depends on the pore size, material concentrations, pretreatment and operating pressure. There is a clear correlation between the operating pressure and energy consumption. Below is the energy consumption per m3 of purified liquid

Data is for purification of drinking water.

UF:	0,2 - 1,0 kWh/m^3
NF:	0,7 - 1,5 kWh/m^3
RO:	1,5 - 10 kWh/m^3

Reagents

There may be addition of chemicals before the membrane process to increase retention of selected substances or to reduce clogging of the membrane. Belgian trials, for instance, showed that acidification before RO increases retention of nitrogen, since RO membrane can better retain charged ions as ammonium rather than non-charged

molecules such as ammonia.
Observations: NA

Economical indicators
Investment cost: NA
Quantifiable incomes: NA
Non economically quantifiable benefits: NA
Operational costs International experience estimates that the cost of treatment of slurry in a membrane plant will be in the range 1.4 to 8 U.S. dollars (approximately 1 to 7 Euro) per tons of manure.

Selected literature references

- Foged, Henning Lyngsø. 2010, Best Available Technologies for Manure Treatment – for Intensive Rearing of Pigs in Baltic Sea Region EU Member States. Published by Baltic Sea 2020, Stockholm. 102 pp.
- Hinge, J. (2005): Technology for slurry separation – membrane filtration and reverse osmosis. Danish Agricultural Advisory Service, DK 8200 Aarhus – A resume of: Miljøprojekt nr. 882, 2004, Membranfiltrering, erfaring og muligheder i dansk vandforsyning, Miljøstyrelsen
- Thörneby, L., Persson, K., Trägårdh, G., 1999, Treatment of liquid effluents from dairy cattle and pigs using reverse osmosis. J. Agric. Engng Res. 73, 159-170.
- Pieters, J.G., Neukermans, G.G.J, Colanbeen, M.B.A., 1999, Farm-scale membrane filtration of sow slurry. J. Agric. Engng Res. 73, 403-409.
- Fugère, R., Mameri, N., Gallot, J.E., Comeau, Y., 2005, Treatment of pig farm effluents by ultrafiltration. Journal of Membrane Science.

Real scale (commercial or pilot) references

- Reverse osmosis :
Kumac BV
Lupinenweg 8a
5753 SC Deurne
Tel.: +31 0493-312721
www.kumac.nl
- Ultra filtration:
Coöperatie van Veehouders Biogreen UA
Weseperweg 45a
111 PJ Heeten
The Netherlands
Tel: +31 0572-381599
http://www.greenpowersalland.nl/

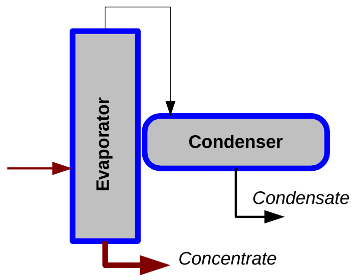
7.2: Concentration by vacuum evaporation

Objectives

The objective of the vacuum evaporation is to concentrate nutrients and organic matter evaporating water at temperatures lower than 100ºC and pressure conditions below vapour pressure of the liquid, recovering the water and volatile emissions by further condensation step.

Level of complexity	Usual scale	Innovation stage
☐ low	☐ on-farm	☐ laboratory/research
☐ medium	☐ medium	☐pilot plant
☒ high complex	☒ large-scale	☒industrial/commercial

General diagram



Applied to

☐ Solid pig manure; ☐ Liquid pig manure; ☐Pig slurry; ☐ Pig deep litter;

☐ Solid Cattle manure; ☐Liquid Cattle manure; ☐Cattle slurry; ☐ Cattle deep litter;

☐ Poultry slurry; ☐ Poultry deep litter.

☒ products of other processes. In this case, a possible combinations is:

30-10-21-55A-43 // 10-21-55A-43-(see Annex A)

Pictures

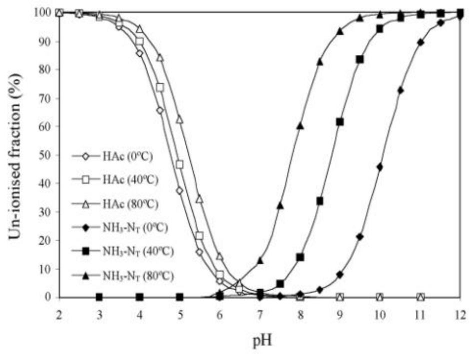
Details of the vacuum evaporation unit at Tracjusa pig manure treatment plant (Juneda, Spain)

Theoretical fundamentals and process description

The goal of evaporation is to vaporize (applying heat) most of the water from a solution (in this case the slurry liquid fraction) containing a desired product (in this case nutrients, organic matter and in general the total solids), that will be maintained inside the evaporator and extracted as the "concentrate" stream. The vapour is removed from the evaporator and recovered in a condenser as "condensate".

When the pressure inside the evaporator unit is reduced below the vapour pressure of the liquid, the liquid evaporates at a lower temperature than normal, with less energy consumption. At industrial operation, evaporation units are usually formed by two or multiple steps. The energy consumption for single-effect evaporators is very high and makes up most of the cost for an evaporation system. Each evaporation step added reduces the energy consumption by 33% (although inversion cost is increased).

To ensure the recovery of nitrogen in the concentrate flow steam, and guarantee its absence in the recovered condensates, ammonia (NH_3-N)-ammonium (NH_4^+-N) equilibrium must be modified, by means of pH control (usually adding a strong acid) If pH inside the evaporator is maintained under pH 5.5 it is guaranteed that ammonium will be recovered in the concentrate (see Figure below).Contrary at pH<5.5 other volatile organics as volatile fatty acids (VFA) are present in its un-ionized form (volatile) and can be easily transferred to condensate, with clearly implications (organic contamination) in condensates post-treatment requirements (see Figure below).



Although with a clear different evaporator designs, the process could be attractive with slurries/manures of a high dry matter content, especially over 30% (e.g. poultry) due to the smaller amounts of water to be removed and higher yields of dry product (Burton and Turner, 2003).

Environmental effects

Effects on air (emissions):

- No negative effects, since evaporated flow is recovered as a condensate. Theoretical "0 gas emissions" including odours

Effects on water/soil (and management)

- Heavy metals are concentrated in the concentrate stream, that can limit product application or land spreading.

Other effects:

- Slurry/manure volume reduction (reducing transport costs) and nutrient recovery (N, P and K in concentrate fraction).
- The concentrate (where N is contained) is also higienized (according to the operation time/temperature).
- Possible necessity of condensates treatment, depending of previous treatment step

Technical indicators

Components conversion/efficiencies

Concentrated obtained with a solid content of 25-30% TS, representing between 15-20% of the process flow rate (from the acidified fraction of a digested pig slurry with TS 2.5-3.5% in an industrial working facility)

>98.0% of nitrogen recovery (remaining in the concentrate) if pH is maintained <5.5 (from analysis and mass balances performed on several working facilities)

Energy consumption or production

Pilot experience at farm scale unit obtained in an unit treating 0,5 m^3/hour:

- electrical energy: 21 kWh/m^3 of treated slurry
- heat: between 107 and 353 kWh/m^3 of treated slurry.

The increasing number of evaporation steps could decrease energy consumption significantly (Agrobiogas, 2006)

At large scale plants (6-8 m^3/h(of acidified pig slurry (with a TS content of 0.9-1.2%) estimated in 250-280 kW/m^3.

Reagents

Sulfuric acid (H_2SO_4) or other strong acid. The acid consumption will depend on the slurry/manure alkalinity, being lower for streams previously treated by anaerobic digestion.

The reagents are not needed to be reagent grade. Consequently, in some applications it has been used H_2SO_4 sub-products of low purity.

Observations:

It requires a previous product (liquid manure/slurry) acidification steps. It implies to introduce and work in the facility with concentrated acids. This fact have implications in:

- The choice of constructive materials (resistance to high temperature and low pH). It requires inox quality>316L.
- Risk of accidents and requirement of training to workers
- Introduction of S forms (if acidification is performed with H_2SO_4) that could appear (at low concentrations) in condensates.

Although this process is applied usually at large scale, there are pilot experiences at farm scale

Economical indicators

Investment cost: NA

Quantifiable incomes:

Due to its pH and reologycal properties, the "concentrate" is not directly sold or applied as fertilizer. Normally a dying post-treatment is required (see drying at chart 6.4)

Non economically quantifiable benefits: NA

Operational costs

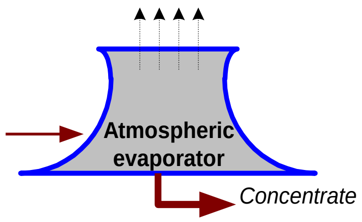
The concentrate (where nutrients are contained) is also hygienized (depending on time/temperature).

Selected literature references

- Agrobiogas (2006). Evaluation of Current and Upcoming Technological Systems for AD. Deliverable 3. Agrobiogas Project: An integrated approach for biogas production with agricultural waste. Project No. 030348 (www.agrobiogas.eu)
- Bonmatí, A., Flotats, X. (2003). Pig slurry concentration by vacuum evaporation: influence of previous mesophilic anaerobic process. J. Air Waste Manage. 53, 21-31. ISSN: 1047-3289.
- Flotats, X., Bonmatí, A., Fernandez, B., Magri, A. /2009). Manure treatment technologies: On-farm versus centralized strategies. NE Spain as case study. Bioresource Technology. 100 (22) 5519-5526; doi:10.1016/j.biortech.2008.12.050
- Burton, C.H., Turner, C. (Eds) (2003). Manure Management. Treatment strategies for sustainable agriculture. Silsoe Research Institute, 490 pps. ISBN: 0-9531282-6-1.
- ITP(2004). Guide pratique du Traitment des effluents porcins. Institute Technique du Porc. ISBN 2-85969-163-4. http://www.adap.org.es/documentos/FOLLETO%20PURINES%20III%2020.06.08.pdf

Real scale (commercial or pilot) references
• TRACJUSA and VAG (Juneda, Spain) • SAVA (Miralcamp, Spain) • VALPUREN-BAÑUELO/VALPUREN POLAN (Toledo, Spain) • ENVAFLO (France)

7.3: Concentration by atmospheric evaporation

<table>
<tr><th colspan="4">Objectives</th></tr>
<tr><td colspan="4">The objective is to concentrate nutrients and organic matter from the liquid fraction of stabilized slurries (after NDN, or aerobic digestion) in the concentrate, using evaporation at atmospheric pressure and moderate temperature.</td></tr>
<tr><th>Level of complexity</th><th>Usual scale</th><th>Innovation stage</th><th rowspan="3">General diagram

</th></tr>
<tr><td>☐ low
☐ medium
☒ high complex</td><td>☐ on-farm
☐ medium
☒ large-scale</td><td>☐ laboratory/research
☐pilot plant
☒industrial/commercial</td></tr>
<tr><th colspan="3">Applied to</th></tr>
<tr><td colspan="4">☐ Solid pig manure; ☐ Liquid pig manure; ☐Pig slurry; ☐ Pig deep litter;
☐ Solid Cattle manure; ☐Liquid Cattle manure; ☐Cattle slurry; ☐ Cattle deep litter;
☐ Poultry slurry; ☐ Poultry deep litter.
☒ products of other processes. In this case, a possible combinations is:
(10 -18) + (59 – 60) +54B (see Annex A)</td></tr>
</table>

Pictures

Atmospheric evaporators at the centralized pig manure treatment plants of Alcarras (left) and Altorricón (right), in Spain (GUASCOR technology)

Theoretical fundamentals and process description

The goal of evaporation is to vaporize most of the water contained in manure or slurry. To avoid nitrogen and organic volatiles (VOC) emissions to the atmosphere, this technology is usually preceded of a biological carbon/nitrogen removal treatment (aerobic digestion and total or partial nitrification-denitrification). Also, it is possible to recover nitrogen in the concentrate, avoiding N atmospheric emissions, if a previous acidification step is introduced.

In the evaporator, the design favours a convective air stream capable of transport the moisture out to the atmosphere.

Although with a clear different evaporator design, the process could be attractive with slurries/manures of a high dry matter content, especially over 30% (e.g. poultry) due to the smaller amounts of water to be removed and higher yields of dry product (Burton and Turner, 2003).

Environmental effects

Effects on air (emissions):

- Possible ammonia and VOC atmospheric emissions if a pre-treatment (NDN or AD+acidification)is not applied
- Generation of odours that must be controlled.

Effects on water/soil (and management)

- In the concentrate stream are also concentrated heavy metals that can limit product application or land spreading.

Other effects:

- Slurry/manure volume reduction (reducing transport costs) and nutrient recovery (N, P and K in concentrate fraction).
- Possibility of partial nutrient recovery.
- The concentrate (where P is contained) is also hygienized (according to the operation time/temperature).
- Possible necessity of condensates treatment, depending of previous treatment step

Technical indicators

Components conversion/efficiencies

High efficiency (up to 90% of nutrients recovery) but with high dependency of previous treatments (organic matter removal/N removal or acidification treatment)

Energy consumption or production

NA. The air flow is natural and, therefore, energy consumption are only expected for pumping the liquid

Reagents

- No reagents when ammonia previously nitrified and partially denitrified by biological processes.
- If ammonia has to be recovered into the concentrate, sulphuric acid or other strong acid is required

Observations:

- Possible problems of solidification (e.g., excessive fouling and material transport) compared to vacuum evaporation.
- The obtained concentrate product must be further dried (dust) and probably pelletized to facilitate land application.

Economical indicators

Investment cost: NA

Quantifiable incomes:

- Dried product can represent an income (depending of its quality) as organic fertilizer.

Non economically quantifiable benefits: NA
Operational costs: NA

Selected literature references

- Burton, C.H., Turner, C. (Eds) (2003). Manure Management. Treatment strategies for sustainable agriculture. Silsoe Research Institute, 490 pps. ISBN: 0-9531282-6-1.
- http://www.adap.org.es/documentos/FOLLETO%20PURINES%20III%2020.06.08.pdf

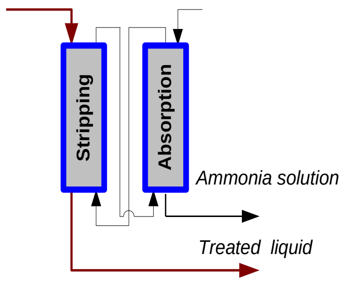
Real scale (commercial or pilot) references

Centralized pig manure treatment plants of GUASCOR company at Spain:

- Alcarràs (Segrià)
- Masies Voltregà and Santa Maria de Corcó (Osona)
- Altorricón (Huesca)

7.4: Ammonia stripping and absorption

Objectives
The objective is the removal of ammonia through volatilization from a liquid phase, by means of a gaseous counterflow (air or steam) and its subsequent recovery in an acidic solution as ammonium salt or by condensation.

Level of complexity	Usual scale	Innovation stage	General diagram
☐ low ☐ medium ☒ high complex	☐ on-farm ☒ medium ☒large-scale	☐ laboratory/research ☒pilot plant ☒industrial/commercial	

Applied to
☐ Solid pig manure; ☐ Liquid pig manure; ☐Pig slurry; ☐ Pig deep litter; ☐ Solid Cattle manure; ☐Liquid Cattle manure; ☐Cattle slurry; ☐ Cattle deep litter; ☐ Poultry slurry; ☐ Poultry deep litter. ☒ products of other processes. In this case, a possible combinations is: (31-32)+ (10-18) + 22 + 55 (see Annex A)

Pictures

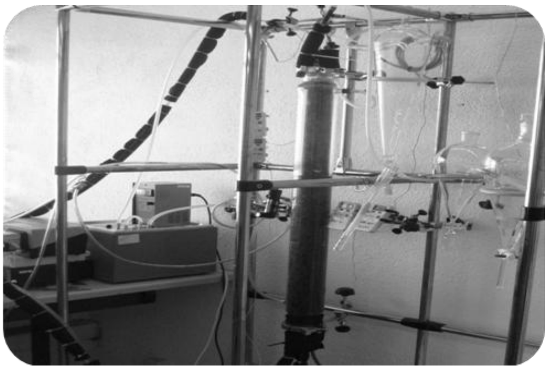


Illustration of a lab scale pilot plant (left) at GIRO (Spain) and a pilot plant in a pig farm (right) at Torelló (Spain)

Theoretical fundamentals and process description

The process is usually performed in vertical columns where the liquid phase is introduced in the upper part while the gaseous phase enters in counterflow from the bottom. To enhance the liquid/gas contact the columns are filled with specifically shaped pieces of inert material (packed column).

The two fundamental control parameters of the process are the temperature and the pH as they establish the equilibrium between ammonia (NH_3) and ammonium (NH_4^+).,. pH is usually set between 9 and 10 by means of base addition or previous CO_2 stripping. For air stripping typical working temperatures are set lower than 100°C while higher temperatures are characteristics of steam stripping (Liao et al., 1995; Zeng et al., 2006; Bonmati and Flotats, 2003).

Stripped ammonia is recovered either by absorption in a second column, with a counter current acid solution, or by vapour condensation, obtaining NH_4OH or salts. Both, liquid ammonia solutions and solid ammonia salts, obtained by condensation and evaporation, could be used directly as fertilizers or sold to other industrial applications (WWT of paper industry,…). Previous anaerobic digestion, with the objective to remove volatile organic matter, enhances the stripping process, avoiding VOC transfer to the absorbed solution.

Environmental effects

Effects on air (emissions):

- Mitigation of possible ammonia and VOC atmospheric emissions by recovering in condensates

Effects on water/soil (and management)

- In the concentrate stream are also concentrated heavy metals that can limit product application or land spreading.

Other effects:

- Slurry/manure volume reduction (reducing transport costs) and nutrient recovery (N, P and K in concentrate fraction).
- The concentrate (where P and N are contained) is also partially hygienized (according to the operation time/temperature).
- Possible necessity of condensates treatment, depending of previous treatment step.

Technical indicators

Components conversion/efficiencies

- Up to 95% of ammonia reduction under optimal conditions
- Almost complete ammonia recovery by absorption in acid solutions is possible with only few acid stoichiometric excess (1.1:2 H_2SO_4:NH_3)

Energy consumption or production

- 14 kWh/kg stripped nitrogen (only for stripping column) (Sagberg et al., 2006),
- At least an equivalent range of values should be considered for the absorption step,
- Depending on the working temperature, heating energy requirements may play a primary role in energy consumption,
- Biogas use in cogeneration equipments could provide the required energy to heat the slurry up,

Reagents

- NaOH, $Ca(OH)_2$ or other bases to increase the pH (if CO_2 stripping is not enough),
- H_2SO_4, HNO_3. H_3PO_4, solution to absorb the NH_3 from the gas phase.

Observations:

- Solid/Liquid separation is usually required as pre-treatment to reduce dry matter content and avoid clogging.

- Anaerobic digestion as pre-treatment enhances stripping efficiency, reduces end product contamination by organic matter and provides energy and heat required for the process.
- Already applied at industrial scale for different residues (landfill leachate, sludge supernatants in WWTP, fertilizer plant wastewaters, industrial wastewaters, wastewaters from composting facilities).

Economical indicators

Investment cost:

For an industrial plant projected in Catalonia for treating 10 m^3/h of digested pig slurry the inversion cost (stripping including storage tanks and condensers), investment cost was estimated in 0.4-0.5M€

For the Ihan plant located in Slovenia (Report 4. Annex F), treating 15 m^3/h, the estimated investment cost of stripping column was 0.25M €

Quantifiable incomes:

Up to 0.35 €/kg of nitrogen recovered in a $(NH_4)2SO_4$ solution at 10% N to be sold to fertilizer company

Non economically quantifiable benefits:

- Reduction of N loads to the fields when manure is applied
- Odour reduction and easier N management
- Favours closing the nutrient cycle, consequently the consumption of fossil fuels used to synthesize chemical fertilizers is reduced

Operational costs:

- Reagent cost: 0.66€/m^3 for NaOH / 0.21 €/m^3 for H_2SO_4
- 2.5-4.5 €/kg of stripped nitrogen (only for the stripping column) (Collivignarelli et al., 1998). At least an equivalent range of values should be considered for the absorption step

Selected literature references

- Bonmatí, A., Flotats, X. (2003). Air Stripping of Ammonia from Pig Slurry: Characterization and Feasability as a Pre- or Post-Treatment to Mesophilic Anaerobic Digestion. *Waste Management*, 23(3): 261-272. doi:10.1016/S0956-053X(02)00144-7
- Collivignarelli, C., Bertanza, G., Baldi, M., &Avezzù, F. Ammonia stripping from MSW landfill leachate in bubble reactors: process modeling and optimization. Waste Management and Research, 1998, 16(5), 455–466.
- Sagberg, P.; Ryrfors, P. and Berg K.G.10 years of operation of an integrated nutrient removal treatment plant: ups and downs. Background and water treatment. Water Science and Technology, 2006, 53(12), 83-90.
- Sommariva. F.. Boccasile. G. Sandionigi. M.L.. Adani. F.. Provoli. G. (2011) Strippaggio dell'azoto. buoni risultati se abbinato all'implianto di biogas. L'informatore Agrario. 29. pp. 14-17.
- Liao, P. H.; Chen, A.; Lo, K. V. Removal of nitrogen from swine manure wastewaters by ammonia stripping.Bioresource Technology, 1995, 54(1), 17-20.
- Zeng, L., Mangan, C., Li, X. (2006). Ammonia recovery from anaerobically digested cattle manure by steam stripping. Water Sci. Technol., 54(8):137-145.

Real scale (commercial or pilot) references

- Farm Ihan, Breznikova, Domzale (Slovenia)
- Condotto Dal Sata AD & Stripping plant (Lombardia Region, Italy)

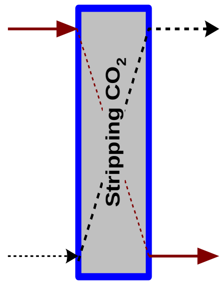
7.5: Carbon dioxide stripping

Objectives

Removal of carbon dioxide (CO_2) through volatilization from a liquid phase by means of a counter current gaseous flow.

Level of complexity	Usual scale	Innovation stage
☐ low	☐ on-farm	☒ laboratory/research
☐ medium	☐ medium	☐ pilot plant
☒ high complex	☐ large scale	☐ industrial/commercial

General diagram



Applied to

☐ Solid pig manure; ☒ Liquid pig manure; ☒ Pig slurry; ☐ Pig deep litter;

☐ Solid Cattle manure; ☒ Liquid Cattle manure; ☒Cattle slurry; ☐ Cattle deep litter;

☐ Poultry slurry; ☐ Poultry deep litter.

☒ products of other processes. In this case, a possible combinations is:

(10-18)+ 56 + 55 // (31-32) + (10-18) +56 + 55 // 56 + 62A // (31-32) +56 + 62A (see Annex A)

Pictures

Not available

Theoretical fundamentals and process description

The process is usually performed in packed columns to enhance the liquid/gas contact surface. pH and temperature are the two major parameters controlling the process. CO_2 volatilization is enhanced at low pH and high temperature.

CO_2 stripping resulted in a pH rise till values around 8-8.5 ($HCO_3^- + H^+ \rightarrow CO_2 + H_2O$). This pH increase is the reason why it is used as pre-treatment to processes that requires high operational pH (e.g. ammonia stripping and struvite precipitation). Alkali saving in the subsequent processes could be higher than 45%.

The major drawback is the simultaneous release by stripping of NH_4^+, if it is not controlled properly. Struvite precipitation with simultaneous CO_2 stripping resulted in a 30% of P recovery, but > 40% of ammonia was removed through non controlled stripping (Song et al., 2011).

Environmental effects

Effects on air (emissions):

- Possible ammonia and VOC atmospheric emissions.

Effects on water/soil (and management)

- *No particular effects of this process alone*

Other effects:

- Alkali savings in subsequent treatment processes requiring high operation pH (e.g. ammonia stripping, struvite precipitation).

Technical indicators	
Components conversion/efficiencies NA	**Energy consumption or production:** Expected similar to ammonia stripping **Reagents :** NA
Observations: Although studied in research works, real applications are not identified	

Economical indicators
Investment cost: NA
Quantifiable incomes: NA
Non economically quantifiable benefits: NA
Operational costs: NA

Selected literature references

- Fattah, E.P., Zhang, Y., Mavinic, D.S., Koch, F.A. (2010). Use of carbon dioxide stripping for struvite crystallization to save caustic dosage: performance at pilotscale operation. *Canadian Journal of Civil Engineering*, 37: 1271-1275.
- Song, Y-H., Wiu, G-L., Yuan, P., Cui, X-Y.,Peng, J-P., Zeng, P., Duan, L., Xiang, L-C., Qian, F. (2011). Nutrient removal and recovery from anaerobically digested swine wastewater by struvite crystallization without chemical additions. *Journals of Hazardous Materials*, 190: 140-149.

Real scale (commercial or pilot) references

NA

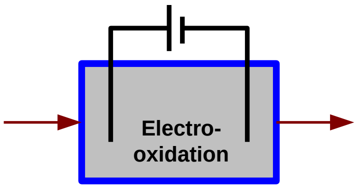
7.6: Electro-oxidation

Objectives

The objective is to produce the oxidation of components such as organic matter, metals, etc in the anode of an electro-chemical reactor by means of an external electric current (application of electrolysis).

Level of complexity	Usual scale	Innovation stage
☐ low	☐ on-farm	☐ laboratory/research
☐ medium	☐ medium	☒ pilot plant
☒ high complex	☒ large scale	☐industrial/commercial

General diagram



Applied to

☐ Solid pig manure; ☐ Liquid pig manure; ☐ Pig slurry; ☐ Pig deep litter;

☐ Solid Cattle manure; ☐ Liquid Cattle manure; ☐Cattle slurry; ☐ Cattle deep litter;

☐ Poultry slurry; ☐ Poultry deep litter.

☒ products of other processes. In this case, a possible combination is:
12+10B+57 (see Annex A)

Pictures

Illustration of an industrial electro-oxidation plant and visual results of lab trials for pig slurry (MWW SL, www.minimalwastewater.com)

Theoretical fundamentals and process description

The organic and toxic pollutants present in treated wastewaters are usually destroyed by a direct anodic process or by an indirect anodic oxidation via the production of oxidants such as hydroxyl or chorine radicals. Reagent addition is not always required and, consequently, secondary contaminants are not produced.

Some of the typical potential chemical reactants are: $H_2O/\bullet OH$ (hydroxyl radical), O_2/O_3 (ozone), $SO_4^{2-}/S_2O_8^{2-}$ (peroxodisulfate), Cl^-/ClO_2^- (chlorine dioxide), Cl^-/Cl_2 (chlorine), $Cr^{3+}/Cr_2O_7^{2-}$ (dichromate) or H_2O/O_2 (oxygen).(Chen, 2004):

- Direct electrooxidation processes. Electrooxidation of pollutants can occur directly on anodes by generating physically adsorbed "active oxygen" (adsorbed hydroxyl radicals, •OH). The anodic oxidation does not need to add a large amount of chemicals to wastewater or to feed O_2 to cathodes, with no tendency of producing secondary pollution.
- Indirect electrooxidation processes. Use of the chlorine and hypochlorite generated anodically to destroy pollutants, use the addition of Fe^{2+} salts or formed in-situ from a dissolving iron anode to make an electro-Fenton reaction[1] or ions addition, usually called mediators, are oxidized on an anode from a stable, low valence state to a reactive, high valence state (Ag^{2+}, Co^{3+}, Fe^{3+}, Ce^{4+} and Ni^{2+})

The goal of electro-oxidation is the possibility or recalcitrant substances degradation, as phenols, without reagents addition or electrode sacrifice. This treatment is applied after organic-colloidal matter elimination, which could interfere in the process efficiency.

1: Fenton is a process that oxidizes contaminants by means of fenton's reagent (a solution of hydrogen peroxide and iron catalyst). In the electro-fenton process, hydrogen peroxide is produced in the required amount from the electrochemical reduction of oxygen

Environmental effects

Effects on air (emissions):

- Potential risk of emissions (NH_3) due to the conversion on N organic forms.

Effects on water/soil (and management)

- Possible formation of chlorinated organic compounds intermediates or final products (Indirect electro-oxidation processes) or secondary pollution from the heavy metals added (mediated electroxidation)

Other effects:

- High reported COD removal and organic N mineralization (N conversion to N-NH_4^+-N)
- High reduction of recalcitrant organic matter (ie. Phenol elimination).
- The presence of colloidal organic matter can produce interference on oxidation (a prior filtration is required).

Technical indicators

Components conversion/efficiencies

MWW Sl (www.minimalwastewater.com) reported following laboratory trials for pig slurry combining electro-coagulation and electro-oxidation:

- N_T, from 6200 to 22 mg/l (99.9 %)
- N-NH_4^+, from 4350 to 4 mg/l (99.9 %)
- COD, from 12300 to 86 (99.3%)

Energy consumption or production

High energy consumption (current density >150 mA/cm^2 or electricity consumption , kW/m^3)
25 kWh/kg COD for oil mill wastewaters (Un *et al.*, 2008).

Reagents

Oxidation effect of chlorine/hypochlorite produced during the electrolysis requires high chloride concentration, typically larger than 3 g/l.

Observations

- High energy consumption (current density >150 mA/cm^2)
- Compact technology

The important part of an anodic oxidation process is obviously the anode material. Anode materials investigated include glassy carbon, Ti/RuO2, Ti/Pt–Ir, fibre carbon, MnO2, Pt–carbon black, porous carbon felt stainless steel and reticulated vitreous carbon. However, none of them have sufficient activity and at the same time stability

(Chen, 2004).

Economical indicators
Investment cost: NA
Quantifiable incomes: NA
Non economically quantifiable benefits: NA
Operational costs: 0.22 and 1.12€/kg COD for oil mill wastewaters (Un *et al*., 2008). MWW SL reports 1.9 €/m3 for pig slurry (www.minimalwastewater.com)

Selected literature references

- Chen, G. (2004). Electrochemical technologies in wastewater treatment. *Separation and Purification Technology* 38, 11–41. doi:10.1016/j.seppur.2003.10.006
- Un, U.T., Altay, U., Koparal, S., Ogutveren, U.B. (2008). Complete treatment of olive mill wastewaters by electrooxidation. *Chemical Engineering Journal* 139, 445–452. doi:10.1016/j.cej.2007.08.009

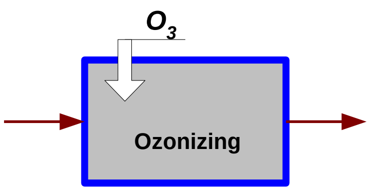
Real scale (commercial or pilot) references
NA

7.7: Ozoning

Objectives
The objective is to produce the oxidation of components such as organic matter and odours by ozone addition

Level of complexity	Usual scale	Innovation stage
☐ low	☐on-farm	☐ laboratory/research
☐ medium	☐ medium	☐pilot plant
☒ high complex	☒ large scale	☒ industrial/commercial

General diagram



Applied to

☐ Solid pig manure; ☐ Liquid pig manure; ☐ Pig slurry; ☐ Pig deep litter;

☐ Solid Cattle manure; ☐ Liquid Cattle manure; ☐ Cattle slurry; ☐ Cattle deep litter;

☐ Poultry slurry; ☐ Poultry deep litter.

☒ products of other processes. In this case, a possible combinations is:

(10 – 18) + 58 // (10 – 18) +59A +58 (see Annex A)

Pictures

Ozonizing units at Alhama de Murcia (Murcia, Spain) pig manure treatment plant, OTSI technology (Infoenviro July/August 2008)

Theoretical fundamentals and process description

Ozone is a very powerful oxidising agent and reacts very rapidly with almost everything. Ozone must be produced locally because it is unstable and cannot be stored. Ozone treatment combined with the flotation of the suspended material in the slurry forms a clear liquid and a concentrated sludge. The fluid can then be further processed to a very high quality outflow, while the sludge fraction should be handled as flotation sludge.

The use of ozone can be applied for the remediation of nuisance odours in liquid manures. Gaseous ozone is bubbled directly into liquid manure in a continuously stirred batch reactor.

Olfactometry determinations demonstrate a significant reduction in odours in ozonized samples as compared to raw and oxygenated samples, however, with big variation among technology suppliers. Watkins et al. (1997) found that volatile fatty acids, nitrate and phosphate concentrations were unchanged by ozoning. The oxidation of organic matter by ozone allows the application of this process previous to an acidification and evaporation steps.

Ozone can be generated from air or by pure oxygen. Operating costs for the production of ozone is relatively high. Although it is theoretically possible to oxidize a very large portion of the organic matter in the slurry with ozone, this is not economically feasible.

Environmental effects

Effects on air (emissions):

- Deodorizing effect (mainly in volatile organic carbon emissions).
- H_2S emissions reduction (even though with lower efficiency as compared to volatile organic carbon emissions)
- The possible formation of secondary by-products like tri-halomethones (THM's) with the use of ozone (at high O_3 doses)

Effects on water/soil (and management)

- Possible formation of chlorinated organic compounds intermediates or final products (Indirect electro-oxidation processes) or secondary pollution from the heavy metals added (mediated electroxidation)

Other effects:

- High reported COD removal including recalcitrant organic matter (function of O_3 dose).
- The presence of colloidal organic matter can produce interference on oxidation (a prior filtration is required).
- Disinfection (microorganism inactivation)

Technical indicators

Components conversion/efficiencies	Energy consumption or production
60-70% in odour reduction (Alkoaik, 2009)	• 115 W/380L (pilot plant Wu et al., 1999) • 1.5 kWh/Tn manure (Alkoaik, 2009) **Reagents** • Reported benefits at O_3 doses of 0.5-1 g/l • Low-dose ozone application is currently being tested at farm level in Denmark (0-150mg/L manure) according to Bildsøe and Feilberg (2010)

Observations:

- High energy consumption (function of O_3 dose)
- Compact technology
- Methods for ozone treatment and separation of manure are being developed, and there are great expectations to the technology

Economical indicators
Investment cost: 22.100 €/m^3 of input slurry (pilot plant Wu et al., 1999)
Quantifiable incomes NA
Non economically quantifiable benefits Odour reduction; oxidation of recalcitrant organic matter
Operational costs: 1.58-3.16 €/m^3 of swine slurry (pilot plant Wu et al., 1999) 0.23$/Tn (Alkoaik, 2009)

Selected literature references

- Alkoaik, F.N. (2009). Ozone treatment of animal manure for odour control. *American Journal of Environmental Science* 5(6): 765-771. ISSN 1553-345X
- Bildsøe P, Feilberg A. (2010). Effect of low ozone dose treatment on emission and composition of pig manure. *Environmental and Sanitary Safety Aspects of Manure and Organic Residues Utilization. RAMIRAN 2010*.
- Infoenviro (2008). Plant in Alhama de Murcia to Treat 105,000 m3/year of Pig Slurry, with 15-MW Cogeneration Plant. July/August, 2008.
- Watkins, B.D., Hengemuehle, S.M., Person, H.L., Yokoyama, M.T., masten, S. (1997). Ozonation of swine manure wastes to control odors and reduce the concentrations of pathogens and toxic fermentation metabolites. *Ozone Science & Engineering* 19, 425-437.
- Wu, J.J., Park, S-H., Hengemuehle, S.M., Yokoyama, M.T., Person, H., Gerrish, J.B., Masten, S.J. (1999). The Use of Ozone to reduce the Concentration of Malodorous Metabolites in Swine Manure Slurry. *Journal of Agricultural Engineering Research*. 72, 317-327.

Real scale (commercial or pilot) references

- FUDEPOR Pig manure treatment plant (100,000 m3/y)
  Calle paraje de la Costera s/n
  Alhama de Murcia
  E-30840 Murcia (Spain)
  Phone: +34 968431720

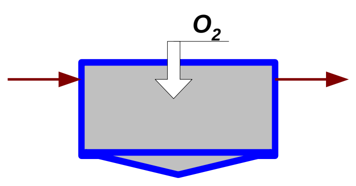
7.8: Aerobic digestion (aeration)

Objectives

Biodegradation of organic matter under aerobic conditions. N-removal through nitrification-denitrification is feasible when oxic and anoxic conditions are alternated in space or time.

Level of complexity	Usual scale	Innovation stage
☒ low	☒ on-farm	☐ laboratory/research
☐ medium	☐ medium	☐ pilot plant
☐ high complex	☐ large scale	☒ industrial/commercial

General diagram



Applied to

☐ Solid pig manure; ☒ Liquid pig manure; ☒ Pig slurry; ☐ Pig deep litter;

☐ Solid Cattle manure; ☒ Liquid Cattle manure; ☒ Cattle slurry; ☐ Cattle deep litter;

☐ Poultry slurry; ☐ Poultry deep litter.

☒ Products of other processes. In this case, a possible combination is:

12-59A (see Annex A)

Pictures

Illustration of an aerobic digestion system based on intermittent aeration aiming to N-removal in a pig farm at Almacelles (Spain).

Theoretical fundamentals and process description

Aerobic digestion consists on the biological decomposition of organic matter to dioxide carbon (CO_2) by aerobic heterotrophic microorganisms. By applying this process, only the biodegradable organic matter can be removed. This process is equivalent to the one applied in wastewater treatment plants (WWTP) for the aerobic removal of organic carbon.

This process can take place together with nitrification (hydraulic residence time longer than 6 days will be needed). When it is coupled with anoxic phases it may result in N-removal depending on the availability of biodegradable organic carbon for denitrification.

Environmental effects

Effects on air (emissions):

- NH_3 emission if the process is not coupled with NDN

Effects on water/soil (and management): -

Other effects:

- High reported COD removal (function of aeration).
- A higher quantity of sludge is produced (from microbial activity) compared with the anaerobic treatment.

Technical indicators

Components conversion/efficiencies: A

Energy consumption or production: Energy consumption depends on the composition of the slurry in terms of BOD and N (when nitrification is allowed). Air is added to the system at an approximate rate of 1.5 kg O_2/kg organic matter oxidized.

Reagents: NA

Observations: Simple technology and simple to install

Economical indicators

Investment cost: NA

Quantifiable incomes: NA

Non economically quantifiable benefits: NA

Operational costs: NA

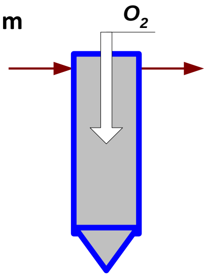
Selected literature references

- Burton, C.H. (1992). A review of the strategies in the aerobic treatment of pig slurry: purpose, theory and method. *J. Agric. Eng. Res.* 53, 249-272.
- Ndegwa, P.M., Zhu, J., Luo, A. (2001). Effect of batch aeration-treatment on the solubility of phosphorus in pig manure. *J. Agric. Eng. Res.* 80, 365-371.
- Park, K.J., Zhu, J., Zhang, Z. (2005). Influence of the aeration rate and liquid temperature on ammonia emission rate and manure degradation in batch aerobic treatment. *Trans. ASAE.* 48, 321-330.

Real scale (commercial or pilot) references

-

7.9: Auto thermal aerobic digestion (ATAD)

Objectives			
Self-heating thermophilic aerobic digestion (ATAD). This type of process causes a biodegradation of organic carbon and it is especially suitable to avoid the dissemination of pathogens.			
Level of complexity	**Usual scale**	**Innovation stage**	**General diagram**
☐ low ☒ medium ☐ high complex	☒ on-farm ☒ medium ☐ large scale	☐ laboratory/research ☐ pilot plant ☒ industrial/commercial	

Applied to

☐ Solid pig manure; ☐ Liquid pig manure; ☒ Pig slurry; ☐ Pig deep litter;

☐ Solid Cattle manure; ☐ Liquid Cattle manure; ☒ Cattle slurry; ☐ Cattle deep litter;

☒ Poultry slurry; ☐ Poultry deep litter.

☒ Products of other processes. In this case, a possible combination is:

(10-18) + 59B (see Annex A)

Pictures

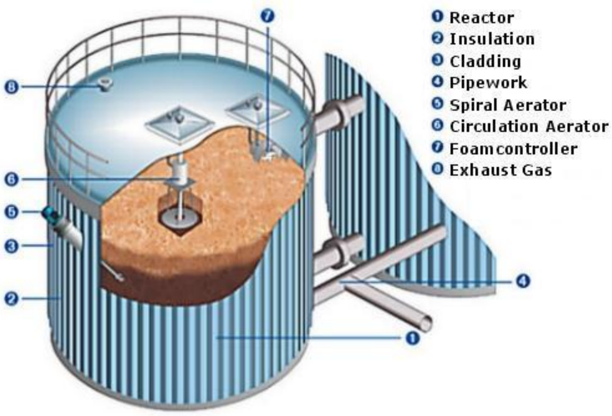


Illustration of an ATAD system (http://isma.pagesperso-orange.fr/en_sat-documentation.html).

Theoretical fundamentals and process description

Aerobic digestion consists on the biological decomposition of organic matter to dioxide carbon (CO_2) by aeration (mediated by aerobic microorganisms). By applying this process, only the biodegradable organic matter can be removed. The objective is to remove organic matter, without seeking for a given C/N ratio or quality for the final product. Heat released by the decomposition of the organic matter results in thermophilic temperatures inside the reactor up to 75ºC (but preferably in the 55-65ºC range) with the consequent advantages of pathogens removal. Under thermophilic conditions no nitrification will occur and nitrogen will be conserved in the liquid phase. Part of the heat released due to biodegradation may be recovered. Foam formation may occur. This process is in commercial stage for treating animal manure (Juteau, 2006).

With a similar concept, a mesophilic system has been proposed for pig or poultry manure after a solid/liquid separation (AMAD, Autoheated Mesophilic aerobic digestion, http://isma.pagesperso-orange.fr/en_sat-documentation.html). Working at a controlled temperature around 34ºC, nitrification can be promoted as well, and integration in a biological nitrogen removal system could be possible.

Environmental effects

Effects on air (emissions):

- NH_3 emission if the ATAD process is not coupled with NDN (AMAD). Emissions of ammonia, increased at thermophilic temperatures (depending on working pH)

Effects on water/soil (and management): -

Other effects:

- Removal of pathogens if thermophilic temperatures are maintained.
- Removal of biodegradable organic matter. High reported COD removal (function of aeration).
- Effluent of ATAD contains two main forms of nitrogen, ammonia and organic nitrogen. In addition an inorganic precipitate such as struvite may be present (Juteau, 2006).
- A higher quantity of sludge is produced (from microbial activity) compared with the anaerobic treatment systems.

Technical indicators

Components conversion/efficiencies: NA

Energy consumption or production: Energy consumption (aeration) depends on the slurry composition (organic matter content). Theoretically, it is needed 1.5 kg O_2/kg organic matter oxidized.

Reagents: --

Observations: NA

Economical indicators

Investment cost: NA

Quantifiable incomes: NA

Non economically quantifiable benefits: Removal of pathogens if thermophilic temperatures are maintained.

Operational costs: NA

Selected literature references

- Blackburn, J.W. (2001). Effect of swine waste concentration on energy production and profitability of aerobic thermophilic processing. *Biomass Bioenergy* 21, 43-51. DOI: 10.1016/S0961-9534(01)00013-7.
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- Juteau, P., Tremblay, D., Ould-Moulaye, C.-B., Bisaillon, J.-G., Beaudet, R. (2004). Swine waste treatment by self-heating aerobic thermophilic bioreactors. *Water Res.* 38, 539-546. DOI: 10.1016/j.watres.2003.11.001.
- Juteau, P. (2006). Review of the use of aerobic thermophilic bioprocesses for the treatment of swine waste. *Livest. Sci.* 102, 187-196. DOI: 10.1016/j.livsci.2006.03.016.

Real scale (commercial or pilot) references

NA

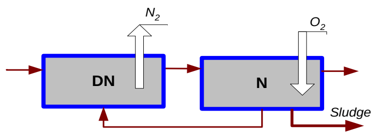
7.10: Nitrification-denitrification - NDN (conventional)

Objectives

Biological conversion of ammonium into di-nitrogen gas (N_2) using classical N-removal process, combining autotrophic[1] nitrification under aeration and heterotrophic[2] denitrification under anoxic conditions and presence of organic-C.

Level of complexity	Usual scale	Innovation stage
☐ low	☒ on-farm	☐ laboratory/research
☒ medium	☒ medium	☐ pilot plant
☐ high complex	☒ large scale	☒ industrial/commercial

General diagram



Applied to

☐ Solid pig manure; ☒ Liquid pig manure; ☐ Pig slurry; ☐ Pig deep litter;

☐ Solid Cattle manure; ☒ Liquid Cattle manure; ☐ Cattle slurry; ☐ Cattle deep litter;

☐ Poultry slurry; ☐ Poultry deep litter.

☒ Products of other processes. In this case, a possible combination is:

12-60 // 10A-14-60-22-62B (see Annex A)

Pictures

Illustration of NDN systems: at pig-farm scale (left) at Calldetenes (Spain); and in a centralized pig manure treatment plant (right) at Langa de Duero (Spain) (Rodríguez, 2003). Below there is a view of the respective biological reactors.

[1] *Autotrophic organisms use an inorganic cabon source for growing (i.e.: bicarbonate).*
[2] *Heterotrophic organisms use an organic carbon source for growing.*

Theoretical fundamentals and process description

During nitrification ammonium is aerobically oxidized to nitrite (eq. 1) by ammonium-oxidizing bacteria, and subsequently nitrite is oxidized to nitrate by nitrite-oxidizing bacteria (eq. 2).

$NH_4^+ + 1.5\ O_2 \rightarrow NO_2^- + 2H^+ + H_2O$ (nitritation) (eq. 1)

$NO_2^- + 0.5\ O_2 \rightarrow NO_3^-$ (nitratation) (eq. 2)

During denitrification nitrate is reduced to nitrogen gas under presence of biodegradable organic carbon being nitrite and nitrogen oxides by-products of this reaction (eq. 3).

$0.20\ NO_3^- + 1.20\ H^+ + e^- \Rightarrow 0.10\ N_2 + 0.60\ H_2O$ (denitrification via nitrate) (eq. 3)

Aeration is one of the main operational parameters during nitrification with theoretical requirements of 4.57 kg O_2 kg^{-1} N. Organic requirements during denitrification are of approximately 6.0 kg COD kg^{-1} NO_3^--N. Pretreatments such as separation and anaerobic digestion may constrain availability of biodegradable organic carbon during denitrification. Process temperature will affect on the process kinetics (optimal: 35ºC). Usual implementation is carried out considering suspended biomass (activated sludge) under loading rates of up to 0.25 kg N m^{-3} d^{-1}. A typical treatment system has two different outputs: treated liquid effluent and biological sludge.

Nitrite short-cut instead of classical performance via nitrate may be adopted for optimizing the process, resulting in savings of 25% aeration and 40% organic carbon (eq. 1 + 4).

$0.33\ NO_2^- + 1.33\ H^+ + e^- \Rightarrow 0.17\ N_2 + 0.67\ H_2O$ (denitrification via nitrite) (eq. 4)

Different control strategies can be applied to avoid nitrate formation: high concentration of ammonia inside the nitrifying reactor, optimal process temperature combined with low solids residence time, low dissolved oxygen levels, etc. It must be assured that this performance strategy does not imply an increase in the emissions of nitrogen oxides (Rajagopal and Béline, 2011).

Environmental effects

Effects on air (emissions):

- Emissions of greenhouse gases (methane and nitrous oxide) and ammonia (NH_3) are reduced when the biological treatment is compared to the use of storage alone (based on 6 months storage before spreading) (Loyon *et al.*, 2007). Risk of emission of N_2O may exist if process is not well managed (Martinez *et al.*, 2009).

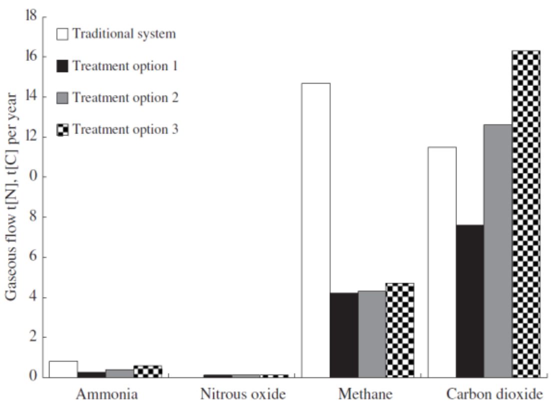


Figure showing estimated annual gaseous flow for four slurry management systems (Traditional: 6 months storage before spreading; Treatment 1: storage + biological treatment + decanting; Treatment 2: storage + compacting screw + biological treatment + decanting; Treatment 3: storage + decanter centrifuge + biological treatment + decanting) (Loyon *et al.*, 2007).

Effects on water/soil (and management): -

Other effects:

- Removal of biodegradable organic matter. High reported COD removal (function of aeration).
- Removal of ammonia in form of N_2 (innocuous) gas. The N removal can enhance the capability of manure/slurry management. Interesting in areas with nitrogen surplus.
- A higher quantity of sludge is produced (from microbial activity) compared with the anaerobic treatment systems.

Technical indicators

Components conversion/efficiencies:

Maximum N-removal efficiencies attainable are up to 70% (rest of N will be separated in the solid fraction, assimilated by the biological sludge, or will remain in the liquid effluent). If efficiency is evaluated on the liquid phase it may be more than attain 90%.

Energy consumption or production:

In the case of slurries, usual values are in the range of 10-20 kWh/m^3. Final value will depend on the composition of the stream to be treated, the efficiency on transferring oxygen of the aeration equipment, operational conditions applied, etc.

Reagents:

4.57 kg O_2/kg N to oxidize ammonium to nitrate (NH_4^+ => NO_3^-)

3.43 kg O_2/kg N to oxidize ammonium to nitrite (NH_4^+ => NO_2^-)

Organic internal requirements during denitrification are of approximately 6.0 kg COD-manure/kg NO_3^--N (NO_3^- => N_2)

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Organic internal requirements during denitrification are of approximately 3.5 kg COD-manure/kg NO_2^--N (NO_2^- => N_2)

Observations: NA

Economical indicators

Investment cost:

240,000-300,000 € (plant treating 15,000 m^3 pig slurry/year)

700,000-1,200,000 € (plant treating 50,000 m^3 pig slurry/year)

Quantifiable incomes: NA

No incomes

Non economically quantifiable benefits:

Economical investment and the operative cost could be worth, in areas of nitrogen surplus, if these costs are lower than the transportation and application cost to long distances.

Operational costs:
Costs are dependent on the composition of the manure to be treated.
1.5-3.0 €/tonne considering exclusively N-removal treatment
2.5-5.2 €/tonne considering previous separation S/L, and the later treatment of the solid fraction by composting.

Selected literature references

- Béline, F., Daumer, M.L., Guiziou, F. (2004). Biological aerobic treatment of pig slurry in France: nutrients removal efficiency and separation performances. *Trans. ASAE.* 47, 857-864.
- Choi E. (2007). Piggery Waste Management: Towards a Sustainable Future. IWA Publishing. ISBN:

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- Loyon, L., Guiziou, F., Beline, F., Peu, P. (2007). Gaseous emissions (NH_3, N_2O, CH_4 and CO_2) from the aerobic treatment of piggery slurry - Comparison with a conventional storage system. *Biosyst. Eng.* 97, 472-780. DOI: 10.1016/j.biosystemseng.2007.03.030.
- Magrí, A., Flotats X. (2008). Modelling of biological nitrogen removal from the liquid fraction of pig slurry in a sequencing batch reactor. *Biosyst. Eng.* 101**,** 239-259. DOI: 10.1016/j.biosystemseng.2008.08.003.
- Magrí, A., Guivernau, M., Baquerizo, G., Viñas, M., Prenafeta-Boldú, F.X., Flotats, X. (2009). Batch treatment of liquid fraction of pig slurry by intermittent aeration: process simulation and microbial community analysis. *J. Chem. Technol. Biotechnol.* 84, 1202-1210. DOI: 10.1002/jctb.2158.
- Martinez, J., Dabert, P., Barrington, S., Burton, C. (2009). Livestock waste treatment systems for environmental quality, food safety, and sustainability. *Bioresour. Technol.* 100, 5527-5536. DOI: 10.1016/j.biortech.2009.02.038.
- Rajagopal, R., Béline, F. (2011). Nitrogen removal via nitrite pathway and the related nitrous oxide emission during piggery wastewater treatment. *Bioresour. Technol.* 102, 4042-4046. DOI: 10.1016/j.biortech.2010.12.017.
- Rodríguez, J. (2003). Planta de tratamiento biológico de purines, con cogeneración asociada, promovida por Ros Roca en Langa de Duero, Soria. *Infopower,* nº 59 *(in Spanish)*.
- Vanotti, M.B., Szogi, A.A., Millner, P.D., Loughrin, J.H. (2009). Development of a second-generation environmentally superior technology for treatment of swine manure in the USA. *Bioresour. Technol.* 100, 5406-5416. DOI: 10.1016/j.biortech.2009.02.019.
- Vanotti, M.B., Szogi, A.A., Vives, C.A. (2008). Greenhouse gas emission reduction and environmental quality improvement from implementation of aerobic waste treatment systems in swine farms. *Waste Manage.* 28, 759-766. DOI: 10.1016/j.wasman.2007.09.034.

Real scale (commercial or pilot) references

- S.A.T. Caseta d'en Grau
  8506 Calldetenes
  Barcelona, Spain
  TEL: +34 607 839 260

- Langa de Duero Enercorr XXI, S.L.
  Empresa del Grupo Ros Roca
  c/ Solana, S/N
  42320 Langa de Duero
  Soria, Spain
  TEL: +34 975 35 31 05

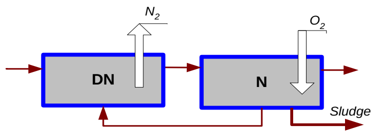
7.11: Partial nitrification – Autotrophic anammox denitrification

Objectives

Biological conversion of ammonium into di-nitrogen gas (N_2) using advanced totally autotrophic[1] N-removal treatment, combining partial nitrification (PN) under aeration and denitrification by anaerobic ammonium oxidation (anammox).

Level of complexity	Usual scale	Innovation stage
☐ low	☐ on-farm	☒ laboratory/research
☐ medium	☐ medium	☐ pilot plant
☒ high complex	☐ large scale	☐ industrial/commercial

General diagram



Applied to

☐ Solid pig manure; ☒ Liquid pig manure; ☐ Pig slurry; ☐ Pig deep litter; ☐ Solid Cattle manure; ☒ Liquid Cattle manure; ☐ Cattle slurry; ☐ Cattle deep litter; ☐ Poultry slurry; ☐ Poultry deep litter.

☒ Products of other processes. In this case, a possible combination is:

31A + 10A + 15 + 61 (see Annex A)

Pictures

Illustration of lab-scale reactors using totally autotrophic N-removal combining partial nitrification and anammox, at the Laboratory of Coastal Plains Soil, Water and Plant Research Centre. ARS-USDA. Florence (SC-USA).

[1] *Autotrophic organisms use an inorganic cabon source for growing (i.e.: bicarbonate).*

Theoretical fundamentals and process description

During partial nitrification, ammonium (NH_4^+) is aerobically oxidized to nitrite (NO_2^-) by ammonium-oxidizing bacteria (eq. 1).

$NH_4^+ + 1.5\ O_2 \rightarrow NO_2^- + 2H^+ + H_2O$ (eq. 1)

According to the anammox needs, only 57% NH_4^+-N should be oxidized to NO_2^--N (1.32 g NO_2^--N g^{-1} NH_4^+-N) (eq. 2). Subsequently, anaerobic ammonium oxidation reaction results in the combination of ammonium and nitrite to form di-nitrogen gas.

$NH_4^+ + 1.32\ NO_2^- + 0.066\ HCO_3^- + 0.13\ H^+ \rightarrow 1.02\ N_2 + 0.26\ NO_3^- + 0.066\ CH_2O_{0.5}N_{0.15} + 2.03\ H_2O$ (eq. 2)

Theoretical requirements for aeration during nitrification are 60% less than complete nitrification. No nitrogen oxides are formed as by-product during this process. Since it is an autotrophic conversion it is expected a low sludge production. Low growth rates of anammox bacteria may imply long periods for the start-up of reactors. Previous anaerobic digestion of manure will decrease biodegradable organic matter content, which is favourable for the process and reduces coexistence of heterotrophic denitrification. Temperature will affect on the process kinetics (optimal: 35ºC). Process implementation may be done considering two separate reactors (PN-anammox) or gathering both processes in the same reactor (CANON).

Environmental effects

Effects on air (emissions):

- Emissions of greenhouse gases (methane and nitrous oxide) and ammonia (NH_3) are reduced when the biological treatment is compared to the use of storage alone (based on 6 months storage before spreading) (Loyon *et al.*, 2007).
- Anammox reaction is not supposed to be related with NOx emissions since such intermediate of heterotrophic denitrification is not produced during the anaerobic oxidation of ammonium (anammox). Partial nitrification (aerobic stage) must be satisfactory controlled to ensure it.

Effects on water/soil (and management): -

Other effects:

- Removal of biodegradable organic matter.
- Removal of ammonia in form of N_2 (innocuous) gas. The N removal can enhance the capability of manure/slurry management. Interesting in areas with nitrogen surplus.
- A lower quantity of sludge is produced (from microbial activity) compared with the classical NDN treatment systems.

Technical indicators

Components conversion/efficiencies:

N-removal efficiencies may achieve values of up to 90%. Due to the low sludge production, the fraction of nitrogen assimilated by the biomass is much lesser than in conventional nitrification-denitrification systems.

Energy consumption or production:

Expected energy requirements are between 4-6 kwh/$m^3$of treated manure. Final energy consumption will depend on the composition of the manure to be treated, the efficiency on transferring oxygen during partial nitritation, etc

Reagents:

3.43 kg O_2 kg^{-1} N oxidized to nitrite

(only 57% of total ammonium needs to be oxidized to nitrite)

Observations: NA

Economical indicators

Investment cost: NA

Quantifiable incomes: NA

Non economically quantifiable benefits: NA

Operational costs:

Significant savings in aeration during nitrification.
Expected costs of 0.7-1.5 €/t considering exclusively N-removal treatment

Selected literature references

- Hwang, I.S., Min, K.S., Choi, E., Yun, Z. (2005). Nitrogen removal from piggery waste using the combined SHARON and ANAMMOX process. *Water Sci. Technol.* 52(10-11), 487-494.
- Karakashev, D., Schmidt, J.E., Angelidaki, I. (2008). Innovative process scheme for removal of organic matter, phosphorus and nitrogen from pig manure. *Water Res.* 42, 4083-4090. DOI: 10.1016/j.watres.2008.06.021.
- Magrí, A., Vanotti, M.B., Szogi, A.A. (2010). Anammox treatment of swine wastewater using immobilized technology. *In:* Cordovil, C.M.d.S., Ferreira, L. (ed.). *14th RAMIRAN International Conference.* Lisboa (Portugal).
- Magrí, A., Vanotti, M.B., Szögi, A.A. (2011). Partial nitritation of swine wastewater in view of its coupling with the anammox process. *In:* IANAS 2011. First International Anammox Symposium, Kumamoto (Japan). Pp. 9-16.
- Molinuevo, B., García, M.C., Karakashev, D., Angelidaki, I. (2009). Anammox for ammonia removal from pig manure effluents: Effect of organic matter content on process performance. *Bioresour. Technol.* 100, 2171-2175. DOI: 10.1016/j.biortech.2008.10.038.
- Qiao, S., Yamamoto, T., Misaka, M., Isaka, K., Sumino, T., Bhatti, Z., Furukawa, K. (2010). High-rate nitrogen removal from livestock manure digester liquor by combined partial nitritation-anammox process. *Biodegradation* 21, 11-20. DOI: 10.1007/s10532-009-9277-8.
- Vanotti, M., Fujii, T., Szögi, A., Rothrock, M., García, M.C., Kunz, A., Magrí, A., Furukawa, K. (2011). Experiences with Anammox in the USA: Isolation, preservation and treatment performance of Brocadia caroliniensis. *In:* IANAS 2011. First Internacional Anammox Symposium, Kumamoto (Japan). Pp. 99-106.

Real scale (commercial or pilot) references

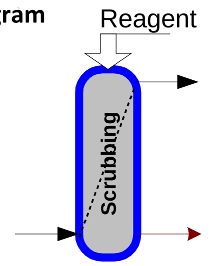
NA

7.12: Struvite (magnesium ammonium phosphate) precipitation

Objectives
Recover nitrogen and phosphorous from liquid manure/slurry in the form of amorphous magnesium nitrogen-phosphate salt called struvite ($MgNH_4PO_4.6H_2O$).

Level of complexity	Usual scale	Innovation stage
☐ low	☒ on-farm	☐ laboratory/research
☒ medium	☒ medium	☒ pilot plant
☐ high complex	☐ large-scale	☒industrial/commercial

General diagram



Applied to
☐ Solid pig manure; ☒ Liquid pig manure; ☐ Pig slurry; ☐ Pig deep litter;
☐ Solid Cattle manure; ☒ Liquid Cattle manure; ☐ Cattle slurry; ☐ Cattle deep litter;
☐ Poultry slurry; ☐ Poultry deep litter.
☒ products of other processes. In this case, a possible combination is:
21 + 10 + 62A // 10 + 56A + 62A // 12 + 60 + 62A (see Annex A)

Pictures

Laboratory reactor for struvite precipitation at GIRO (Spain), left, and two views of a struvite producing plant from animal slurry, courtesy of Dr. Kazuyoshi Suzuki (Japan)

Theoretical fundamentals and process description

Struvite formation means the crystallization of N and P in the form of struvite ($MgNH_4PO_4.6H_2O$), also called MAP, which is a valuable and slow N releasing fertiliser for field crops. The struvite precipitation is forced by introduction of the Mg^{2+} ion, for instance in the form of $Mg(OH)_2$ or $MgCl_2{\cdot}6H_2O$, when the concentration of Mg^{2+}/NH_4^+ and PO^{3-} exceed the solubility product. pH adjustment will often be necessary to force the process (optimum at pH>9).

The major parameters that affect the process efficiency are:

- pH
- Reactor design: agitation, sedimentation properties and process temperature. Most of those parameters affect the size of the formed crystals or the nucleation process.
- Presence of competitive cations (Ca^{2+} with possible formation of other salts as: hydroxyapatite $Ca_5(PO_4)_3OH$, Monenite ($CaHPO_4$) or Brushite ($CaHPO_4{\cdot}2H_2O$))
- Presence of organic matter (it affect to the purity of the obtained salt).

Environmental effects

Effects on air (emissions):

- In highly agitated reactors, or when aeration is introduced for pH increase (CO_2 stripping) it exist the risk of ammonia volatilization

Effects on water/soil (and management)

- -

Other effects:

- Possibility of simultaneous nutrient recovery (N and P). Since struvite contains both ammonia and P, this can be removed from the manure and be applied or used otherwise. Struvite can be used directly as a fertiliser with a slow release of nutrients, according to German and many other studies.
- Nutrient concentration that can enhance the capability of manure/slurry management. Struvite precipitates as crystals that can be removed as a dry product that can be transported as a stable fertiliser. Interesting in areas with nitrogen surplus.

Technical indicators

Components conversion/efficiencies

- The major limitation in liquid slurries/manures is the P concentration. With N/P molar equivalence, high efficiencies in N/P removal can be obtained if the initial concentration (also Mg) are correct for a complete reaction (>95%).
- Low reaction times (few hours)

Energy consumption or production

Only stirring (few kWh/m^3). For a facility capable to treat 10 m^3 of pig manure/day, the operation cost (electric power) can be estimated in 500-1,000 €/year (Suzuki, K., personal communication 2011)

Reagents

- MgOH or MgCl $6H_2O$ that is needed in 1:1:1 molar concentration (Mg^{2+}:NH_4^+:PO_3^-). For animal manures/slurries the Mg content this ratio needs to be increased by a factor of 6 and phosphorus by a factor of 3-4, compared to raw manure/slurry (Burton and Turner (2003)
- Some experiences reported in literature used low magnesium oxide content salts, recovered from the calcinations of natural magnesite ($MgCO_3$) from the production of magnesium oxide (MgO), reducing the reagents costs (Chimenos et al., 2010).
- NaOH or other base reagent to increase pH if necessary (up to 9)

Observations:

- The pH adjustment is less critical in manure/slurries than in other technological fields where struvite precipitation is used (wastewater treatment plants). Also, the pH of a slurry/manure (7.5-8.0) can be increased by CO_2 stripping, reducing the reagents cost.
- A previous organic matter degradation process could increase the struvite purity, and consequently the expected incomes.

Economical indicators

Investment cost:

- From Thames Water Engineering (Jaffer et al., 2002) and WWTP: Precipitation reactor: 0.40 €/m^3 (pounds in 2002)
- From Swine manure pilot plant (Suzuki, K., personal communication 2011): Crystallization reactor: 4.85-7.25 €/m^3. "Simplified" crystallization reactor: 2.41-3.62 €/m^3

Quantifiable incomes: Dried struvite, depending on nutrient concentration can represent and income of 200€/tonne.

Non economically quantifiable benefits: Struvite should be considered as a slow-release fertilizer, and consequently a valuable substrate. Struvite crystals contain phosphorous and magnesium, and should have potential as a source material for glaze and ceramics body. Investigations into its possibilities have been carried out at Saga Ceramics Research Laboratory (Suzuki et al., 2008)

Operational costs: An estimation of reagents cost could be:

- MgO (price 0.6€/kg) / H_3PO_4 $_{75\%}$ (price 0.8€/L) / NaOH $_{30\%}$ (price 0.2 €/L)
- >1 €/m^3 if MgO subproducts are used (Chimenos et al., 2010).
- The chemicals needed for the precipitation: 6€/kg of NH_4^+-N or 48€/m^3 (if manure have 8 kg N/m^3) according to Burton and Turner (2003)

Selected literature references

- Vrielink, M.G.M., Verdoes, N., Van Gastel, J.P.B.F. (1997). Reducing the ammonia emission with a chemical air scrubber. Report P. 1.178, rosmalen, The Netherlands: Praktijkonderzoek.
- Suzuki, K., Tanaka, Y., Kuroda, K., Hanajima, D., Fukumoto, Y., Yasuda, T., Waki, M. (2007). Removal and recovery of phosphorous from swine wastewater by demonstration crystallization reactor and struvite accumulation device. Bioresource Technology 98, 1573–1578. doi:10.1016/j.biortech.2006.06.008
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- Shu, L., Schneider, P., Jegatheesan, V., Johnson, J. (2006). An economic evaluation of phosphorus recovery as struvite from digester supernatant. Bioresource Technology 97, 2211–2216. doi:10.1016/j.biortech.2005.11.005
- NYSERDA (2006). STRUVITE RECOVERY FROM DIGESTED DAIRY MANURE AND REGIONAL MANURE ANAEROBIC DIGESTION STUDY. FINAL REPORT. http://www.nyserda.org/publications/06-10%20FINAL%20REPORT-%20web.pdf
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Real scale (commercial or pilot) references

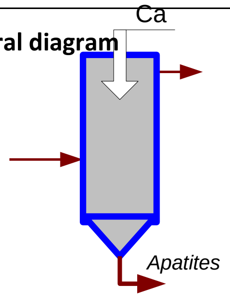
3 Japanese swine manure demonstration plants in Saga, Kanagawa and Okinawa (Suzuki et al., 2008).

7.13: Calcium phosphate precipitation

Objectives
Recover phosphoric compounds with lime-milk (CaO) by means of precipitation (calcium phosphate salts - Apatites).

Level of complexity	Usual scale	Innovation stage
☐ low	☒ on-farm	☐ laboratory/research
☒ medium	☒ medium	☐pilot plant
☐ high complex	☒ large-scale	☒industrial/commercial

General diagram



Applied to

☐ Solid pig manure; ☒ Liquid pig manure; ☐ Pig slurry; ☐ Pig deep litter;

☐ Solid Cattle manure; ☒ Liquid Cattle manure; ☐ Cattle slurry; ☐ Cattle deep litter;

☐ Poultry slurry; ☐ Poultry deep litter.

☒ products of other processes. In this case, a possible combination is:

10 + 21 + 62B // 10 + 60 + 62B (see Annex A)

Pictures

Illustration of the calcium phosphate precipitation unit at Tyndall Farm (South Carolina, USA).
Detail of the CaO mixing chamber and of the final product obtained (see section 4.2)

Theoretical fundamentals and process description

Apatite formation means the crystallization of P in the form of hydroxyapatite ($Ca_5(PO_4)_3OH$), also called HAP. The apatite precipitation is forced by adding lime-milk (CaO). pH adjustment will often be necessary to force the process (optimum at pH>9). See section 4.2 (pH increasing)

The major parameters that affect to the process efficiency are:

- pH
- Reactor design: agitation, sedimentation properties and process temperature. Most of those parameters affect the size of formed crystals or nucleation process.
- Presence of competitive cations (Mg^{2+} with possible formation of struvite)
- Presence of organic matter (it affect to the purity of obtained salt).
- The kinetic rates of apatite formation are lower than for struvite (MAP), and is also considered as a by product of struvite formation in the presence of Ca^{2+} ions.

Environmental effects

Effects on air (emissions):

- In highly agitated reactors, or when aeration is introduced for pH increase (CO_2 stripping) it exist the risk of ammonia volatilization

Effects on water/soil (and management)

- -

Other effects:

- Nutrient recovery (P).
- Possibility of N recovery with the formation of CaNH4PO4 4H2O salts, and entrapment of ammonia in apatite flocs (function of pH and operational conditions)
- Nutrient concentration that can enhance the capability of manure/slurry management. Apatite precipitates as crystals that can be removed as a dry product that can be transported as a stable fertiliser.

Technical indicators

Components conversion/efficiencies:

High efficiencies. The phosphorous concentration in the clarified liquid can be less than 2 ppm.

Energy consumption or production : Only stirring (few kWh/m^3)

Reagents

- 35-40 kg CaO/m^3 slurry
- NaOH or other base reagent to increase pH if necessary (up to 9)

Observations:

A previous organic matter degradation process could increase the apatite purity, and consequently the expected incomes.

Economical indicators

Investment cost: NA

Quantifiable incomes: NA

Non economically quantifiable benefits: NA

Operational costs: NA

Selected literature references

- Burton, C.H., Turner, C. (Eds) (2003). Manure Management. Treatment strategies for sustainable agriculture. Silsoe Research Institute, 490 pps. ISBN: 0-9531282-6-1.
- QUAN, x., Ye., C., Xiong, Y., Xiang, J., Wang, F. (2010). Simultaneous removal of ammonia, P and COD from piggery wastewater using an integrated process of chemical precipitation and air stripping. Journal of Harzardous Materials 178, 1-3, 326-332.

Real scale (commercial or pilot) references

NA

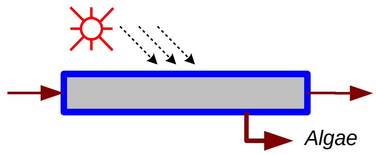
7.14: Algae production on liquid manure substrates

Objectives

Basic principle of algae controlled ecosystems treatments is the nutrients, or other pollutants, uptake by the biomass and their removal from the system through harvesting. Harvested material may be processed into a valuable product.

Level of complexity	Usual scale	Innovation stage
☐ low	☒ on-farm	☐ laboratory/research
☒ medium	☐ medium	☒ pilot plant
☐ high complex	☐ large-scale	☐industrial/commercial

General diagram



Applied to

☐ Solid pig manure; ☒ Liquid pig manure; ☐ Pig slurry; ☐ Pig deep litter;

☐ Solid Cattle manure; ☒ Liquid Cattle manure; ☐ Cattle slurry; ☐ Cattle deep litter;

☐ Poultry slurry; ☐ Poultry deep litter.

☒ products of other processes. In this case, a possible combination is:

(10 – 18) + 63 // (31A - 31B) + (10-18) + 63 (see Annex A)

Pictures

Pilot studies of algae production from dairy manure (Mulbry et al., 2008)

Theoretical fundamentals and process description

Already applied on different kinds of effluents, the use of algae as treatment system has been proven efficient as well with livestock manures. The challenging idea behind this technology is the use algae organisms, which grow thanks to the nutrients contained in manure and solar radiation (photosynthesis). Recovered biomass presents a very wide range of application, going from biofertilizer to substrate for biogas or bioethanol production, as well as for animal feed. (Muñoz and Guieysse, 2006; Mulbry *et al.,* 2005).

Fresh and anaerobically digested slurries have been used, mainly at pilot scale, and nitrogen and phosphorus concentrations varied between 200-3000 and 20-800 mg/l, respectively. At the same time, excluding closed bioreactors, hardly used with livestock manures, usually the temperature is the ambient one and the pH varies between 7.5 and 9.0, depending on the biomass.

Main constraints to the application of the technology are the costs of biomass harvesting, in particular with suspended biomass and its drying. Moreover, depending on the species involved, low temperature and high salinity and ammonium concentrations could result in growth inhibition and overall efficiency reduction.

Environmental effects

Effects on air (emissions): NA

Effects on water/soil (and management): NA
Other effects:

- Nutrient recovery (C, N, P and other nutrients)
- Nutrient concentration that can enhance the capability of manure/slurry management. Recovered biomass presents a very wide range of application, going from biofertilizer to substrate for biogas or bioethanol production, as well as for animal feed.

Technical indicators

Components conversion/efficiencies: COD reduction efficiency in the manure is reported between 77 and 95%. Authors obtained a 46 and 85-fold concentration of N and P, respectively, on volumetric basis in the algae compared to manure (Wilkie and Mulbry, 2000).

Energy consumption or production : NA

Reagents: NA

Observations:

- It can be considered a simple and low energy intensive technology (biomass mediated), although the biomass harvesting is the most complex/costly step.
- It is needed a high area needed for algae growth. Authors estimated the area needed for algal treatment of the manure effluents to be approximately 1 ha for every 100 dairy cows (Mulbry *et al.*, 2005)
- Cost of drying the harvest algae is the biggest drawback to implementing the technology. When considered in conjunction with an anaerobic digestion system, where energy is recovered from manure, the cost of drying the harvested algae could be reduced. Also, since anaerobic digestion increases the availability of manure nutrients, the combination of anaerobic digestion followed by algal production could be synergistic. Without AD the cost will be 36% higher (Pizarro *et al*., 2006).

Economical indicators

Investment cost: NA.

Quantifiable incomes: 0.25-1.70€ per kg of dried algal biomass (Pizarro et al., 2006)

Non economically quantifiable benefits:

- Production of a valuable product that could be used in different industrial applications.

Operational costs: 4.5-5.5€ per kg of recovered N (Pizarro et al., 2006)

Selected literature references
• Wilkie, A.C., Mulbry, W.W. (2002). Recovery of dairy manure nutrients by benthic freshwater algae. Bioresource Technology 84, 81-91. • Mulbry, W.,Kondrad, s., Pizarro, C.,Westhead, E-K. (2008). Treatment of dairy manure effluent using freshwater algae: Algal productivity and recovery of manure nutrients using pilot-scale algal turf scrubbers. Bioresource Technology 99, 8137–8142 • Mulbry, W., Westhead, E-K., Pizarro, C., Sikora, L. (2005). Recycling of manure nutrients: use of algal biomass from dairy manure treatment as a slow release fertilizer. Bioresource Technology 96, 451–458. • Pizzarro, C., Mulbry, W., Blerch, D., Kangas, P (2006). An economic assessment of algal turf scrubber technologyfor treatment of dairy manure effluent. Ecological Engineering 26, 321-327. • Muñoz, R.;Guieysse, B. Algal-bacterial processes for the treatment of hazardous contaminants: A review. Water Research, 2006, 40(15), 2799-2815.

Real scale (commercial or pilot) references
NA

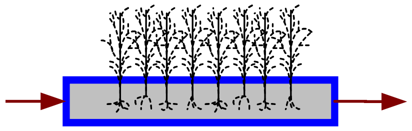
7.15: Constructed Wetlands

Objectives

Removal of the nutrients, or other pollutants, by means of biomass (plants and microorganisms) uptake and removal from the system through harvesting and denitrification.

Level of complexity	Usual scale	Innovation stage
☒ low	☒ on-farm	☐ laboratory/research
☐ medium	☒ medium	☐ pilot plant
☐ high complex	☒ large-scale	☒industrial/commercial

General diagram



Applied to

☐ Solid pig manure; ☒ Liquid pig manure; ☐ Pig slurry; ☐ Pig deep litter;

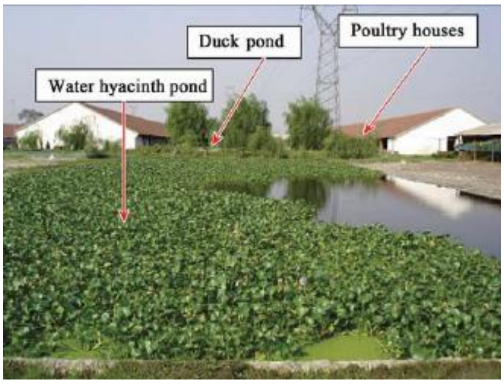
☐ Solid Cattle manure; ☒ Liquid Cattle manure; ☐ Cattle slurry; ☐ Cattle deep litter;

☐ Poultry slurry; ☐ Poultry deep litter.

☒ products of other processes. In this case, a possible combination is:

(10 – 18) + 64 (see Annex A)

Pictures



Pilot plant for the study of the use of water hyacinth (Lu et al., 2008), left, and a wetland in a pig farm at Chile (right)

Theoretical fundamentals and process description

Constructed wetlands, engineered systems designed to simulate natural wetlands, are low cost, simple and low energy intensive technologies that require little maintenance after construction. Organic matter content in manure is decreased by biological decomposition. Besides the solids and organic matter, the most important constituents in liquid manure are nitrogen and phosphorus and these can both be uptake by plants in constructed wetlands if conditions are appropriate. Wetlands have successfully been applied, also at industrial scale, for the treatment of dairy, cattle, swine and poultry manures, mainly with marsh vegetation.

Nevertheless, reported nitrogen removal efficiencies are usually very low, 20-60%. A more sound approach, for nutrients recovery, is the use of floating aquatic macrophytes characterized by higher nitrogen uptake efficiencies, over 90% in optimized conditions. Moreover, floating species offer simple harvesting systems, from hand collection to mechanical conveyors. There are relatively few studies focused on livestock manures treatment with floating plants and they refer mainly to *water hyacinth* and *duckweed*.

Ammonia (NH_4) may be lost from the system through volatilization (NH_3-NH_4^+), taken by plants or microbes, or oxidized to nitrite in nitrification process, while nitrate (NO_3^-) and nitrite (NO_2^-) are removed by plant uptake and denitrification process. Denitrification is the most important removal pathway for nitrogen in most wetlands, with a risk of N_2O emissions, while adsorption in solids is the main responsible of phosphorous removal (Cronk., 1996).

Cronk (1996) reported some recommended plant species to be used in wetlands for the treatment of animal manure.

Common name	Latin binomial	Source
Emergents		
Arrowhead	*Sagittaria* spp.	NRCS, 1991; Hammer, 1993
Bulrush	*Scirpus* spp.	NRCS, 1991; Hammer, 1993
Canna lily	*Canna flaccida*	NRCS, 1991
Cattail	*Typha* spp.	NRCS, 1991; Hammer, 1993
Elephant ear	*Colocasia esculenta*	NRCS, 1991
Giant bulrush	*Scirpus californicus*	Surrency, 1993
Giant cutgrass	*Zizaniopsis milacea*	NRCS, 1991; Surrency, 1993
Iris	*Iris versicolor*, *I. pseudacorus*	NRCS, 1991; Hammer, 1993
Maidencane	*Panicum hemitomon*	NRCS, 1991
Pickerelweed	*Pontederia cordata*	NRCS, 1991
Plantain	*Alisma* spp.	Hammer, 1993
Giant reed	*Phragmites australis*	NRCS, 1991; Biddlestone et al., 1991
Rush	*Juncus* spp., *Cyperus* spp. *Fimbristylis* spp., *Eleocharis* spp.	NRCS, 1991; Hammer, 1993
Water chestnut	*Eleocharis dulcis*	NRCS, 1991
Submergents		
Coontail	*Ceratophyllum demersum*	Hammer, 1993
Naiad	*Najas* spp.	Hammer, 1993
Pondweed	*Potamogeton* spp.	Hammer, 1993
Water weed	*Elodea canadensis*	Hammer, 1994
Wild celery	*Valisneria americana*	Hammer, 1994
Floating		
Big duckweed	*Spirodela punctata*	Koles et al., 1987
Duckweed	*Lemna* spp.	Koles et al., 1987
Rooted floating leaves		
American water lily	*Nelumbo lutea*	Hammer, 1993
Gentian	*Nymphoides* spp.	Hammer, 1993
Water lily	*Nymphea* spp.	Hammer, 1993

Examples of constructed wetlands: In the USA such wetlands are used for the disposal of the liquid fraction that are collected from feedlots (Foged, 2009), in Holland for reject water from a nitrification -denitrification plant (Foged, 2009), and in Denmark they are in connection to high-tech biogas plants. The NRCS (National Resources Conservation Service, USA) recommends that wetlands for animal wastewater treatment are designed with the following requirements:

- Allowable BOD_5 loading rate of 73 kg ha^{-1} day^{-1}
- A residence time at least of 12 days

Environmental effects

Effects on air (emissions):

- Risk for emission of N_2O, since the nitrification and denitrification process are difficult to control

Effects on water/soil (and management)

- -

Other effects:

- Nutrient recovery (C, N, P and other nutrients). N and P removal rates dependent of environment temperature and pH (microbial growth), and consequently its efficiency present seasonal variations.
- Nutrient concentration that can enhance the capability of manure/slurry management. Recovered biomass presents a very wide range of application, going from biofertilizer to substrate for biogas or bioethanol production, as well as for animal feed.

Technical indicators
Components conversion/efficiencies: Possibility to obtain an outflow of BOD5<30 mg L^{-1}, TSS<30 mg L^{-1} and NH_3+NH_4^+-N <10 mg L^{-1} and a removal P rate of 23 mg P m^{-2} day^{-1} (Cronk., 1996; DeBusk *et al*., 1995)
Energy consumption or production : NA
Reagents: NA
Observations: • When plants surpass a certain density in the wetland, its growth rate tends to decrease and, consequently, its biological capacity to remove the nutrient load also reduces. For this reason, it is necessary to continually control the density (Costa *et al*., 2003). • It can be considered a simple and low energy intensive technology (biomass mediated), although the biomass harvesting is the most complex/costly step. • High energy cost for drying if harvested material is converted to animal feed due to their high moisture content.

Economical indicators
Investment cost: NA. Constructed wetlands are relatively inexpensive and easy to construct
Quantifiable incomes: NA
Non economically quantifiable benefits: • Production of a valuable product that could be used in different industrial applications
Operational costs: NA

Selected literature references
• Lu, J.; Fu, Z.; Yin, Z. Performance of a water hyacinth (Eichhorniacrassipes) system in the treatment of wastewater from a duck farm and the effects of using water hyacinth as duck feed. Journal of Environmental Sciences, 2008, 20(5), 513-519. • Cronk, J.K. (1996). Constructed wetlands to treat wastewaters from dairy and swine operations: a review. Agriculture, Ecosystems and Environment. 58, 97-114.Shu, L., Schneider, P., Jegatheesan, V., Johnson, J. (2006). An economic evaluation of phosphorus recovery as struvite from digester supernatant. Bioresource Technology 97, 2211–2216. doi:10.1016/j.biortech.2005.11.005 • DeBusk, T.A:, Peterson, J.E., reddy, K.R. (1995). Use of aquatic and terrestrial plants for removing phosphorus from dairy wastewaters. Ecological Engineering. 5, 371-390. • Costa, R.H.R., Zanotelli, C.T., Hoffmann, D.M., Filho, P.B., Perdomo, C.C., Rafikov. M. (2003). Optimization of the treatment of piggery wastes in waterhyacinth ponds. Water Science and Technology. 48(2), 283–289

Real scale (commercial or pilot) references
NA

8: AIR CLEANING (AS PART OF MANURE PROCESSING PLANT)

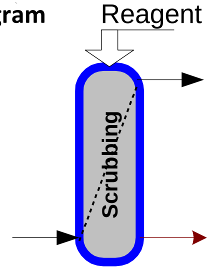
8.1: Air Scrubbing

Objectives

The objective of air scrubbing is to reduce/recover particles and pollutants from air streams by means of liquid-reagent wash. In the field of manure/slurry treatment the main focus of scrubbing techniques is to treat/control gas emissions from raw/digested slurries: mainly ammonia (NH_3), sulphur (H_2S) and odours (VOCs) by acid scrubbing.

Level of complexity	Usual scale	Innovation stage
☐ low	☒ on-farm	☐ laboratory/research
☐ medium	☒ medium	☐ pilot plant
☒ high complex	☒ large-scale	☒industrial/commercial

General diagram



Applied to

☐ Solid pig manure; ☐ Liquid pig manure; ☐ Pig slurry; ☐ Pig deep litter;

☐ Solid Cattle manure; ☐ Liquid Cattle manure; ☐ Cattle slurry; ☐ Cattle deep litter;

☐ Poultry slurry; ☐ Poultry deep litter.

☒ products of other processes. In this case, a possible combination is:

AIR CLEANING as part of manure processing plant

Can be also applied for air treatment from farm buildings

Pictures

Illustration courtesy of DMT Environmental Technology, The Netherlands (www. dmt-et.nl), left, and Illustration from *F. Prenafeta-Boldú*, right.

Theoretical fundamentals and process description

A packed tower air scrubber is a reactor that has been filled with an inert or inorganic packing material. The packing material usually has a large porosity, or void volume, and a large specific area. Water is sprayed on top of the packed bed and consequently wetted. Contaminated air is introduced, either horizontally (crosscurrent) or upwards (counter-current), resulting in intensive contact between air and water, and enabling mass transfer from gas to liquid phase. A fraction of the trickling water is continuously recirculated; another fraction is discharged and replaced by fresh water (Melse and Ogink, 2005).

The mass transfer of ammonia (from air inlet to water) is regulated by the equilibrium reaction (below), that is influenced by pH and temperature, in a similar way than explained in Stripping Technology chart (section 7.4). To improve process efficiency, an acid reagent (mainly sulphuric acid) is usually added into water recirculation stream.

$$NH_3(g)+H_2O(l) \leftrightarrow NH_3(aq)+H_2O(l) \leftrightarrow NH_4^+(aq)+OH^-(aq)$$

The efficiency of odour removal by an acid scrubber is the result of dissolution of the odorous compounds in the water phase and the water discharge rate. As the water solubility of odorous compounds may vary from very low to very high, odour removal efficiencies vary as well (Melse and Ogink, 2005).

The treatment of exausted air at farms is hardly used in practice in general. In Flanders there exist regulations obligating to this treatment. In other countries, the regulation demanded by authorities are based on minimum distances (from farm to population) to avoid odour problems. In a context where minimum distance can not be kept (business expansion), that technology can be demanded (Hahne and Varlop, 2001). Also air treatment may be of major importance for compliance with current and future PM10 and PM2.5 standards (particulate matter).

Ammonium salts are usually delivered to fertilizers production companies.

Environmental effects

Effects on air (emissions):

- Particles and odour reduction

Effects on water/soil (and management)

- -

Other effects: NA

- Potentially dangerous or harmful chemicals are needed, such as H_2SO_4.
- Nitrogen (N) can be recovered as in the form of ammonium salt (mainly sulphate).
- The process only moves the unwanted substance from the exhaust gases into a liquid solution, solid paste or powder form. This must be disposed off safely, if contain substances that can not be reused.

Technical indicators

Components conversion/efficiencies

Up to 95% NH3 and 29% odour removal in full-scale piggery farms acid scrubbers (Melse and Ogink, 2005).

Energy consumption or production

Electricity consumption for ventilation. For piggery on-farm emission control is estimated in 50kWh/place year (Vrielink et al., 1997)

Reagents

H_2SO_4 to maintain pH<4. Acid is normally added to the recirculation water (3.0-3.5 L H_2SO_4/pig place)

Observations:

- It is necessary to control the process with pH measurements and system discharge (concentrated water <150 g NH_{4+}/L). Replacement of concentrated water is estimated in 70L water/pig or 2L/broiler place according to Melse and Ogink (2005).

- Dust accumulation in scrubbers can cause air channelling and a decrease in efficiency. It is necessary to perform regular cleaning.

Economical indicators
Investment cost: 1.3 $/broiler place and 42 $/growing-finishing pig (Melse and Ogink,2005).
Quantifiable incomes: Not quantified. Possible income by ammonium salt water market (function of its concentration and purity)
Non economically quantifiable benefits: Odour reduction (animals healthy improvement, reduction of environment emissions, benefits for surrounding population)
Operational costs 0.47 $/broiler place year and 14.82 $/growing-finishing pig year (Melse and Ogink, 2005).

Selected literature references

- EPA. Air Pollution Control Technology http://www.epa.gov/ttn/catc/dir1/fbiorect.pdf
- Hahne, J., Vorlop, K-D. (2001). Treatment of waste gas from piggeries with nitrogen recovery. Landbauforschung Völkenrode, 51 (3), 121-130.
- http://www.ag.iastate.edu/wastemgmt/Mitigation_Conference_proceedings/CD_proceedings/Animal_Housing-Biofilters_and_Scrubbers/Melse-multi-pollutant_scrubber.pdf
- MARM (Spanish Ministry of Agriculture). http://www.marm.es/es/ganaderia/temas/requisitos-y-condicionantes-de-la-produccion-ganadera/ganaderia-y-medio-ambiente/mejores-tecnologias-disponibles-en-avicultura-y-porcino/
- Melse, R.W., Ogink, NWM. (2005). Air scrubbing techniques for ammonia and odour reduction at livestock operations: Review of on-farm research in the Netherlands. Transactions of the ASAE 48, 2303-2313.
- Melse, R., Ogink, N., Bosma, B. (2008). Multi-pollutant Scrubbers for Removal of Ammonia, Odor, and Particulate Matter from Animal House Exhaust Air. Proceedings from the National Conference on Mitigating Air Emissions from Animal Feeding Operations Exploring the advantages, limitations, and economics of mitigation technologies.
- Vrielink, M.G.M., Verdoes, N., Van Gastel, J.P.B.F. (1997). Reducing the ammonia emission with a chemical air scrubber. Report P. 1.178, rosmalen, The Netherlands: Praktijkonderzoek.

Real scale (commercial or pilot) references

Acid scrubber for air effluent from the thermal drying unit are installed at:

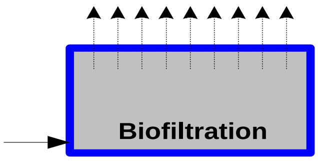
- TRACJUSA and VAG pig manure treatment plants (Juneda, Spain)
- SAVA pig manure treatment plant (Miralcamp, Spain)
- POLAN and BAÑUELO pig manure treatment plants (Toledo, Spain)

8.2: Air biofiltration

Objectives
The objective of biofiltration is to eliminate/reduce particles and pollutants from air streams by means of microorganism action. In the field of manure/slurry treatment the main focus of biofiltration techniques is to treat gas emissions from raw/digested slurries: mainly odours (VOCs), NH_3 and H_2S .

Level of complexity	Usual scale	Innovation stage
☐ low	☐ on-farm	☐ laboratory/research
☐ medium	☒ medium	☐ pilot plant
☒ high complex	☒ large-scale	☒industrial/commercial

General diagram



Applied to

☐ Solid pig manure; ☐ Liquid pig manure; ☐ Pig slurry; ☐ Pig deep litter;

☐ Solid Cattle manure; ☐ Liquid Cattle manure; ☐ Cattle slurry; ☐ Cattle deep litter;

☐ Poultry slurry; ☐ Poultry deep litter.

☒ products of other processes. In this case, a possible combination is:

AIR CLEANING as part of manure processing plant

Pictures

Illustration of the biofiltration unit at TRACJUSA (Juneda, Spain), left, and DMT Environmental Technology (The Netherlands) www. dmt-et.nl, right

Theoretical fundamentals and process description

Biofilters are known to be very successful and low cost systems to degrade odours in practice. The exausted gas is pressed or sucked through the biofilter bed and odourants as well as other air compounds are degraded by microorganism (bacteria and fungi) which are immobilized on carriers as compost, peat or porous clay (Hahne and Varlop, 2001). Problems arise if biofilters are loaded with an imbalanced nitrogen/carbon ratio or nutrients needed for microorganism growth or sufficient humidity. The ammonia removal efficiencies are controversial, and related to adsorption, absorption and nitrification process (only in liquid phase) and dependent of humidity (reaction in liquid phase) and gas flow loading rates (required low).

There are process modifications able to treat simultaneously liquid and gas effluents. The principle consists on passing the liquid (manure or water) and gas effluents throught and organic media. The organic media act in two ways, as an adsorbent, adsorbing several type of pollutants and/or as support of various types of microorganisms capable to degrade retained substrates (see ORGANIC BED-BIOFILTRATION in Buelna *et al.*, 2007 or BIOTRICLING in Melse and Ogink, 2005). The biomass in the system growth as a film and is suspended in the liquid inflow that is being re-circulated. The dissociated NH3 is available for bacterial oxidation to nitrite (NO_2^-) and subsequently from nitrite to nitrate (NO_3^-) in nitrification process, mediated by *Nitrosomonas* and *Nitrobacter* species (Melse and Ogink, 2005).

$$NH_4^+(aq)+OH^-(aq)+1.5\ O_2(g)\rightarrow NO_2^-(aq)+H^+(aq)+2\ H_2O(l)$$

$$NO_2^-(aq)+H^+(aq)+2\ H_2O(l)+0.5\ O_2\rightarrow NO_3^-(aq)+H^+(aq)+2\ H_2O(l)$$

A bio-trickling-filter is a combination of a scrubber and a biofilter The filter consists of a packed absorption column, continuously or intermittently by circulation or single supply of nutrients and wetting is provided The idea is that the biomass on the packing remains and the water is not carried. After absorption in the thin film of water, the contamination by a broken seal on the growing layer of microorganisms ("biofilm"), possible degradation products are transported by the same water phase. Its mobile water phase is the removal of acidic degradation products may be better than biofilters with a stationary water phase, the acidity of the circulating current can be (slightly) corrected by dosage or lye water supplementation.

Environmental effects

Effects on air (emissions):

- Particles and odour reduction.
- Possible N removal (in form of nitrate and nitrite) and H_2S (if pH is controlled in biotrickling filter).
- A possible NH_3 accumulation in the system can inhibit nitrification.

Effects on water/soil (and management)

- Low waste water amount (leachate) produced compared with other air cleaning techniques.

Other effects: NA

- Poorly maintained biofilters have the potential to spread disease-causing bacteria (ex. *Legionella*). The problem is a result of inadequate cleaning.

Technical indicators

Components conversion/efficiencies

High efficiencies in odour reduction. To obtain high efficiencies in NH_3 reduction it is necessary to adopt bio-scrubbing or biotrickling configurations. In biotrickling filters configuration is possible to obtain high ammonia removals (up to 90%) and higher odour removals (60%) compared to acid scrubbers (Melse and Ogink, 2005).

Energy consumption or production

The biofilters consumes little energy (<1 KW /m^3 h). The pressure drop that must be overcome is around 2.5-15 mbar.

Reagents

- Requirement of pH regulation (6-8), nutrients addition and humidification

Observations:

• The main limitation is to have a properly designs of air distribution system to prevent short-circuiting and channelling (Sheridan et al., 2002.) • Wastewater (leachate) production around 5 litres per 1,000 m^3, dependent on gas saturation level

Economical indicators
Investment cost: 8,000-14,000 € /1000 m^3 of manure input (DMT Environmental Technology). Installation costs are low. Most biofilters are constructed from common materials locally available such as lumber, fibre-glass, and plastic pipes.
Quantifiable incomes: NA
Non economically quantifiable benefits: Odour reduction (animals healthy improvement, reduction of environment emissions, benefits to surrounding population, etc.)
Operational costs: 140-200 €/year for a 1000 m^3/h unit (KTBL, 2008). These costs consist of electricity to operate the primary blower and the humidification pump, part-time labour to check on the process, and small quantities of macronutrients Natural bed media used in biofilters must be replaced every 2 to 5 years. Bed replacement can take 2 to 6 weeks, depending on bed size.

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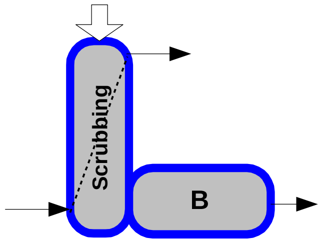
Real scale (commercial or pilot) references	
DMT Environmental Technology P.O. Box 231 8440 AE Heerenveen Yndustryweo 3 8501 SN Joure (The Netherlands)) www. dmt-et.nl	TRACJUSA pig manure treatment plant Juneda, Spain

8.3: Bioscrubbing (Aerobic biofilter)

Objectives
The objective of biofiltration is to eliminate/reduce particles and pollutants from air streams by means of liquid-reagent wash and micro-organism action. In the field of manure/slurry treatment the main focus of biofiltration techniques is to treat gas emissions from raw/digested slurries: mainly dust (PM), ammonia (NH_3) and odours (VOCs) by combined action of scrubbing and biological reactor.

Level of complexity	Usual scale	Innovation stage	General diagram
☐ low	☐ on-farm	☐ laboratory/research	
☐ medium	☒ medium	☐ pilot plant	
☒ high complex	☒ large-scale	☒ industrial/commercial	

Applied to

☐ Solid pig manure; ☐ Liquid pig manure; ☐ Pig slurry; ☐ Pig deep litter;

☐ Solid Cattle manure; ☐ Liquid Cattle manure; ☐ Cattle slurry; ☐ Cattle deep litter;

☐ Poultry slurry; ☐ Poultry deep litter.

☒ products of other processes. In this case, a possible combination is:

AIR CLEANING as part of manure processing plant

Pictures

Illustration courtesy of AERISTEC (Spain) www.aeristec.com

Theoretical fundamentals and process description

The fundamental principle of biological scrubbers or bioscrubbers is the separation of an absorption tower on the one hand and an aerated regeneration tank with active microorganisms on the other. If the absortion velocity is quite different from the microbial degradation velocity, the separation of both processes is useful (Hahne and Varlop, 2001). Just as the biotrickling filter is an enhancement of the biofilter, the bioscrubber is an enhancement to the biotrickling filter. The bioscrubber attempts to solve two problems with the biotrickling filter: 1) to improve the absorption of pollutants into the liquid, and 2) to lengthen the time the microbes have to consume the pollutants. These are accomplished in two ways: the tower packing is flooded with a liquid phase and the discharge effluent from the bioscrubber is collected in a storage tank (sump) before being recycled back to the bioscrubber. The idea is that the biomass on the packing remains and the water is not carried. There are also other process configurations that combine scrubbers with biofilters or biological reactors. Hartung (2008) proposes different configurations as function of their suitability to treat gaseous emissions from animal housing facilities:

Treatment System	Utilization	Housing System	Assessment of Reduction Efficiency		
			Total Dust	Ammonia	Odor
Biofilter	pigs, cattle	not littered systems	+	n. g.	++
Biological Scrubber	pigs, cattle	not littered systems	+	+	+
Chemical Scrubber	pigs, cattle, dry poultry dung store	not littered systems	+	++	n. g
Multistage air treatment systems *two-stage*	pigs, cattle, poultry	littered and not littered systems			
• Wet Scrubber & Chemical Scrubber			++	++	0 / +
• Wet Scrubber & Biofilter			++	0 / +	++
• Chemical Scrubber & Biofilter			++	++	++
• Chemical Scrubber & Biological Scrubber			++	++	+
three-stage	pigs, cattle, poultry	littered and not littered systems			
• Wet Scrubber & Wet Scrubber & Biofilter			+++	+	++
• Wet Scrubber & Chemical Scrubber & Biofilter			+++	+++	+++

n. g.: unsuitable; 0: conditionally suitable; +: suitable; ++: good; +++: very good

pH control and nutrients feed can be automated.

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Environmental effects

Effects on air (emissions):

- Particles and odour reduction.
- Possible N removal (in form of nitrate and nitrite). Possible NH_3 accumulation in the system can inhibit nitrification reactor.

Effects on water/soil (and management)

- It is not necessary to humidify emissions prior to treating them. This could save the cost of installing a humidification process. Little wastewater (leachate) produced compared with other air cleaning techniques.

Other effects: NA

Technical indicators

Components conversion/efficiencies: NA. Better efficiency than biofilters.

Energy consumption or production: NA

Reagents : NA

Observations:

- The main limitation is to have properly designs for process integration (scrubber and biofilter).
- Over feeding can cause excessive biomass growth, which can plug the bioscrubber.

Economical indicators
Investment cost: NA. More expensive to install than other air filtration techniques
Quantifiable incomes: NA
Non economically quantifiable benefits: • Odour reduction (animals healthy improvement, reduction of environment emissions, benefits to surrounding population, etc.) • No potentially dangerous or harmful chemicals are needed. • No harmful pollutants are released in the operation of the system
Operational costs: NA. Operating cost can be higher than other bioreactor processes (High energy required).

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Real scale (commercial or pilot) references

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9: PROCESSES COMBINATIONS

Although the 45 unitary processes identified could be theoretically combined and integrated in different ways in a given facility, the fact is that only few combination or groups of combinations are possible and interesting for building a technological strategy fitting a given objective.

In the charts explaining the characteristics of every process, in the chapters above, when a technology usually treats products of other processes, possible or interesting combinations were identified. These combinations have been synthesized in the Table 9.1. This Table presents for each process (in rows), the process that applies or can be applied before it (in columns), identifying the order in which every process acts on the main stream by numbers.

For a given treatment technology, a previous process is required for changing the characteristics of the stream in order to increase the efficiency of this technology or just for making it possible. If it is necessary to adopt a specific final technique producing a desired effect (i.e. to partially remove nitrogen by nitrification-denitrification (NDN) in order to fit nutrients requirements of the nearby land, or to recover nutrients by thermal concentration (drying, pelletizing) if waste heat is available, then the plant flow-sheet will include the key process as final unit (NDN or pelletizing in these cases, respectively) and the required previous processes for preparing the streams. These simple concepts indicate that a relatively few number of strategies, or groups of strategies, can be built, and only some combinations are possible or interesting.

In the following sections, a few comments are addressed for every group of technologies, grouped in rows in Table 9.1. Every row or groups of rows indicate technologies producing a specific end-product.

9.1: Solid/liquid separation

Regarding Solid/liquid separation in Table 9.1., these techniques can be combined for allowing a better management of manure, to obtain a solid fraction to be sold, to be transported to long distances, to be composted on-site or to be treated in a centralized composting plant. After an anaerobic digestion process, the application of a high rate separation system (centrifuge in Table 9.1) allows to obtain a solid fraction with low easily biodegradable organic matter content. A deep description of this last combination will be done as case study of operational facilities.

9.2: Additives and other pre/1st treatment

The use of additives as a process is usually a stand alone technique, such as acidification of manure for avoiding ammonia emissions, or an intermediate process needed to prepare material to further process by other technologies (such as pH increasing by liming, for enhancing ammonia stripping or phosphates precipitation). This could be also the case for thermal pre-treatment processes, specifically designed for the sanitation of some industrial co-substrates for anaerobic co-digestion or co-composting. In some plants, it can be more interesting to apply a thermal sanitation process as a final treatment unit, because the mechanical properties of the effluent allow an easier operation, or because hygienization is a requirement of the end-users. In Table 9.1., this process appears combined after anaerobic digestion.

Table 9.1: Some combinations of processes, where rows indicate the reference process and columns express the processes to be included previously, with the order indicated by number.

Previous processes → / ↓ Considered process	10: Separation	10A Coagulation-Flocculation	10B Electro coagulation	11 Separation by grate	12 Separation by screw pressing	13 Separation by sieves	14 Separation by filter pressing	15 Separation by centrifuge	16 Air Flotation	17 Separation by drum filters	20: Additives and other pre/1st treatments	21 Acidification	22 pH increasing (liming)	23 Temperature and pressure treatment	24 Applying other additives to manure	30: Anaerobic treatment	31A/B anaerobic digestion	40: Treatment of the fibre/solid fraction	41 Composting	42 Bio drying	43 Thermal drying	44 Pelletizing	45/46/47Thermo chemical	50: Treatment of the liquid fraction	51 Microfiltration	52 Ultra filtration	53 Reverse osmosis	54A Conc.by vacuum evap.	54B Conc.by atmospheric evap.	55 Ammonia stripping and absorption	56 Carbon dioxide stripping	57 Electro-oxidation	58 Ozonizing	60 Nitrification-denitrification	61 PN-anammox	62A Struvite precipitation	62B Calcium phosphate precipitation	63 Algae production	64 Constructed wetlands
10: Separation																																							
10A Coagulation-Flocculation		2			1																																		
10B Electro coagulation			2		1																																		
14 Separation by filter pressing		1					2																																
15 Separation by centrifuge		1						2																															
16 Separation by centrifuge					1			3									2																						
16 Air Flotation		2			1				3																														
17 Separation by drum filters		1								2																													
20: Additives and others																																							
23 Temperature and pressure														2			1																						
40: Treatment of the fibre fraction																																							
41 Composting					1										2				3																				
41 Composting							2								3		1		4																				
43 Thermal drying								2				3					1				5							4											
43 Thermal drying								1													4								3					2					
43 Thermal drying								1													4							3					2						
44 Pelletizing																					1	2																	
45/46/47 Thermo-chemical																				1	1		2																
50: Treatment of the liquid fraction																																							
51 Microfiltration		1						2																	3														
52 Ultra filtration								1																		2													
53 Reverse osmosis		1					2		3																		4												
54A Conc.by vacuum evap.								1																				3						2					
54A Conc.by vacuum evap.								2				3					1											4											
54A Conc.by vacuum evap.		2			1			3																					5				4						
54B Conc.by atmospheric evap.								1																					3					2					
55 Ammonia stripping and absorp.								2					3				1													4									
57 Electro-oxidation			2		1																											3							
60 Nitrification-denitrification		1					2																											3					
61 PN-anammox		2						3									1																		4				
62A Struvite precipitation								2					3				1																			4			
62A Struvite precipitation								1					3																					2		4			
62B Calcium phosphate precip.								2					3				1																				4		
62B Calcium phosphate precip.							1						3																					2			4		
63 Algae production		2						3									1																					4	
64 Constructed wetlands		1						2																															3

9.3: Anaerobic digestion

Anaerobic digestion can be a stand alone technology or a pre-treatment to other processes; it is not usual to have it as final treatment after other processes. This is why anaerobic digestion does not appear in Table 9.1 in rows.

Nevertheless, in some cases solid/liquid separation equipments could be applied for concentrating organic matter feeding anaerobic digestion, in order to increase biogas production while lowering the reactor volume. This could be the case of a centralized plant receiving solid fractions from different farms where a solid/liquid separation unit has been adopted.

Although energy production by anaerobic digestion can be an objective by itself, it must be taken into account that this process offers other technical advantages, such as odors abatement (Wilkie, 1998), greenhouse gasses emission mitigation, decrease of manure viscosity and particle size, decrease of weed seeds contents in digested manure and mineralization, which also favors the efficiency of many other processes dealing with nutrients recovery, or with the N-removal when combined with the autotrophic anaerobic ammonium oxidation process. Anaerobic digestion clearly represents a unitary process to be considered in any sustainable manure treatment strategy.

9.4: Treatment of solid fractions

Composting (including its variants of vermicomposting and bio-drying), thermal drying, pelletizing (as complement to drying) and thermo-chemical processes (including combustion, gasification and pyrolysis) have been considered technologies applied at the latest phase in the treatment strategy and, thus, indicated in rows in Table 9.1.

Composting can be combined with previous solid/liquid separation systems, for obtaining a solid fraction, and with anaerobic digestion, although this will imply a lower carbon source for a good composting process. In any case, it must be considered the addition of a bulking agent for increasing porosity and oxygen uptake, and as a carbon source in order to equilibrate the C/N ratio.

Thermal drying, or pelletizing, can be combined with many processes if the raw manure is liquid. Since thermal drying processes work with solids, previous steps dealing with solid/liquid separation and with concentration by evaporation (vacuum or atmospheric) must be included. Since ammonia can be volatilized during drying, previous processes conducted for its fixation (acidification) or removal (nitrification-denitrification) must be also included. Volatile organic matter can be also volatilized at increasing temperatures, obligating to adopt a system for its previous removal, by oxidative or reductive processes. Systems applied in full scale facilities, previous to evaporation and drying for volatile organic matter removal are anaerobic digestion, nitrification-denitrification and ozonizing. Plants producing a dry product, as powder or pellets, are characterized by the methods adopted for addressing the problems of ammonia volatilization and organic matter stabilization. A centralized pig manure treatment plant producing pellets, combining anaerobic digestion, acidification, concentration by vacuum evaporation and thermal drying, will be analyzed in deep as case study.

Thermo-chemical processes, producing heat, gasses, ashes and chars, require always a previous step of drying.

9.5: Treatment of liquid fractions

The membrane separation systems (microfiltration, ultrafiltration and reverse osmosis) produce a "permeate" and a "concentrate", where nutrients and salts are concentrated, which is a valuable end-product. All these systems require an initial good solid/liquid separation system, in order to avoid clogging of the membranes. Also no indicated in Table 9.1., these systems could be combined with anaerobic digestion.

The concentration by vacuum or atmospheric evaporation could be an end-process, producing concentrates till 25-30% of total solids and allowing cheaper transport costs than the raw liquid manure, but usually these are combined with a further drying system. In any case, and due to the reasons explained above for drying, evaporation must be combined with previous processes dealing with the organic matter and ammonia volatilization.

Ammonia stripping and absorption processes efficiency increases, in case the pH and/ or the temperature of the input product are previously increased. The quality of obtained ammonia salts or ammonia concentrate increases when volatile organic matter has been previously removed. Thus, considering the requirements of heat and organic matter removal, stripping and absorption will be associated to an initial anaerobic digestion step.

Electro-oxidation must be always associated with efficient solid/liquid separation systems, i.e. screw pressing or centrifugation and electro-coagulation, in order to obtain a clear liquid fraction allowing low electrical consumption during electro-oxidation.

The removal of nitrogen by biological denitrification combined with nitrification in the called nitrification-denitrification (NDN) unitary process, treating liquid streams, requires organic matter. This is why it is difficult to combine it with anaerobic digestion or other processes dealing with organic matter oxidation. Nevertheless, the combination with anaerobic digestion is possible if enough organic matter is entering the plant, as co-substrate for mixing with manure, and by-passed to the denitrification section.

The problem of limited organic matter for both anaerobic digestion and denitrification should be solved with the new anammox process, which requires an influent almost free of organic matter. In this case, anaerobic digestion, and probably a further aerobic digestion for ensuring organics oxidation, is a necessary process to be combined with the partial nitrification and the autotrophic anammox process. This system is at lab – pilot scale still.

The recovery of phosphate salts (struvite, apatites) by precipitation requires pH increasing by means of a previous process. In order to avoid the interference of organic matter and to obtain a product mainly composed with the desired precipitates, valuable for the fertilizers industry, the system must be combined also with methods dealing with organic matter removal, such as anaerobic digestion or NDN processes.

Finally, the algae production or the wetland systems can be seen as more addressed to be a tertiary depuration system. Nevertheless, methods to separate organic matter and nutrients, such as anaerobic digestion or different kinds of solid/liquid separation systems must be adopted as initial stages. In general, these systems could be combined with systems producing a residual liquid with relatively lower nutrients and organic matter content compared with the raw manure.

9.6: Air cleaning (as part o manure processing plant)

These processing technologies have not been included in Table 9.1, since these are a necessary complement to any plant potentially affecting air pollution.

A cleaning system should be compulsory combined with thermal drying and thermo-chemical conversion processes at any scale. It will be usual to adopt air cleaning system in large scale plants, where the concentration of a huge amount of organic materials can produce large emissions. It must be considered also that techniques such as acid scrubbing can help to recover ammonia, which can be further processed for fertilizers production.

10: CLASSIFICATION OF STRATEGIES

Manure processing technologies can be classified into 4 main groups: 1) techniques treating raw manure or a mixture with other organic matter; 2) techniques treating slurries (raw manure); 3) techniques treating liquid fractions after separation of raw manure; 4) techniques treating solid fractions or solid manures. However, most of the facilities are a combination of these processes, therefore it is necessary to classify the combined processes using terms and variables allowing an easy classification, in order to avoid a large variety of situations.

Classification depends on the problem to be solved and, mainly, on the driving force for the establishment of objectives to be fitted by the strategy to be adopted. As indicated in chapter 1, improved nutrients management has been identified as the priority by farmers, followed by GHG emission mitigation and renewable energy production, with a priority weight depending of the subsidies and energy prices in each Country.

Renewable energy production is related to GHG mitigation, if produced energy substitute fossil fuels. Nevertheless, it must be taken into account that the maximum effect on GHG mitigation is obtained minimizing the storage time before any treatment (see chapter 11). A primary classification of strategies aimed at renewable energy production will classify combinations that include the following two kinds of processes:

1. Biological energy production by means of anaerobic digestion.
2. Thermo-chemical energy production by means of combustion or gasification

The above simple classification is compatible with any further classification focusing on nutrients management.

A primary classification of strategies focusing on nutrients management, could divide processes depending whether or not there is a nutrient surplus in the area. When there is no surplus, processes to be applied must be focused on increasing the management capacity, to increase economical value of manure (e.g. increase its efficiency) and to decrease economical costs related to manure management (e.g. decrease manure transportation costs). These methods are solid-liquid separation, anaerobic digestion and composting. This can be done either at farm or centralized scale, depending on whether or not the balance in nutrients is found at farm scale or at regional scale.

When the problem to be solved relates to nutrients surpluses, processing methods can be classified in three types, where the first two include recovery nutrients methods and the third includes removal nitrogen methods. These strategies can be applied at farm or centralized scale, depending on whether the nutrients surplus problems to be solved are found at farm or regional level, or on the technological complexity of the process. The three groups of technological strategies are:

1. Nutrients recovery without anaerobic digestion. It includes the following sub-groups:
    a. mechanical/physic-chemical separations for exporting solid fraction
    b. composting solid manure or solid fractions, for reducing volumes and exporting compost
    c. membrane processes for concentrating nutrients and subsequently export them
    d. evaporation/drying/pelletizing techniques for exporting pellets
2. Nutrients recovery with anaerobic digestion. It includes the following sub-groups:
    a. anaerobic digestion (AD) for energy production
    b. AD combined with composting of solid fraction and export of compost

c. AD combined with stripping and absorption of ammonia of the liquid fraction and export of ammonia

d. AD combined with membrane separation of liquid fractions, composting and export of concentrates and compost

e. AD combination with evaporation and drying and export of pellets

This kind of strategies benefits from co-digestion with other organic waste.

3. Nitrogen removal. It includes the following sub-groups:

   a. nitrification-denitrification (NDN) process

   b. separation of solid/liquid fractions and NDN of liquid fraction, without or with composting and export of solid fraction or combustion and pyrolysis of the solid fraction

   c. previous processes combinations with membrane separation technologies or water evaporation, drying and export of pellets.

   This kind of strategies could include an anaerobic digestion step if additional organic matter (i.e. industrial organic waste) enters the plant in order to increase biogas yield and/or to provide organic carbon for denitrification.

The above three groups of options can go from a simple system to a very complex one. The basic hypothesis to be adopted is that if a given simple process option can solve the problem, it is not necessary to adopt more complex systems, considering that the more complexity the more economical investment and operational cost. Energy cost and prices, and other subsidies related to GHG mitigation, vary in each country and this can modify the decision making process. Therefore, it is difficult to adopt classifications based on economical costs and technological complexity.

Figures 10.1, 10.2 and 10.3 show some possible diagrams from groups 1, 2 and 3, respectively. For every group, three schemes with increasing complexity degree are shown. These are simple examples about how technological strategies can be built depending on the objectives that must be fitted for solving a given nutrients surplus problem, or for obtaining some valuable products (biogas, compost, concentrate, etc.).

As it has been explained before, there is not a unique technological strategy suitable for all situations and, clearly, there is not a process capable of removing manure. Only nitrogen (N) and carbon (C), besides of water, can be "removed" through the conversion of different N-forms to dinitrogen gas (N_2), and organic-C to methane (CH_4) or carbon dioxide (CO_2). Other components of manure can just be separated or concentrated. Nitrogen is the unique nutrient which can be removed or recovered, while the other can be separated and recovered only, and, therefore, technological strategies can be classified taking this into account (chapter 10.1 and Table 10.1). There are also other factors on which focusing when planning a processing strategy, such as odours removal, hygienization, removal of xenobiotic compounds (emerging pollutants), or just energy recovery through anaerobic digestion.

Use of tools concerning Life Cycle Assessment (LCA) can provide new insights and help in objective discussion of the advantages and disadvantages of a given management model including treatments (Lopez-Ridaura *et al.*, 2009; Prapaspongsa *et al.*, 2010). In this kind of analysis it is necessary to consider all significant impacts to decide the best management option taking into account local issues and also climatic conditions (Sommer *et al.*, 2010). Clearly, treatment cost, including capital investment and operation, is also a main factor that will be considered by livestock producers before making any decision.

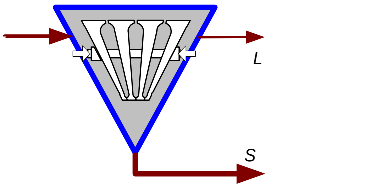
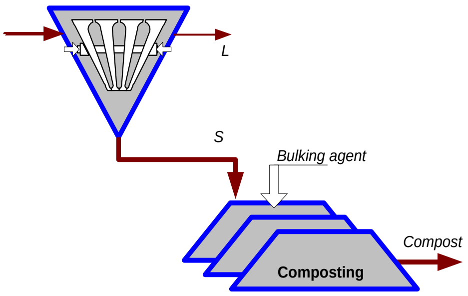
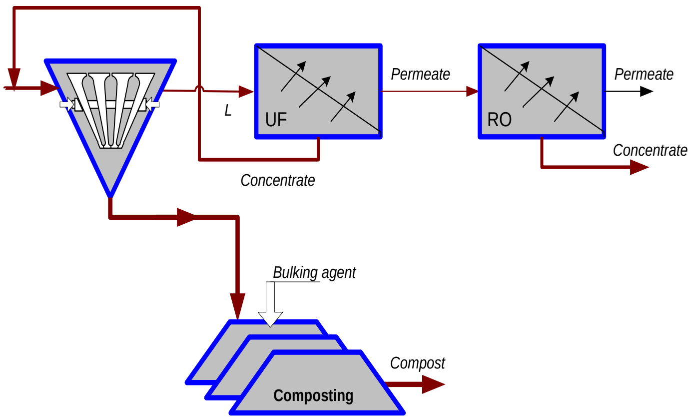
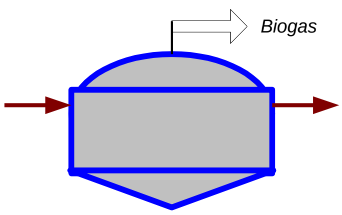
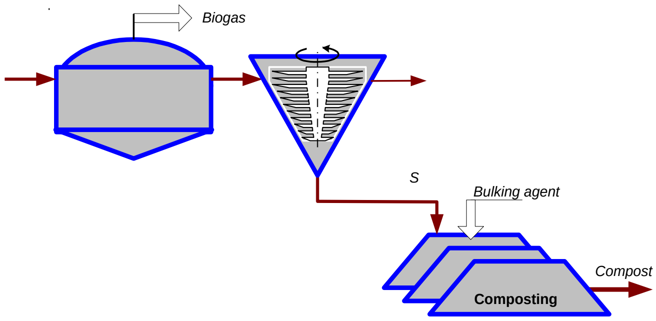
Solid-Liquid separation. Filter press as example	
Solid-liquid separation with composting of the solid fraction, with the objective to export compost and to use liquid fraction as fertilizer in the nearby land.	
Solid liquid separation with composting of the solid fraction and different membrane separation methods applied to the liquid fraction, with the objective to export compost and concentrates and use the permeate for irrigation.	

Figure 10.1: Examples of technological strategies of group 1, from simple to complex processes combination.

Anaerobic digestion with the objective of renewable energy production and odours mitigation	

Anaerobic digestion with solid-liquid separation and composting of the solid fraction, with the objective to produce biogas, to export compost and to use the liquid fraction as fertilizer in the nearby land



Anaerobic digestion with solid-liquid separation, composting of the solid fraction and ammonia stripping with consequent absorption, with the objective to produce biogas, to export compost and ammonia concentrate, and to use the treated liquid for irrigation

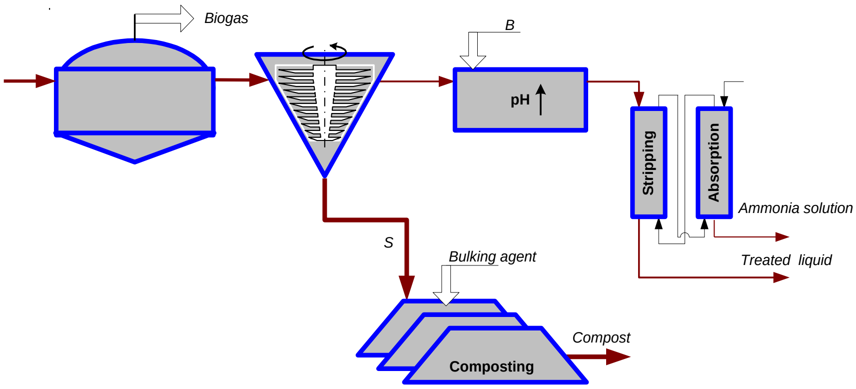
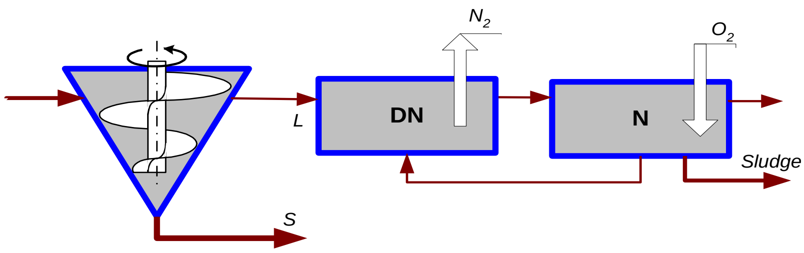
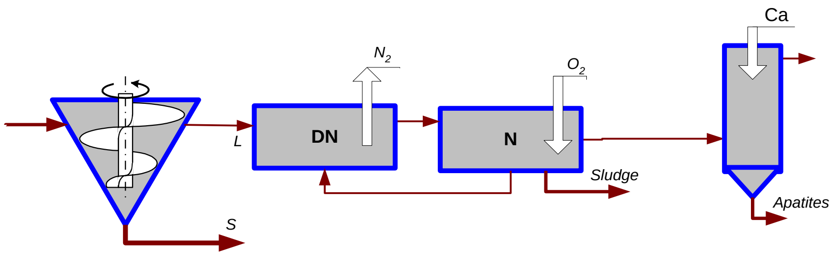


Figure 10.2: Examples of technological strategies of group 2, from simple to complex processes combination.

Solid-liquid separation and nitrification-denitrification of the liquid fraction, with the objective to partially remove nitrogen and to use the remaining products in the nearby land



Solid-liquid separation, nitrification-denitrification of the liquid fraction and precipitation of phosphorous salts, with the objective to partially remove nitrogen, to export phosphorous salts (apatites) and to use the remaining products in the nearby land



Solid-liquid separation, nitrification-denitrification of the liquid fraction, precipitation of phosphorous salts and biodrying of the solid fraction and sludges, with the objective to partially remove nitrogen, to export phosphorous salts (apatites), to export dried solids and to use the remaining liquid treated for irrigation

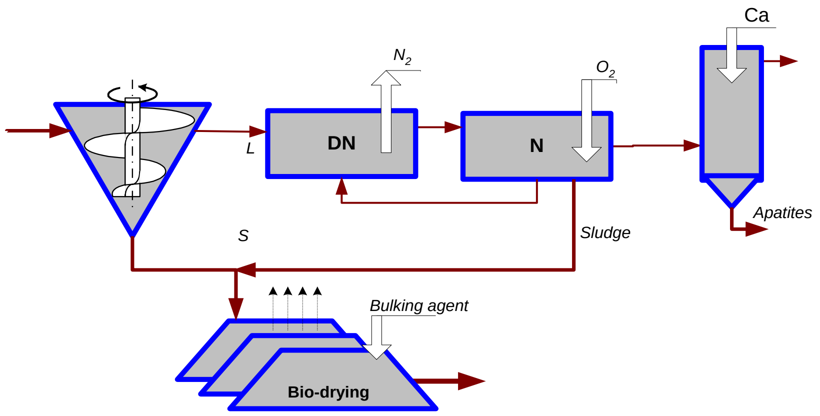


Figure 10.3: Examples of technological strategies of group 3, from simple to complex processes combination.

10.1: Strategies dealing with nutrients balance

Phase separation can be used as a simple method to improve manure management. It allows separating manure into a solid fraction, which can be composted on-farm, transported to long distances or delivered to a centralized composting plant, and a liquid fraction, which can be used in the nearby lands by means of irrigation systems or further processed (Burton, 2007). Separation efficiency can be enhanced by using flocculant agents (Campos *et al*., 2008), or by shortening the storage time of the raw manure (Kunz *et al.*, 2009).

N-recovery by means of stripping-absorption (Bonmatí and Flotats, 2003a), by thermal concentration (Bonmatí and Flotats, 2003b) or by ammonium and phosphate salt precipitation -struvite-, takes benefit from a previous anaerobic digestion step. The higher the organic mineralization achieved during digestion, the higher the quality of outflows. A favorable market for the commercialization of recovered products (Rulkens *et al.*, 1998) and energy prices encouraging anaerobic digestion are essential for successful practical application of these techniques. At the moment, there exist successful experiences of evaporation and concentration at farm scale (Melse and Verdoes, 2005) and large scale (Palatsi *et al.*, 2005). Several unsuccessful centralized experiences in the past reported as limiting factors the high operational costs, the lack of an adequate financial and organizational framework and the need of a well established network for the distribution of the products obtained.

N-removal through nitrification-denitrification (NDN) is a well-known process which has already been implemented mainly at individual scale to successfully deal with N-surpluses (Béline *et al.*, 2008; Vanotti *et al.*, 2009). Availability of biodegradable organic carbon is a key factor when combining this process with an anaerobic digestion step (Deng *et al.*, 2007; Bortone *et al.*, 2009). Optimization of the process can be achieved by avoiding formation of nitrate (Magrí and Flotats, 2008; Anceno *et al.*, 2009). Reductions in gaseous emissions of ammonia and GHG are also attainable in comparison to traditional management practices based on manure storage before land spreading (Loyon *et al.*, 2007; Vanotti *et al.*, 2008). New totally autotrophic N-removal approaches based on the anaerobic ammonium oxidation (anammox) process represent a promising treatment alternative (Karakashev *et al.*, 2008; Magrí *et al.*, 2010). This process implies significant reductions on oxygen needs during nitrification (60% less), no requirements of organic-C and the possibility of working with more compact reactors at higher loading rates.

Table10.1: Technological strategies based on nitrogen management

	Objective	Comments

Strategies based on nitrogen recovery		
Manure acidification	To avoid ammonia volatilization and to improve the fertilization quality	Applicable to liquid manure
Phases separation and/or concentration by membranes (reverse osmosis)	Separating into liquid and solid/concentrated flows to favor further treatments or managing each of them separately	Applicable to liquid manures and suspensions
Ammonia stripping and absorption	Nitrogen recovering as a salt or in a liquid solution	Applicable to liquid fractions. Previous anaerobic digestion favors the process
Thermal concentration (vacuum evaporation and drying)	Nutrients concentration to reduce transportation costs	Evaporation can be applied to liquid fractions and drying to concentrates and raw manures. Previous anaerobic digestion favours the process
Ammonium salts precipitation (struvite)	Nitrogen recovering as ammonium-phosphate salt	Applicable to liquid fractions Previous anaerobic digestion favours the process
Composting	Nitrogen recovering in organic form	Ammonia losses by volatilization should be prevented
Strategies based on nitrogen removal		
Nitrification-denitrification (NDN)	Nitrogen removal by ammonium oxidation to nitrite/nitrate and further reduction to N_2	Applicable to liquid fractions. Biodegradable organic matter is required for denitrification
Partial nitrification-anaerobic ammonium oxidation (PN-anammox)	Nitrogen removal by partial ammonium oxidation to nitrite and further reduction to N_2	Applicable to liquid fractions. No requirements of organic matter. Less energetic requirements than conventional NDN
Electro-oxidation	Nitrogen and recalcitrant organic matter removal by oxidation	Applicable to liquid fractions very well separated, with high electrical energy consumption

Ammonium and phosphate from liquid manures can be precipitated together forming struvite (Uludag-Demirer *et al.*, 2005; Çelen *et al.*, 2007). Also, phosphorus can be precipitated as calcium phosphate (Szogi and Vanotti, 2009). Once precipitated, both minerals can be converted into a valuable product. In order to reduce consumption of reagents to increase the pH, strategies such as CO_2 stripping (Fattah *et al.*, 2010) or nitrification (Szogi and Vanotti, 2009) can be applied.

10.2: Treatments dealing with hygienization

Managing manure can pose the risk of a possible transmission of zoonotic agents to other animals or the contamination of the human food chain (Venglovsky *et al.*, 2009). Manure contains enteric micro-organisms, a small percentage of which are pathogens, some of them being parasites (they cannot survive outside of their hosts). Generally speaking, the higher the temperature and storage/treatment time, the lower the survival of bacterial pathogens. However, besides pathogen bacteria there are also parasitic protozoa and spore-forming bacteria much less sensitive to the temperature. Viruses seem to be more resistant to inactivation than bacteria (Turner and Burton, 1997).

A temperature-time criterion of 70ºC for 1h has been established as a minimum for specific thermal treatments, prompting reductions equivalent to 4-$\log_{10}$ units (although it could be excessive for certain pathogens and low for others) (Heinonen-Tanski *et al.*, 2006). The composting process requires thermophilic temperatures during the decomposition phase, favoring manure hygienization, although high variability of operational conditions and the lack of monitoring (especially in rural facilities) can make the effectiveness of the process questionable (Martens and Böhm, 2009). Although pathogens reduction exists in both mesophilic and thermophilic anaerobic reactors, in the first case it is quite low. Aerobic digestion of liquid manures in self-heated thermophilic bioreactors (ATAD) has been proposed as effective for hygienization (Juteau *et al.*, 2004), although with high electrical power requirements for transferring oxygen. NDN processes are relatively efficient for the reduction of pathogens. In this sense, Vanotti *et al.* (2009) obtained 2.6-$\log_{10}$ reduction through such treatment, increasing to 4-$\log_{10}$ units in a subsequent stage running at pH of 9.5 for the recovery of phosphorus as calcium phosphate.

10.3: Treatments dealing with emerging pollutants and xenobiotic compounds

Xenobiotics are human-made chemicals that are unnaturally present in the environment and that could cause environmental and sanitary problems. In the case of livestock industry, there are compounds, such as antibiotics and hormones, of special concern, due to their routinely use in farms. Such substances are not completely absorbed by animal bodies and thus excreted as parent compounds or metabolites (Kemper, 2008). Release of antibiotics to the environment is of considerable concern because it may lead to the development of antibiotic-resistant bacteria (Chee-Sanford *et al.*, 2009). Numerous xenobiotics are susceptible of photodegradation, which can occur at the surface of manure in storage facilities, and at the soil-atmosphere interface, once manure is applied to soil. Nevertheless, sorption phenomena protect xenobiotics against photolysis and other potential degraders (Jjemba, 2002). Hydrolysis can be another degradation pathway (Chee-Sandford *et al.*, 2009) being highly influenced by temperature, pH and the molecular composition of chemical compounds. Generally, the degradation of most xenobiotics is faster and more complete under aerobic as compared to anaerobic conditions (Thiele-Bruhn, 2003). Antibiotics also can negatively affect bioprocesses performance when processing manure (Álvarez *et al.*, 2010). More research is needed in this field.

11: THE ROL OF STORAGE

The efficiencies of many processes analysed in the present report depend on the initial storage time, before beginning the processing.

Different authors studying efficiencies of solid/liquid separation systems concluded that these efficiencies increase when the storage time is as short as possible (Zhu et al., 2000; Ndegwa et al., 2002; Møller et al., 2002; Kunz et al., 2009). This lower efficiency is due to the natural microbiological activity during storage, which degrades organic matter, mineralize nutrients and increase soluble components concentrations in the liquid phase. When a separation system is applied after, less material can be separated in the solid phase. It must be taken into account that the microbiological activity increases with temperature, being its importance higher if manure is stored in pits below animal confinements, where manure temperature is close to the temperature of animal houses.

A previous long storage can affect seriously also the anaerobic digestion process performance. Bonmatí et al. (2001) found a decrease of 72% of the methane potential by anaerobic digestion for pig slurry when manure was previously stored in pits below animals for around 3 months. This decrease is coincident with the emission factor proposed by IPCC (2006) for evaluating methane emissions for pit storage in warm climate regions (actually, the climate inside the animal buildings). Bonmatí et al. (2001) found also that, while a thermal pre-treatment at 80ºC can significantly improve the anaerobic biodegradability of fresh pig manure, this was decreased for long term stored manure.

Storage has not been considered a processing technology in the present report, but it must be taken into account in any processing strategy. The recommendation will be always to decrease as much as possible the initial storage time before processing. To store liquid fractions after separation will be preferable, in order to decrease emissions, since organic matter and total nitrogen concentrations are lower than in raw manure.

Anaerobic lagooning has been considered a storage method instead of a treatment technology in the present report. IRPP BREF (2011) considers it an effective treatment method for decreasing BOD_5 before land spreading, and Portugal and Greece have a large number of facilities (communicated by experts from these countries during the survey), but the conversion of the organic charge to CH_4 that is emitted to the atmosphere makes this treatment process not recommendable.

IPCC guidelines (2006) proposes a methane emission factor for uncovered anaerobic lagoons from 66% to 79% of the methane potential of the volatile solids, for temperatures in the range 10ºC - 25ºC, being the manure management method with the highest methane emissions.

Covering storage tanks, for recovering CH_4, could be a reasonable method to be applied. In any case, the storage phase, before, during and after treatment, must be considered as an active biological system, and included in the whole process flow sheet and mass balances.

12: BEST AVAILABLE TECHNOLOGIES

IPPC Directive (96/61/EC), updated by Industrial Emissions Directive (IED) Directive 2010/75/EC, on industrial emissions (integrated pollution prevention and control), defines a Best Available Technology (BAT) as follows:

"Best available techniques' means the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole:

(a) 'techniques' shall include both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned;

(b) 'available techniques' means those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator;

(c) 'best' means most effective in achieving a high general level of protection of the environment as a whole.

In determining the best available techniques, IPPC Directive (1996) indicate that special consideration should be given to the items listed in its Annex IV, bearing in mind the likely costs and benefits of a measure and the principles of precaution and prevention. These items are:

1. The use of low-waste technology;

2. The use of less hazardous substances;

3. the furthering of recovery and recycling of substances generated and used in the process and of waste, where appropriate;

4. Comparable processes, facilities or methods of operation which have been tried with success on an industrial scale;

5. Technological advances and changes in scientific knowledge and understanding;

6. the nature, effects and volume of the emissions concerned;

7. The commissioning dates for new or existing installations;

8. The length of time needed to introduce the best available technique;

9. The consumption and nature of raw materials (including water) used in the process and energy efficiency;

10. The need to prevent or reduce to a minimum the overall impact of the emissions on the environment and the risks to it;

11. The need to prevent accidents and to minimise the consequences for the environment;

12. The information published by the Commission pursuant the IPPC (2008) *Article 17(2)* relative to information exchange, *or by International organisations.*

Expressing in short, BAT could be defined as the techniques and methods that allow a high environmental protection at an acceptable cost.

BAT reference documents (BREF) are prepared to propose the best available technologies for a given activity sector for decreasing its environmental impact and to comply with the IED Directive. The methodology for preparing a BREF is based on a multi-step process (Dijkmans, 2000) and was mainly developed by VITO –Belgium (2011). A state of the art of the BREF development process can be found in Schoenberger (2009).

BREF documents related to manure management, or indicating technologies that could be applied in manure processing systems are:

- IRPP BREF (2003). Reference Document on Best Available Techniques for Intensive Rearing of Poultry and Pigs, July 2003. ftp://ftp.jrc.es/pub/eippcb/doc/irpp_bref_0703.pdf.
- IRPP BREF (2011). Draft Reference Document on Best Available Techniques for Intensive Rearing of Poultry and Pigs, Draft 1, March 2011. ftp://ftp.jrc.es/pub/eippcb/doc/irpp_d1_0311.pdf.
- WT BREF (2006). Reference Document on Best Available Techniques for the Waste Treatment Industries, August 2006. ftp://ftp.jrc.es/pub/eippcb/doc/wt_bref_0806.pdf
- WI BREF (2006). Reference Document on Best Available Techniques for Waste Incineration, August 2006. ftp://ftp.jrc.es/pub/eippcb/doc/wi_bref_0806.pdf

The best available techniques for the treatment of pig and poultry manure are explained in the IRPP BREF (2011) document and from the documents WT BREF (2006) and WI BREF (2006) some process units can be adopted in a manure processing system, as they are similar to those applicable to the activity sectors for which these documents are prepared.

The identified processes are listed in Table 12.1. It can be observed that these documents use different nomenclature. While, WT and Wi BREFs identify unitary processes to be combined for a given objective, the IRPP BREF identify typologies of processing plants combining different unitary processes. The present report tries to use the nomenclature of unitary processes to be combined, depending of the objective.

All the processes listed in Table 12.1 can be considered technically feasible and providing high environmental protection level, if they are operated properly. There are two exceptions:

- Gasification and pyrolysis: the WI BREF document indicates that these processes can be technical and environmental feasible, but are not widely proven at industrial scale. This could be the same for the livestock sector.

- Anaerobic lagoons: IRPP BREF (2011) indicates that it is questioned whether in some cases anaerobic lagoons solve or create problems related to manure application. Moreover, the high methane emissions from anaerobic lagoons (IPCC, 2006) makes it not candidate to be a BAT.

A manure treatment technology can be candidate to be BAT if it complies with the following three main requisites:

- Technically feasible, demonstrated with some plants continuously operating

- Provide high environmental protection, decreasing emissions and producing end-products that can decrease leaching and other environmental impacts when properly managed

- Economically acceptable for the sector.

The first condition is relatively easy to evaluate as plants can be found at on-farm and/or centralized scale. The environmental protection assured for each process depends on the adequate combination of unitary processes. The third condition depends on the allowable cost for the farmers, which depends on the economical gross margin of their business, taking into account the subsidies or incentives defined in every country. As example, although anaerobic digestion is a good process to be applied for decreasing methane emissions and for improving manure quality, it could be economically acceptable only if an adequate incentive to renewable energy production is established. Nowadays, all MS are trying to promote or have established incentives for biogas production, making reasonable to consider anaerobic digestion as BAT, including from an economical point of view, although many barriers must be overcome in many countries still.

Table 12.1: Processes applicable for processing manure, or to be included in a processing system, identified in the documents IRPP BREF (2011), WT BREF (2006) and WI BREF (2006).

Technology/process	Correspondence to processes identified in the present document: Process num (chapter.section)
IRPP BREF (2011):	
Mechanical separation	10 (3)
Screw press and auger separator	12 (3.4)
Decanter – centrifuge separator	15 (3.7)
Flocculation	10A (3.1)
Mechanical separation and biological treatment of pig manure	Combination of 12 (3.4) or 15 (3.7) or 18 (3.10) with 60 (7.112)
Aeration of liquid manure	59A (7.10)
Composting of solid manure	41 (6.1)
Composting	41 (6.1)
Co-composting of poultry manure using pine bark	41 (6.1)
Composting with a biological inoculum	41 (6.1)
Anaerobic treatment of manure in a biogas plant	30 (5)
Anaerobic lagoon system	Not considered
Evaporation and drying of manure	Combination of 54A (7.4) or 54B (7.5) with 43 (6.4)
Slurry belt dryer	Included in 43 (6.4)
Slurry acidification	21 (4.1)
Incineration of poultry manure	45 (6.6)
Ammonia stripping	55 (7.6)
Manure additives	24 (4.4)
WT BREF (2006)	
Biological processes	
Activated sludge	60 (7.12)
Aerated lagoons	59A (7.10)
Aerobic digestion	59A (7.10)
Anaerobic digestion	30 (5)
Composting	41 (6.1)
Physical -chemical processes	
Air scrubbing	101 (8.1)
Centrifugation	15 (3.7)
Drying	43 (6.4)
Evaporation and distillation	54A (7.4)
Filtration (by membranes)	52 (7.2)
Filtration/ sieving	13 (3.5)
Flotation	16 (3.8)
Oxidation	58 (7.9)
Pelletizing (for sludge)	44 (6.5)
Precipitation/ flocculation	10A (3.1)
Reverse Osmosis	53 (7.3)
Screening	11 (3.3), 17 (3.9)
Sedimentation (settlement)	18 (3.10)
Sorption (absorption)	Included in 55 (7.6)
Stripping	55 (7.6)
Wet air oxidation	48 (6.9)
WI BREF (2006)	
Combustion	45 (6.6)
Gasification (Not widely proven)	46 (6.7)
Pyrolysis (Not widely proven)	47 (6.8)

There are many external conditions, independently of the technical adequacy of a process, which makes a technology be a BAT. WI and WT BREFS (2006) dedicate most of the document to describe how to operate the systems and how to obtain and storage raw materials in order to have good processes efficiencies and minimize the emissions in the whole plant. A possible BREF document focussed on manure processing should indicate also operation and management conditions, in the context of the whole farming system, at farm level or at regional level for centralized plants, including the best conditions for using end-products. As simple examples, separation techniques, anaerobic digestion or denitrification to N_2 gas are processes that work better when the storage time has been minimized before processing. This minimization contributes to lower methane and ammonia emissions in the context of the farming system, making the processing more economically feasible also.

Considering only the technological process, instead of overall manure management system, brings us to the adoption of conditional BAT concept: a technique is conditional BAT if complies with the three requisites for being BAT only in some circumstances. In this sense, all the manure processing techniques could be conditional BAT. With the current information, it is not possible to identify completely a BAT for manure processing technology, but to identify candidates.

The description of the best management and operation methods, for each described process, for raw manure to be processed and for each end-product to be further used is out of the scope of the present report, and should be the aim of a BREF document about manure management and treatment.

For the identification of candidate processes to be BAT, it will be considered that these processes operate under the best conditions, being only the economical acceptability the variable that could be considered conditional.

Table 12.2 shows the list of the processes previously described, indicating whether the process is being applied on-farm or in centralized scale plants, running continuously (pilot or laboratory plants are not considered); whether the process is contributing directly or indirectly to decrease emissions to atmosphere or water bodies and whether the investment and operative costs can be acceptable. For this last variable, the existence of incentives to renewable energy production, or other subsidies must be considered. Also, although a given cost could be considered high, it could be low compared with the environmental cost of "doing nothing" or compared to the cost of transporting manure to long distances, from nutrients surplus regions to regions with nutrients demand. In most of the cases, for these high cost technologies the evaluation considers that these are conditional BAT (CBAT), and could be considered BAT in certain circumstances.

Variables or circumstances to be evaluated in order to consider CBAT as BAT could be:

- Incentives to renewable energy production
- Incentives to the use of wasted heat of a CHP plant
- Market prices of the end-products obtained
- Stability of prices and markets during the installation life period
- Comparison of the net installation costs with the cost of transporting manure from nutrients surplus areas to others with nutrients demand, which could be the reference scenario

Anaerobic digestion process, which has been evaluated as BAT, has economical feasibility depending on the incentives to renewable energy production, different for every country and on the possibility to co-digest manure with industrial organic waste.

Table 12.2: Identification of processes that could be BAT candidates. Y: there are plants at the indicated scale, contributing to environmental protection if operated properly or can be considered economically acceptable in the context of its application, and finally can be considered as BAT; N: the above conditions are not met or the technique is at pilot plant; C: the condition is met in certain circumstances; CBAT: technique is a conditional BAT candidate.

Chapter	Livestock Manure Treatment Technology	Technically feasible		Environ. protection	Economic. acceptable	BAT candidate
		On farm	**Large scale**			
3	**10: Separation**					
3.1	10A Coagulation-Flocculation	Y	Y	C	Y	CBAT
3.2	10B Electro coagulation	Y		y	C	CBAT
3.3	11 Separation by grid	Y	Y	Y	Y	Y
3.4	12 Separation by screw pressing	Y	Y	Y	Y	Y
3.5	13 Separation by sieves	Y		Y	Y	Y
3.6	14 Separation by filter pressing	Y		Y	Y	Y
3.7	15 Separation by centrifuge		Y	Y	Y	Y
3.8	16 Air Flotation		Y	Y	y	Y
3.9	17 Separation by drum filters	Y		Y	Y	Y
3.10	18 Natural settling separation	Y	Y	Y	Y	Y
4	**20: Additives and other pre/1st treatments**					
4.1	21 Acidification of liquid livestock manures	Y	Y	Y	Y	Y
4.2	22 pH increasing (liming)	Y	Y	Y	C	CBAT
4.3	23 Temperature and pressure treatment		Y	Y	C	CBAT
4.4	24 Applying other additives to manure	Y	Y	Y	C	CBAT
5	**30: Anaerobic treatment**					
5.1	31A Mesophilic/thermophilic	Y	Y	Y	Y	Y
6	**40: Treatment of the fibre/solid fraction**					
6.1	41 Composting of solid livestock manure or separation solids	Y	Y	C	Y	CBAT
6.2	41A Vermicomposting		Y	Y	C	CBAT
6.3	42 Bio drying	Y		C	C	CBAT
6.4	43 Thermal drying		Y	Y	C	CBAT
6.5	44 Pelletizing		Y	Y	C	CBAT
6.6	45 Combustion		Y	Y	C	CBAT
6.7	46 Thermal gasification	N	N			N
6.8	47 Pyrolysis	N	N			N
6.9	48 Wet oxidation	N	N			N
7	**50: Treatment of the liquid fraction**					
7.1	51 Microfiltration	N	N			N
7.2	52 Ultra filtration		Y	Y	C	CBAT
7.3	53 Reverse osmosis		Y	Y	C	CBAT
7.4	54A Concentration by vacuum evaporation		Y	Y	C	CBAT
7.5	54B Concentration by atmospheric evaporation		Y	Y	C	CBAT
7.6	55 Ammonia stripping and absorption		Y	Y	C	CBAT

Chapter	Livestock Manure Treatment Technology	Technically feasible		Environ. protection	Economic. acceptable	BAT candidate
7.7	56 Carbon dioxide stripping	N	N			N
7.8	57 Electro-oxidation	N	N			N
7.9	58 Ozonizing		Y	Y	C	CBAT
7.10	59A Aerobic digestion (aeration)	Y	Y	C	Y	CBAT
7.11	59B Auto thermal aerobic digestion (ATAD)		Y	Y	C	CBAT
7.12	60 Nitrification-denitrification (conventional)	Y	Y	Y	Y	Y
7.13	61 Partial nitrification - autotrophic anammox denitrification	N	N	C		N
7.14	62A Struvite (magnesium ammonium phosphate) precipitation	Y	Y	Y	C	CBAT
7.15	62B Calcium phosphate precipitation	Y	Y	Y	C	CBAT
7.16	63 Algae production on liquid manure substrates	N	N			N
7.17	64 Constructed wetlands	Y	Y	C	C	CBAT
8	**100: Air cleaning (as part of manure processing plant)**					
8.1	101 Air scrubbing		Y	Y	Y	Y
8.2	102 Air bio filtration		Y	Y	Y	Y
8.3	103 Bioscrubing (Aerobic bio filter)		Y	Y	Y	Y

In Table 12.2 it is assumed that the processes are operated in a manner they ensure environmental protection. However, the following must be considered:

- flocculation can only be acceptable in case it is performed with safety polymers;
- composting, nitrification-denitrification and other oxidation processes can be considered as BAT's only in case measures are taken to ensure collection of emissions of ammonia, laughing gas, etc.;
- evaporation and drying can be considered as BAT only in case are operated in close circuits with collection and treatment of the flow gases and vapours;
- stripping of ammonia can be considered as BAT's only in case they are operated linked to an absorption process for avoiding ammonia emissions to the atmosphere and to recover this resource; etc.

Air cleaning systems are evaluated as BAT: their economical cost should be included in the overall plant cost, when these systems are required to avoid significant emissions to the atmosphere, especially in large plants.

13: REFERENCES AND FURTHER READING

In chapters 3 to 8, specific references for every processing technology have been included in the section focused on it. The following references have been referred in other sections.

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14: ABBREVIATIONS AND ACRONYMS

ABP	Agro Business Park A/S
AU	Animal Unit. Danish coefficient that expresses the nutrient load of livestock. 1 AU = 100 kg N in livestock manure ex. storage = app. 36 produced slaughter pigs from 32 to 107 kg.
BAT	Best Available Technique, as defined in Directive 2008/1/EEC
BREF	Reference Document on Best Available Techniques for Intensive Rearing of Poultry and Pigs
Ca	Calcium - the conversion factor from CaO to Ca is 0.7146.
CO_2	Carbon Dioxide
CPH	Combined Heat and Power
DG ENV	European Commission, Directorate-General Environment
DM	Dry matter
EU	European Union
FAO	Food and Agriculture Organisation of the United Nations.
GIRO	GIRO Centre Tecnològic
IED	Industrial Emissions Directive 2010/75/EEC
IPPC	Integrated Pollution Prevention and Control, as defined in Directive 2008/1/EEC, now replaced by the Industrial Emissions Directive 2010/75/EEC
IRPP	Intensive Rearing Pigs and Poultry
IRR	Internal Rate of Return
K	Potassium - the conversion factor from K_2O to K is 0.8301.
Laughing gas	Nitrous oxide, N_2O – a greenhouse gas with a climate impact that is around 300 times that of CO_2
LSU	The livestock unit, abbreviated as LSU (or sometimes as LU), is a reference unit which facilitates the aggregation of livestock from various species and age as per convention, via the use of specific coefficients established initially on the basis of the nutritional or feed requirement of each type of animal (see table below for an overview of the most commonly used coefficients). The reference unit used for the calculation of livestock units (=1 LSU) is the grazing equivalent of one adult dairy cow producing 3 000 kg of milk annually, without additional concentrated foodstuffs. See also http://epp.Eurostat.ec.Europa.eu/statistics_explained/index.php/Glossary:Livestock_unit_(LSU).
MBE	Morsø BioEnergy
Mg	Magnesium - the conversion factor from MgO to Mg is 0.6031.
MS	Member State of the European Union
N	Nitrogen
Na	Sodium - the conversion factor from Na_2O to Na is 0.741839763.
NVZ	Nitrate Vulnerable Zone, as defined in Directive 676/91/EEC
OU	Odour Units.
P	Phosphorus – the conversion factor from P_2O_5 to P is 0.436681223.

VS	Volatile solids

ANNEX A: "LONG-LIST" OF CONSIDERED MANURE PROCESSING TECHNOLOGIES

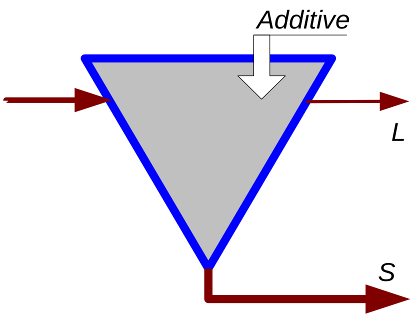
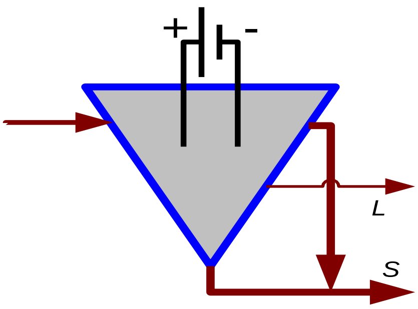
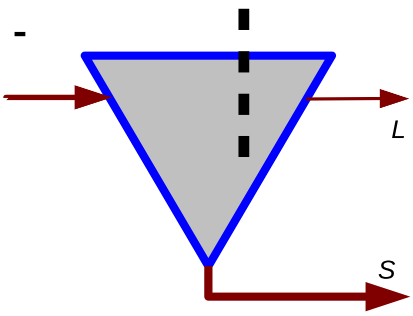
Chapter	Livestock Manure Treatment Technology	Stand alone	Combined
3	**10: Separation**		
3.1	10A Coagulation-Flocculation		✓
3.2	10B Electrocoagulation		✓
3.3	11 Separation by grid		✓
3.4	12 Separation by screw pressing	✓	✓
3.5	13 Separation by sieves	✓	✓
3.6	14 Separation by filter pressing	✓	✓
3.7	15 Separation by centrifuge	✓	✓
3.8	16 Air Flotation		✓
3.9	17 Separation by drum filters	✓	✓
3.10	18 Natural settling separation		✓
4	**20: Additives and other pre/1st treatments**		
4.1	21 Acidification of liquid livestock manures	✓	✓
4.2	22 pH increasing (liming)	✓	✓
4.3	23 Temperature and pressure treatment	✓	✓
4.4	24 Applying other additives to manure	✓	✓
5	**30: Anaerobic treatment**		
5.1	31A Mesophilic anaerobic digestion	✓	✓
5.2	31B Thermophilic anaerobic digestion	✓	✓
6	**40: Treatment of the fibre/solid fraction**		
6.1	41 Composting of solid livestock manure or fibre fractions of liquid livestock manure	✓	✓
6.2	41A Vermicomposting	✓	✓
6.3	42 Biodrying	✓	✓

Chapter	Livestock Manure Treatment Technology	Stand alone	Combined
6.4	43 Thermal drying		✓
6.5	44 Pelletizing		✓
6.6	45 Combustion		✓
6.7	46 Thermal gasification		✓
6.8	47 Pyrolysis		✓
6.9	48 Wet oxidation		✓
7	**50: Treatment of the liquid fraction**		
7.1	51 Microfiltration		✓
7.1	52 Ultra filtration		✓
7.1	53 Reverse osmosis		✓
7.2	54A Concentration by vacuum evaporation		✓
7.3	54B Concentration by atmospheric evaporation		✓
7.4	55 Ammonia stripping and absorption		✓
7.5	56 Carbon dioxide stripping		✓
7.6	57 Electro-oxidation		✓
7.7	58 Ozonizing		✓
7.8	59A Aerobic digestion (aeration)	✓	✓
7.9	59B Autothermal aerobic digestion (ATAD)	✓	✓
7.10	60 Nitrification-denitrification (conventional)		✓
7.11	61 Partial nitrification - autothrophic anammox denitrification		✓
7.12	62A Struvite (magnesium ammonium phosphate) precipitation		✓
7.13	62B Calcium phosphate precipitation		✓
7.14	63 Algae production on liquid manure substrates		✓
7.15	64 Constructed wetlands		✓
8	**100: Air cleaning (as part of manure processing plant)**		

Chapter	Livestock Manure Treatment Technology	Stand alone	Combined
8.1	101 Air scrubbing		✓
8.2	102 Air biofiltration		✓
8.3	103 Bioscrubing (Aerobic biofilter)		✓

ANNEX B: PROCESS TECHNOLOGIES DIAGRAMS

Arrows	
Raw manure, liquid or semi-liquid (slurry)	
Solid manure, solid fraction or other concentrated streams	
Liquid fraction after some processes	
Streams with no significant concentration of N, P or K	

10: Separation		
10A Coagulation-Flocculation		
10B Electro coagulation		
11 Separation by grid		

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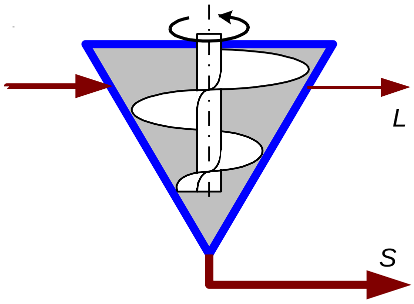
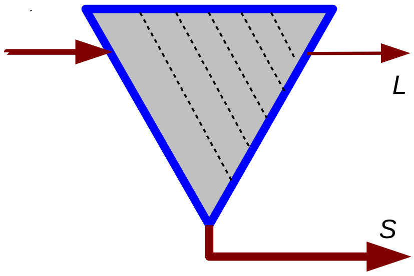
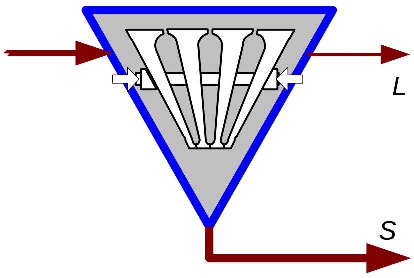
<tr><td>12 Separation by screw pressing</td><td></td><td>
</td></tr>
<tr><td>13 Separation by sieves</td><td></td><td>
</td></tr>
<tr><td>14 Separation by filter pressing</td><td></td><td>
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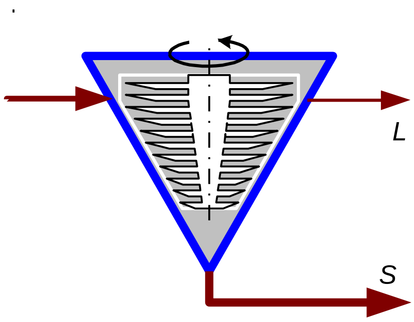
<tr><td>15 Separation by centrifuge</td><td></td><td>
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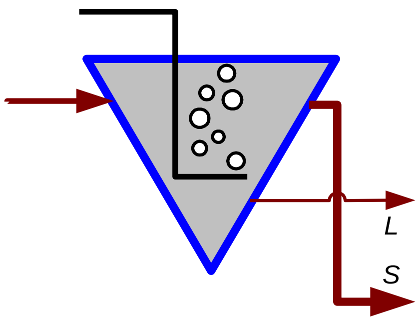
<tr><td>16 Air Flotation</td><td></td><td>
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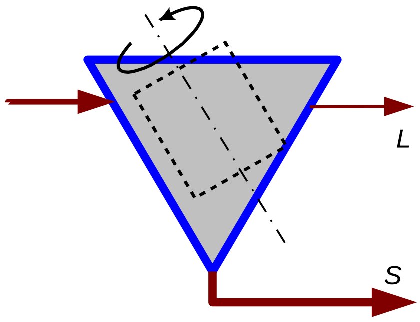
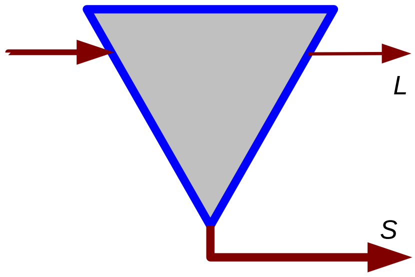
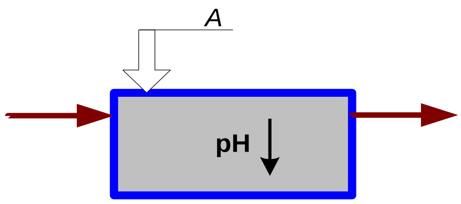
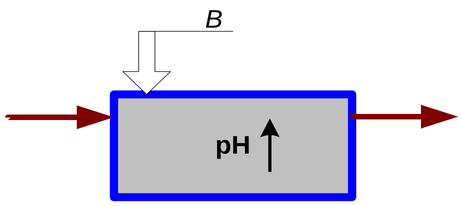
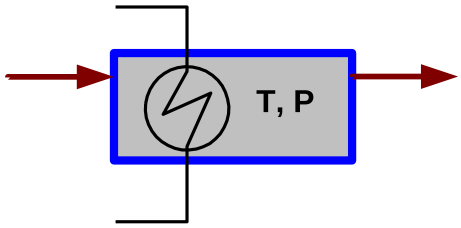
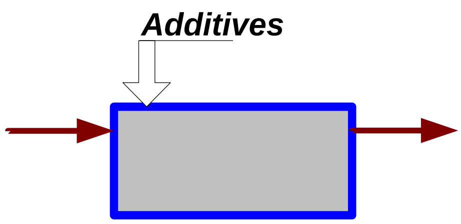
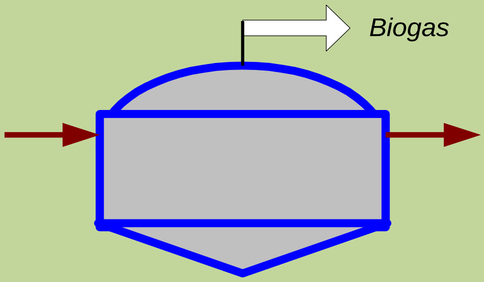
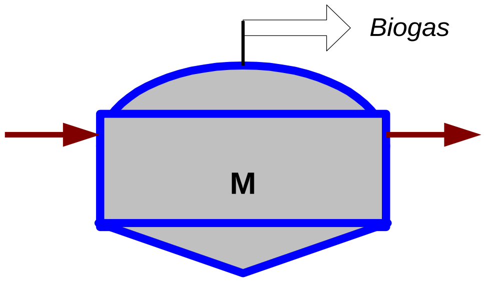
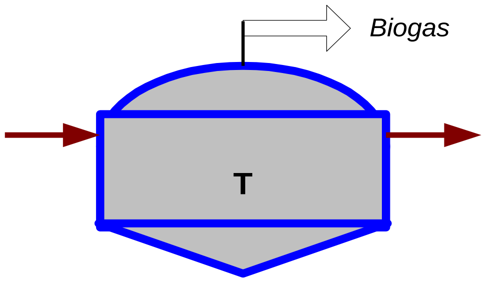
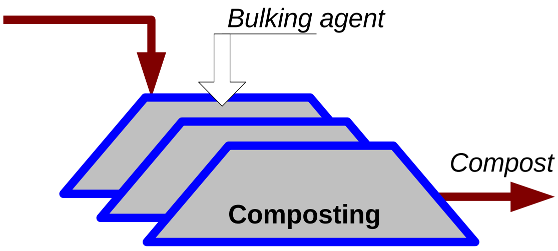
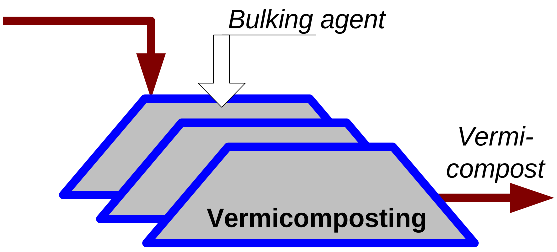
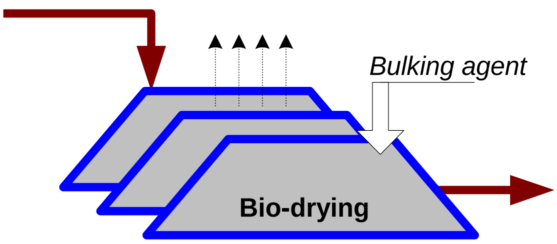
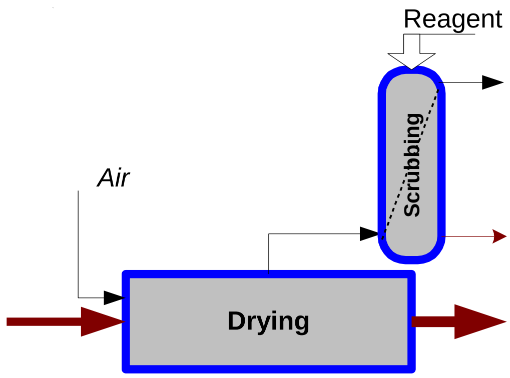
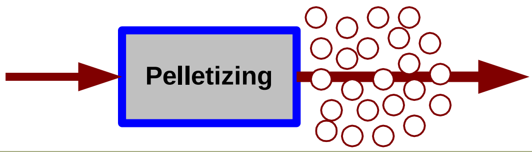
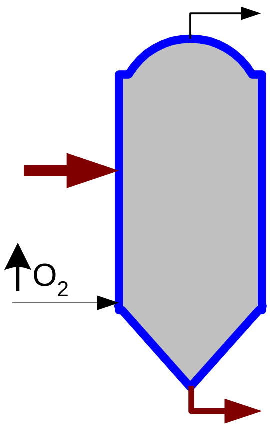
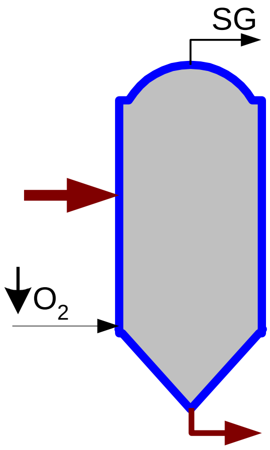
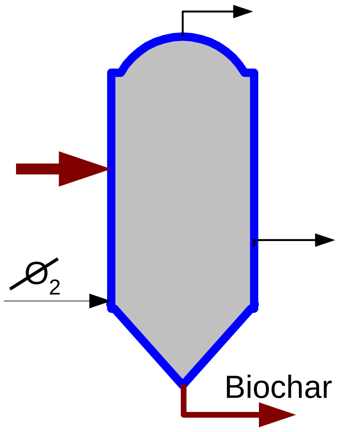
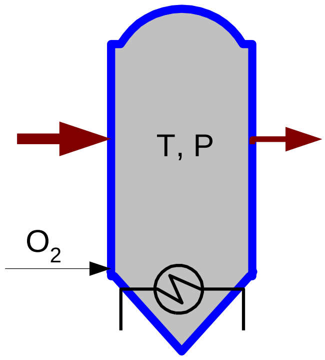
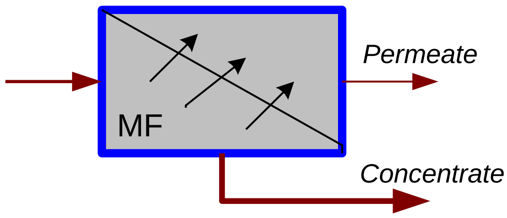
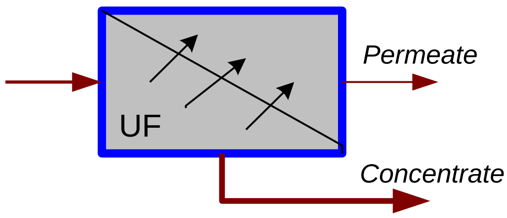
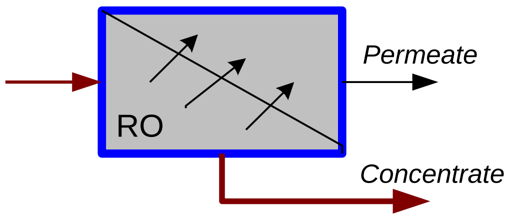
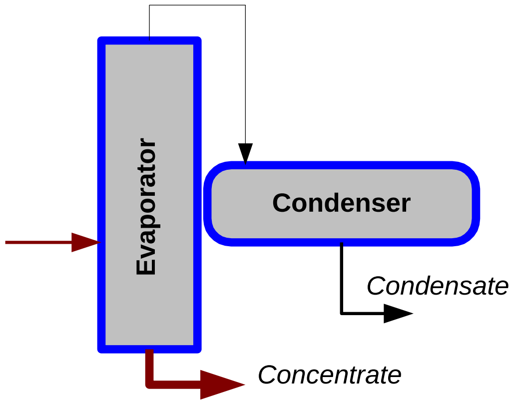
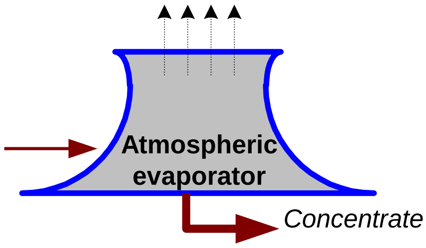
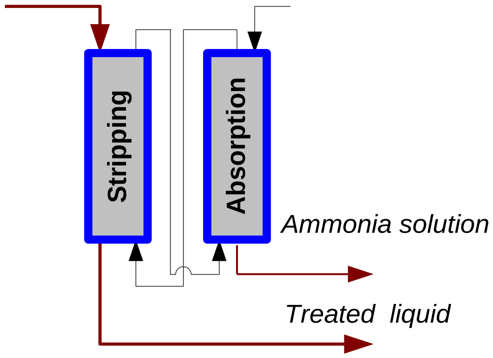
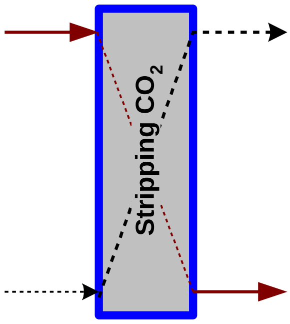
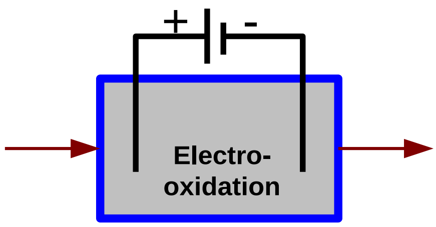
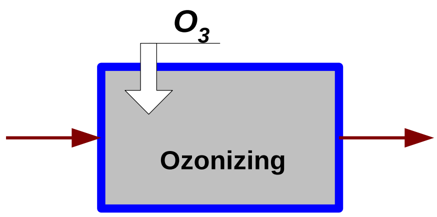
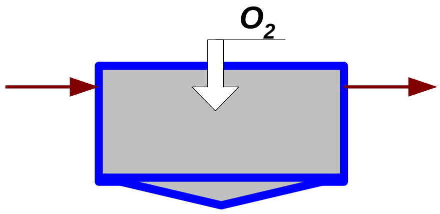
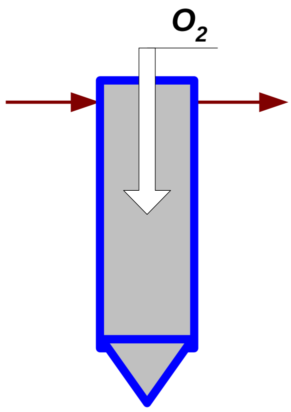
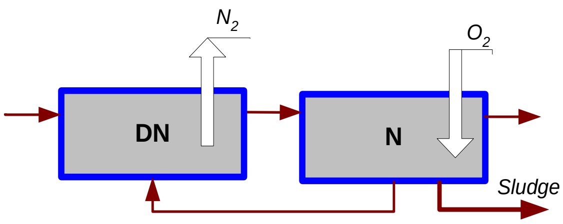
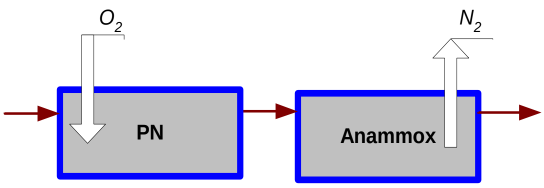
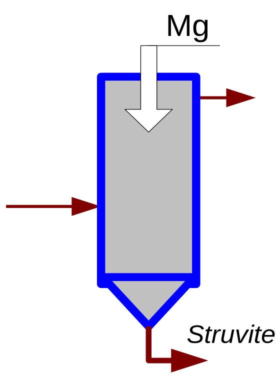
17 Separation by drum filters	
18 Natural settling separation	
20: Additives and other pre/1st treatments	
21 Acidification of liquid livestock manures	
22 pH increasing (liming)	
23 Temperature and pressure treatment	
24 Applying other additives to manure	

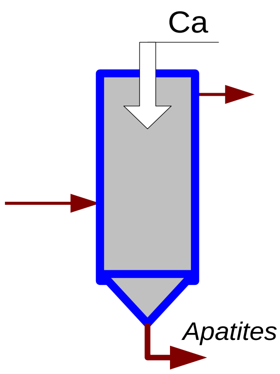
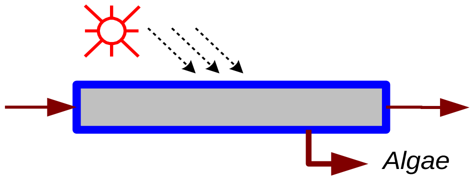
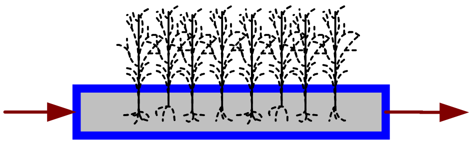
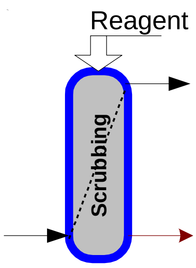
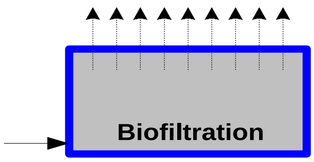
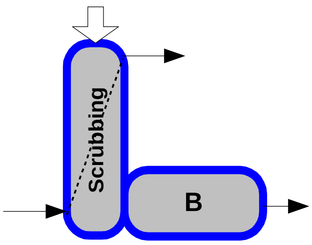
30: Anaerobic treatment	
31A Mesophilic anaerobic digestion	
31B Thermophilic anaerobic digestion	
40: Treatment of the fibre/solid fraction	
41 Composting of solid livestock manure or fibre fractions of liquid livestock manure	
41A Vermicomposting	
42 Bio drying	

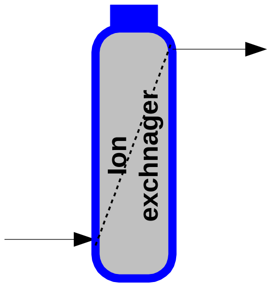
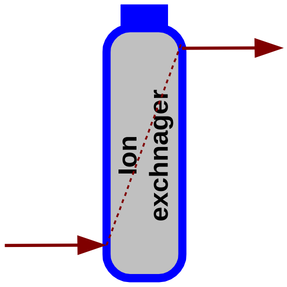
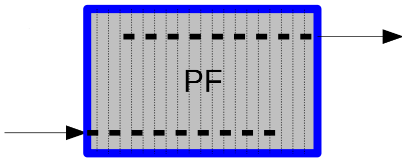
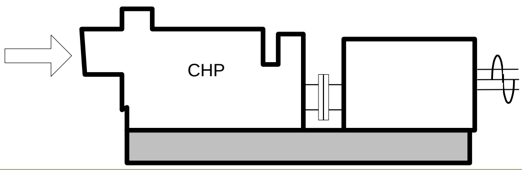
43 Thermal drying		
44 Pelletizing		
45 Combustion		
46 Thermal gasification		

47 Pyrolysis		
48 Wet oxidation		
50: Treatment of the liquid fraction		
51 Microfiltration		
52 Ultra filtration		
53 Reverse osmosis		

54A Concentration by vacuum evaporation		
54B Concentration by atmospheric evaporation		
55 Ammonia stripping and absorption		
56 Carbon dioxide stripping		
57 Electro-oxidation		

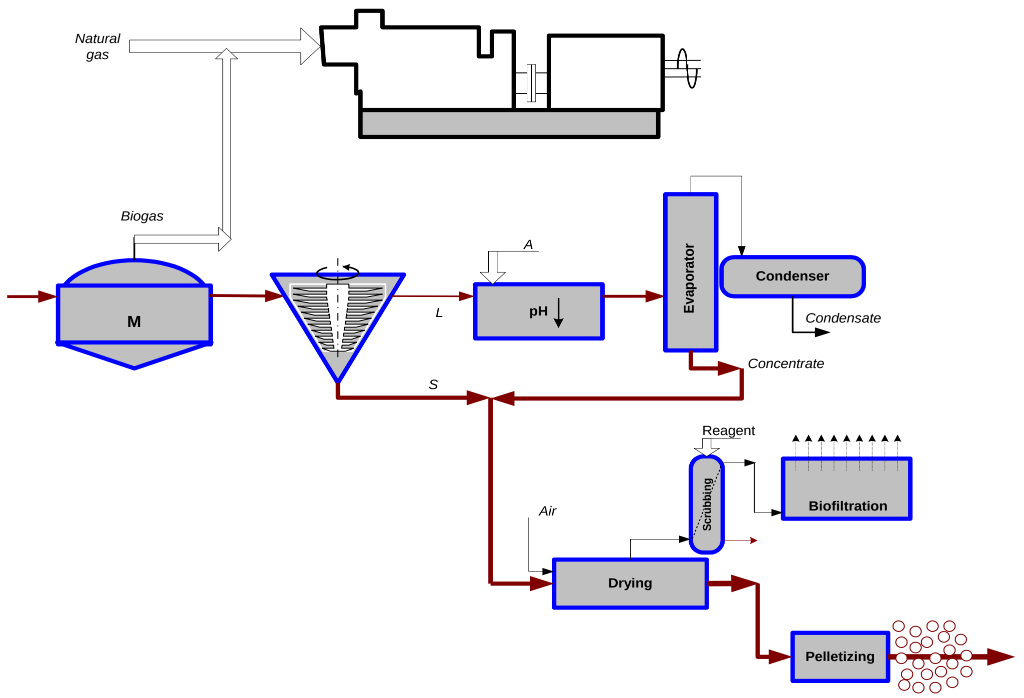
58 Ozonizing		
59A Aerobic digestion (aeration)		
59B Auto thermal aerobic digestion (ATAD)		
60 Nitrification-denitrification (conventional)		
61 Partial nitrification - autotrophic anammox denitrification		
62A Struvite (magnesium ammonium phosphate) precipitation		

62B Calcium phosphate precipitation		
63 Algae production on liquid manure substrates		
64 Constructed wetlands		
100: Air cleaning (as part of manure processing plant)		
101 Air scrubbing		
102 Air bio filtration		
103 Bioscrubbing (Aerobic biofilter)		

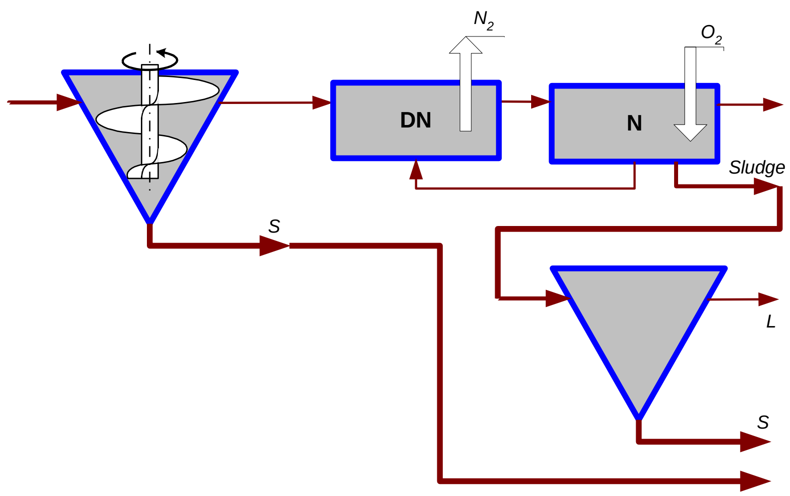
Other processes diagrams	
Ion exchange (treating streams with no significant concentration of N, P or K)	
Ion exchange (treating liquid fractions)	
Paper filtration	
CHP	

COMBINED SYSTEMS (examples)

Anaerobic digestion – concentration by vacuum evaporation, drying and pelletizing (plant of Tracjusa, described in report IV)



Solid-liquid separation – nitrification-denitrification –(plant of Calldetenes, described in Report IV)



ANNEX C: GUIDELINES FOR FILLING PROCCESSING TECHNOLOGIES CHARTS

1: THE CHART

Write at the first row the group of techniques (left) and the process name (right), including the numbering previously established.

Development level: indicate if this technology is at research, pilot plant or commercial stage. We could consider also if plants at commercial/industrial stage are relatively new (less than 5-10 years) or old. Indicate this at process description, with sentence such as “stripping is a know process, but with very recent experiences for ammonia recovery from liquid fractions of manure”.

Add some **pictures** (from 1 to a maximum 3)

Diagram: Include the adequate diagram, defined in Annex B.

Theoretical fundamentals and process description: explain in short the fundamentals of the process and how the device or process works. Include also a comment about the optimal working conditions (i.e., requirement of a previous process removing organic matter for a ammonia stripping process) and general scenario justifying the need of the process (i.e., structural nitrogen surplus in the area for nitrification-denitrification process)

Environmental effects: explain positive or negative effects on environmental issues, such as emissions mitigation, odours, NH_3 emissions,…

Level of complexity and usual scale: Usually low complexity will allow to be applied the process at farm scale, and high complex at large scale, with professional operators, but there are simple systems working at large scale. Tick with “☑” when appropriate:

☐ low ☐ medium ☐ high complex

☐ on-farm ☐ medium ☐ large-scale

Low: complex: a usual farmer can operate the plant

Medium complex: a trained farmer can operate the plant

High complex: only professional and trained operators can manage the plant

On farm, medium (centralized and < 50,000 tons/y) and large scale (centralized > 50,000 tons/y) defined as usual in the project.

If a given technology can be found either at farm, medium or large scale, tick for every case.

Applied to: Tick with “☑” when appropriate, several possible cases if necessary.

☐ Solid pig manure; ☐ Liquid pig manure; ☐ Pig slurry; ☐ Pig deep litter; ☐ Solid Cattle manure; ☐ Liquid Cattle manure; ☐ Cattle slurry; ☐ Cattle deep litter; ☐ Poultry slurry; ☐ Poultry deep litter.

☐ products of other processes. In this case, the usual combinations are:

In this case, indicate the previous usual processes (use numbers identifying the process) for applying the current process. As example: previous to stripping, apply anaerobic digestion (number 31) for removing organic matter, a solid/liquid separation system (15) and finally stripping and absorption: 31-15-55

This part is important to define the most usual and interesting combined systems (see part 4 below)

Technical indicators:

Components conversion/efficiencies: indicate efficiencies on conversion/removal of TS, VS, N, P, K, COD, etc. Include a Table if required. Define how efficiencies are expressed: i.e., for S/L separators expressed as % of mass transfer to solid fraction. Use interval values, but avoid to use "security interval", such as "A NDN system can remove 10-70% of N".

Energy consumption or production: positive or negative kW·h/ton of influent, or other useful unit. Use primary energy values and not final electrical or other final energy units. Problem will arise for anaerobic digestion, because every substrate can produce different energy values.

Reagents: amount of chemicals, O_2, or other additives required for the process.

Observations: Other relevant information, related to operation and maintenance: noises, risk of accidents, complexity, requirements of training, etc.

Economical indicators

Investment cost: investment values (€) referenced to a defined unit (i.e., tones treated). Use interval values or add a graphic with variation of investment cost depending on plant size.

Operational costs: indicate just the running cost and reference to tons treated. Do not indicate the mortgages costs of investment. Do not include incomes, which will be indicated in the following box.

Quantifiable incomes: sales of electricity (€/ton treated), sales of by-products, mineral fertilizers saved, etc. Since electricity prices are very different among European countries, indicate some values identifying the country.

Non economically quantifiable benefits: sanitation, odours mitigation, enabling livestock production activity, etc. These are conceptual benefits, but it is important to notice.

Selected literature references: add some (no more than 2-4) selected scientific references and, if possible, add a link with DOI.

Real scale (commercial or pilot) references: indicate name of the farm, city, country, and the name of the company responsible of the implantation, with some value reflecting the size. In case of many facilities, reference some report informing of these installations.

2: AMOUNT OF INFORMATION

The initial idea is to fill the chart in order to obtain two landscape pages. Do not hesitate to use 2.5 pages, or if a box is filled with a large table and all is moved; a final edition will be required in any case.

3: GENERAL TRENDS OF THE INFORMATION PROVIDED

In general, information of each technique will try to include elements considered in the "IPPC BREF outline and guide". From this document, some parts are copied below related to the required information. The key is to remember these guidelines in order not to forget the kind of information required, but not necessarily all information must be included in detail.

- Description: Brief technical description using, as appropriate, pictures, diagrams and flow sheets;
- Achieved environmental benefits: the potential environmental advantages to be gained through implementing this technique including emission and consumption data where available, including any qualification of those data in terms of how they are measured and expressed;
- Operational data: Actual performance data (including reference conditions and monitoring periods) on emissions / wastes and consumption (raw materials, water and energy). Any other useful information on how to operate, maintain, control etc the technique;
- Cross-media effects: Potential effects due to implementing the technique (advantages and disadvantages supported by data if available) in various environmental compartments (whole environment) such as:

- energy consumption and contributions to global warming
- stratospheric ozone depletion and photochemical ozone creation potential
- acidification resulting from emissions to air
- particulate matter (including micro-particles and metals)
- eutrophication of land and waters resulting from emissions to air or water
- oxygen depletion potential in water
- persistent / toxic / bioaccumulable components in water or to land (incl. metals)
- creation or reduction in (waste) residues
- ability to re-use or recycle (waste) residues
- noise and/or odour
- risk of accidents
- consumption of raw materials and water.

- Applicability: Consideration of plant age (new or existing) and factors involved in retrofitting (e.g. space availability). Consideration of plant size (large or small). Thereby highlighting where the technique can and cannot be implemented and noting constraints to implementation in certain cases;
- Economics: Information on costs (investment and operating) and any savings (e.g. reduced raw material consumption, waste charges) where appropriate. Economic information relevant to new build and retrofit to existing installations will be included;
- Driving force for implementation: Specific conditions or requirements which have driven implementation of the technique to date. For example, legislation or other reasons such as increased yield or improvement in product quality. By inference this information leads to the extent to which the technique might be appropriate to the sector as a whole within the framework of IPPC.
- Example plants: examples of plants where the technique has been implemented. The degree to which the technique is in use in Europe or world-wide may be useful information.
- References to literature: literature for more detailed information on the technique. To be able to compare and assess the performance of the various techniques, data will be explained, as far as information is available, in terms of methods used for sampling, analysis and data processing (averaging etc.).
- Data on emissions may be expressed as absolute or concentration values, and relative to actual production or production capacity. The most relevant economic aspects of each of the techniques will be described to identify, where possible, the overall economic impact of any given technique. Various expressions may be used for costs and consumption, referring to units of production or time.
- Example plants: examples of plants where the technique has been implemented. The degree to which the technique is in use in Europe or world-wide may be useful information.
- References to literature: literature for more detailed information on the technique.

4: COMBINED SYSTEMS

Based on results of the survey and the most usual combinations appearing in the charts (previous processes for an optimal operation of a given process), usual combinations will be classified. As examples: for some processes a previous organic matter removal is required and also a solid/liquid separation system; with this, a general classification could be done, without the need to go to an extremely high number of possible combinations. This is why it is important to indicate the previous process required for every process.

Manure processing is presently a subject that enjoys considerable attention in the EU due to the ongoing revision of the Reference Document on Best Available Techniques for Intensive Rearing of Poultry and Pigs (BREF), as well as due to current efforts to implement policies and legislation on EU and Member State level, for instance concerning renewable energy targets, targets for reducing the loss of plant nutrients to the environment, targets for reduction of greenhouse gases, and targets for manure handling in agriculture in relation to legislation about water protection and manure surpluses in livestock intensive areas.

This report is prepared for the European Commission, Directorate General Environment, as part of the implementation of the project "Manure Processing Activities in Europe", project reference: ENV.B.1/ETU/2010/0007. The Report includes deliveries related with Task 2 concerning Manure Processing Technologies.