Study of the water cycle on pig farms and development of new methods for its reuse

Summary

The region of Osona is one of the areas most heavily affected by the problem of livestock manure. In this region, the direct application of slurry to the soil for fertilisation has been the most extensively used alternative for the management of livestock manure. Unfortunately, the product's high moisture content makes transportation and application to other nearby areas where soils are low in nutrients unfeasible. This has led to the development and implementation of new technologies for the treatment of livestock waste aimed at stabilising organic matter, concentrating and/or eliminating nutrients and producing energy. However, none of these technologies has focused on the reuse of water, or considered comprehensive systems valorising all the effluents obtained based on the concept of "zero waste".

To provide a solution to this problem, nitrification-denitrification (NDN) systems have been connected to electrodialysis (ED) and ozonation technologies in the treatment of liquid effluents, obtaining high quality water that can be reused in the same industrial/agricultural process or for environmental purposes. A composting process was also carried out with the solid fractions (the solid fraction from the separator and dehydrated sludge) obtained from the NDN treatment units, in order to valorise all the effluents obtained in the process.

Objectives

The aim of the project is to **valorise the liquid effluents from livestock manure** by means of ED treatment and ozonation, **thereby obtaining high quality water without any pollutants**, salts or nutrients **that could be reused** on the farm, or used to recharge aquifers and provide other environmental services.

The project aims to provide a solution to one of the main limitations of NDN technology, by **connecting NDN systems with electrodialysis and ozonation technologies** to treat the liquid effluents obtained.

The solid fractions are also valorised by composting, and finally, the implementation of the results obtained was assessed in technical, economic and environmental terms.

Description of the actions carried out in the project

In order to achieve the objectives established, this project was divided into 5 main activities:

- Activity 1: Design and construction of the ED pilot plant.
- Activity 2: Treatment of NDN effluents by ED.
- Activity 3: Treatment of ED effluents by ozonation.
- Activity 4: Treatment of solid fractions and sludge by composting.
- Activity 5: Technical, environmental and economic assessment of the process using life cycle analysis (LCA) and cost cycle analysis techniques.

Final results and practical recommendations

Activity 1: Design and construction of the ED pilot plant

The various effluents from the NDN slurry treatment plant were first classified in order to obtain broader knowledge of the main effluents that needed treatment in this project, and to be able to produce a custom design of the ED plant based on the needs involved.

The high potassium values at the outlet of the NDN reactor highlighted the need for an effluent treatment system to reduce the potassium content and to lower the conductivity to permitted levels, either for reuse or discharge into the environment in accordance with current legislation. The reduction in the solid content present at the NDN outlet is also an important parameter for the correct functioning of ED technology.

Prior to the start of pilot-scale ED testing, laboratory-scale ED experiments were carried out to test its effectiveness as a technology for reducing conductivity, potassium content, and emerging organic compounds (EOCs). There was a need to reduce the colloidal material content as a high level of fouling of the ED membranes was observed, which led to a reduction in the permeate flow rates obtained. Although the concentration of input solids was higher than the optimal levels for the process, a significant decline in both conductivity and potassium content was observed. The percentage of water recovered in consecutive ED cycles was around 80%, thereby demonstrating the high efficiency of ED technology for both the recovery of clean water and the reduction of salts.

Given that physico-chemical parameters such as the number of solids (colloidal particles) and conductivity in the NDN effluent may be factors in the correct functioning of the ED system, possible operational scenarios for solids concentration and conductivity were assessed, and the need for an efficient coagulation/flocculation pretreatment system prior to the pilot-scale ED stack was observed.

The pilot plant was therefore designed and constructed based on the need to have a pre-treatment system prior to the ED stack in order to ensure its proper operation, to avoid operational problems and maximise efficiencies in the process. The main items in the pretreatment system incorporated in the plant were a coagulation/flocculation process, sand filter filtration and an ultrafiltration (UF) membrane system.

Activity 2: Treatment of NDN effluents by ED

Various operational tests of the pretreatment system (coagulation/flocculation, sand filter filtration and ultrafiltration) were performed prior to the commissioning of the ED stack. The results showed the efficiency of the sand filter for the reduction of the content of total solids up to 65% of inlet solids, but no reduction in the turbidity of the incoming effluent. On the contrary, the ultrafiltration process reduced the turbidity of the water below the threshold required to be able to treat the water with an ED process. For the COD, neither the sand filter nor the ultrafiltration membrane provided an effluent below the threshold value for the effluent to be treated with the ED stack without the membranes possibly being fouled due to the presence of organic matter.

In order to assess the likelihood of fouling due to the high concentrations of COD, and to thereby assess the feasibility of using the technology for the treatment of NDN effluent, it was necessary to perform a function test without performing any chemical cleaning for a period of 50 hours, which is the equivalent of one week of continuous operation of the stack. No change or decline in flow rates was observed, or any increase in pressure in the ED stack, and operating conditions were restored with daily cleaning without any oxidising agent being used. These three conditions show that the presence of organic matter in the effluent entering the stack would not lead to biofouling problems on the surface of the membranes during continuous operation over long working days.

Simulations were also performed to determine the maximum working salt concentration (conductivity) so that salt does not accumulate on the membrane surface. A high risk of membrane fouling due to the precipitation of calcium carbonate ($CaCO_3$) was determined at the pH values at which the experiments were being performed, meaning that the stack could not operate at conductivities above 18000 µS in long-term operations. Acid must be added to the concentrated effluent in order to increase the solubility of these salts in order to avoid scaling problems under these operating conditions (CE > 18000 µS).

The commissioning of the ED pilot plant at the Monellots slurry treatment plant began in September 2020. In order to confirm that the ED stack was working properly, the limit on the current density of the stack was determined by recording the amperage with a gradual increase in the stack's voltage. The optimum working voltage is usually considered to be 70-80% of the limit value (the turning point of the curve). In this case, the plant rectifier limited the voltage for application to 55 V. In view of the results obtained on the curve, the decision was taken that between 40 and 50V could be a good working range. In addition, the conductivity was recorded in order to check the efficiency and the stack's correct operation in terms of separation.

Four operational scenarios were proposed to assess water recovery and salt rejection in the system. These were selected based on the output conductivity of the end product of the ED, and operational parameters such as the discharge flow. The outlet conductivity of the ED is the key parameter that determines the destination or use of the outlet effluent. Low conductivities (2500 µS/cm) are on the threshold for animal consumption, while values of around 4000 µS/cm should be allocated to discharge into the public river bed.

- Scenario 1 (S1): An end product of around 2500 µS is obtained, with a high discharge rate that would permit working below the concentrate's threshold conductivity value in terms of fouling due to precipitation of salts.
- Scenario 2 (S2): An end product of around 2500 µS and a low discharge rate is obtained. This scenario involves the addition of acid to the concentrate in order to be able to work with higher conductivity levels than the solubility threshold of the concentrate.
- Scenario 3 (S3): An end product of around 4000 µS and a low discharge rate is obtained.
- Scenario 4 (S4): An end product of around 2500 µS and a low discharge rate is obtained, and in this case no acid will be added despite conductivities above the solubility threshold of the salts being obtained.

With the results obtained, E3 and E4 were established as possible real scenarios in the plant for carrying out the detailed study of these two scenarios with the consequent treatment with ozonation. Scenario E3 was selected to address the issue of obtaining a product suitable for discharge into the river bed in terms of conductivity, and scenario E4 was selected for obtaining a product with a possible use for drinking water on the farm itself.

Activity 3: Treatment of ED effluents by ozonation

After scenarios E3 and 34 had been selected as suitable for the evaluation of ED and ozonation technology for NDN effluent treatment, a detailed classification of the effluents obtained in these two scenarios was carried out. The end products obtained in the ozonation process were then treated by an ozonation process at different doses. The results showed that the potassium content of the products obtained in the ED process declined by 70%. The ED process did not lead to a significant reduction in other parameters such as phosphorus or organic matter content. Although the ozonation process was evaluated at different levels of ozone concentration, no organic matter elimination efficiencies of over 30% were obtained.

The bacterial and pathogenic load of the final products obtained in the processes of ED and ozonation in scenario E3 and E4 was determined in order to evaluate the possible use of the treated water not only for animal consumption but for its possible reuse. The results obtained in the microorganism analysis showed that the high doses of ozone used in this experiment, of up to 2.88 g O_3/L, were not sufficient to remove the bacterial load present in the effluents obtained in the ED process. Under the conditions of ozonation assessed, this process would not be sufficient to reuse the effluent as water for animal consumption.

The concentration of 23 emerging organic compounds (EOCs) was determined in order to evaluate the efficiency of the electrodialysis process to reduce the presence of EOCs. Of the 23 EOCs selected, only 6 compounds were detected at the entrance to the ED during the sampling. During the ED treatments, a reduction in the mass charge total was observed in the concentration of these six compounds, with overall average reductions of 50%, regardless of the operational system in the ED stack. The results obtained for ozonation showed considerable potential for reducing the concentration of EOCs, as over 99% of 3 of the 6 EOCs detected in the end product of ED was eliminated even when the lowest ozone dose was applied (0.7 g O_3/L). For the other 3 compounds detected (more recalcitrant organic compounds) a correlation between the ozone dose applied and its elimination efficiency of these compounds was observed, with elimination values of over 95% reached when higher doses of ozone were applied.

Activity 4: Treatment of solid fractions and sludge for composting

Another of the project's objectives was to valorise the solid slurry fraction of the NDN process in order to obtain high quality compost. Two composting experiments were carried out to evaluate this process:

- A composting process of the solid fraction of the slurry obtained from the liquid-solid separator.
- A composting process of the solid slurry fraction obtained from the liquid-solid separator enriched with (added) concentrated product or waste obtained in scenario E3.

At the end of the maturation processes in the composting and the co-composting of the solid fraction, biostabilised materials with IRD24 of less than 1 g O_2 h^{-1} kg SV^{-1} were obtained, which is lower than the benchmark value for consideration as stable.

Given the copper and zinc concentrations in the final materials in the two composting processes, both the solid fraction compound and co-composting with the ED concentrate would be considered class B material suitable for agriculture.

Co-composting would make it possible to obtain a high quality compost, and avoid the need to manage or transport the concentrated product in the ED process.

Activity 5: Technical, environmental and economic assessment of the process using life cycle analysis (LCA) and cost cycle analysis techniques

One of the most important activities within the framework of the project was the analysis of the cost cycle that enables the viability of the technologies studied to be assessed. The calculations were made for four different possible scenarios that could arise in a real situation and for the two alternatives for implementation of the technologies (rental or purchase), and different distances when transporting the flows (products).

The results only showed a financial saving (without losses) when an ED+O3 system was implemented which included the recovery of water for reuse at the time it was necessary to transport the current NDN effluent over a distance more than 95 km if the equipment is rented, and 75 km if it is purchased.

The life cycle analysis (LCA) was performed according to the PEF2.0 methodology, and 3 indicators were selected: climate change, the depletion of water resources and fossil fuels. The results showed that the proposed treatments would have an impact on the climate change category six times greater than the current situation, in which the NDN effluent is only transported a distance of three kilometres.

A relationship was identified between the impact in kg CO_2 and the kilometres of transport, which indicated that the impacts on climate change between the new technologies proposed and the current management carried out would be comparable when the transport is over 18 kilometres.

The impact associated with the depletion of water resources in each of the scenarios showed that in the current operating format and with only ED implemented, which are scenarios in which the treated water is used for agriculture, the impact is much greater as the model does not include any return of water to the system due to evapotranspiration. The reduction in the impact is only evident in cases where the effluents are discharged into the river bed and where the water is reused in the facilities, since this leads to savings in the extraction of the water resource.

Conclusions

The following conclusions have been drawn from the implementation of this project:

1. Electrodialysis for the treatment of NDN effluent has been shown to be highly efficient in reducing **conductivity** and potassium content, which were reduced by 60% and 70% respectively under optimum operating conditions.
2. Electrodialysis treatment provides **recovery** percentages of treated water of up to 85%.
3. The two technologies in cascade (ED + ozonation) reduce the load of **emerging organic compounds** by around 99%, while the use of ED alone achieves a 50% reduction.
4. The large residual organic load at the outlet of the ED process means that it is difficult to eliminate **microorganisms** completely, which prevents the water from attaining the quality required for reuse with animals.
5. Under the conditions studied, ozonation would provide an end product with sufficient quality for reuse as **cleaning water** in facilities according to the legislation in force.
6. The **co-composting** process of the solid fraction would provide a biostabilised compost suitable for use in agriculture, and would prevent the need for transportation of the concentrated fraction from the ED process, thereby reducing some of the management costs.
7. **Taking into account the initial investment made with the proposed treatment, financial savings** would only be made if the current NDN effluent had to be transported more than 75 km away from the point of origin.
8. Life cycle analysis shows the **carbon footprint** of the current treatment is smaller than the implementation of the proposed technologies, and that these would have the same impact as the current situation when the transport exceeds 18 km. This carbon footprint would be significantly reduced if renewable energies were used as an energy source, and the scenarios would be comparable if the effluents had to be transported 9.3 km.
9. The proposed technologies where water is returned to the river bed or reused for cleaning uses would have a much lower impact on the depletion of **water resources**, reducing the impact by almost 75%.

Leader of the Operational Group

ORGANISATION: GRANGES TERRAGRISA, SL

Other members of the Operational Group (not recipients of the grant)

ORGANISATION: Balmes University Foundation (UVIC)

CONTACT E-MAIL: sergio.ponsa@uvic.cat

Subject area(s) of application

☒ Water management

☒ Waste and by-product management

Geographical area(s) of application

PROVINCE(S): BARCELONA
REGION(S): OSONA

Dissemination of the project: publications, seminars, multimedia, etc. (State links)

Participation in the "International Animal Production Show 2021 (FIGAN 2021, https://www.feriazaragoza.es/figan-2021" in Saragossa, Spain on 22 September 2021. Lecture entitled "Implementation of innovative technologies for water recovery in the treatment of pig manure".

Project website

https://betatechcenter.com/ca/projectes/study-of-the-water-cycle-in-pig-farms-and-development-of-new-methods-for-its-reuse/

More information on the project

PROJECT DATES	TOTAL BUDGET
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