Integrated solution for the treatment of livestock effluents aiming at materials and energy recovery

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Extended summary

An innovative, integrated treatment scheme is developed for the complete treatment of livestock waste in order to maximize materials and energy recovery for an industry treating livestock waste in Cyprus. Although anaerobic digestion is widely practiced for the treatment of livestock waste in Europe, the resulting digestate is often poorly managed resulting in adverse environmental problems. Effective post-treatment of the digestate can result in further recovery of materials and minimize environmental hazards. The methodology for the implementation of the integrated treatment scheme consists of the following steps: (i) physicochemical characterization of the livestock waste that should be treated, (ii) laboratory and pilot scale experiments, (iii) design and construction of the integrated scheme, (iv) installation and operation of the integrated schemes at the premises of an industry treating livestock waste in Nicosia of Cyprus. This work presents the progress implemented in (i), (ii) and (iii) up to the preliminary design of the integrated livestock waste treatment scheme. The system consists of various subsystems in order to provide a complete solution for the effective treatment of the solid, liquid and air emissions. It consists of the following components:

a) Mixing and homogenization tanks of the feed material and of the composting mixture
b) Anaerobic digester for the treatment of livestock waste and the production of biogas in order to recover energy
c) Solid/liquid separation scheme for the separation of the liquid from the solid part of the digestate. The separation system consists initially of a centrifuge. Then the liquid fraction is further treated by an ultrafiltration (UF) membrane unit. The resulting solid stream and the UF concentrate are fed to the composter, while the UF permeate can be fed to the SBR and the struvite crystallization unit.
d) Sequencing batch reactor (SBR) for the biological nutrient removal via nitrite from the liquid fraction of the digestate
e) Struvite crystallization unit for the recovery of phosphorus from the liquid fraction of the anaerobic digestate
f) Composter for the aerobic biological treatment of the solid fraction of the digestate and the UF concentrate
g) Biofilter system for the treatment of the odours produced during the various processes, including storage and composting.
h) Biotrickling filter combined with activated carbon for the removal of sulphide from biogas

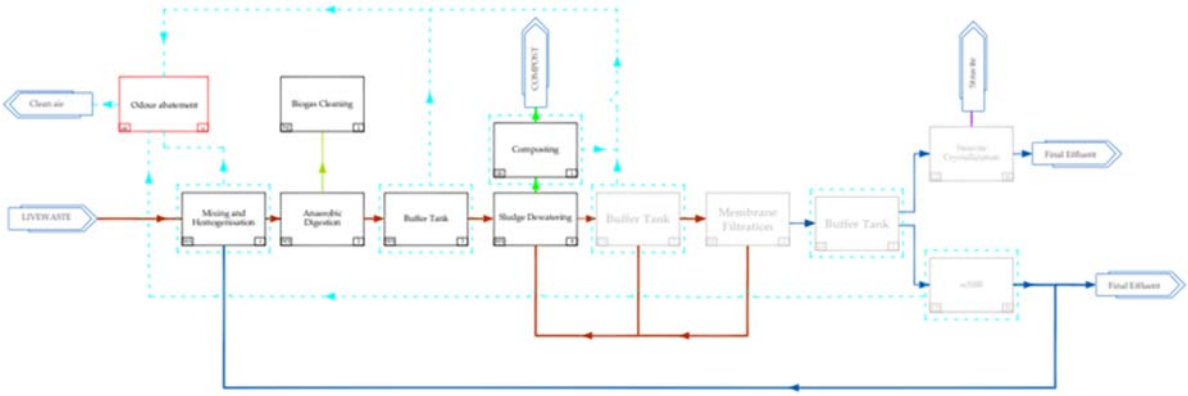

Figure 1: Flow chart of the various processes involved in the integrated, innovative scheme for the treatment of livestock waste

The philosophy of this integrated prototype system is to maximize the benefits resulting from livestock waste treatment through energy and materials recovery. The former is accomplished through biogas production during anaerobic digestion and the latter through the production of mature compost to be used as soil conditioner and the production of struvite that has a high fertilizer value. The experimental trials for the treatment of livestock waste (pig and cattle slurry, cow and rabbit manure) through anaerobic digestion showed that the specific gas production (SGP) was 0.2-0.4 m^3/kgTVS. This could be increased through the co-treatment with energy crops to 0.4-0.6 m^3/kgTVS. During the anaerobic digestion, high concentration of ammonia was released in the final anaerobic digestate due to the hydrolysis of organic matter. The biological nitrogen removal from the liquid fraction of the digestate from pig slurry was investigated by operating a pilot scale SBR. The efficiency of the nitrogen removal via nitrite process was examined and evaluated by the continuous operation of the SBR for more than three months. The maximal treatment capacity that was achieved was 0.8 kgN/m^3d for the treatment of anaerobic digestate of pig slurry with acetic acid being dosed as an external carbon source. Short chain carbon sources (i.e. acetic acid) can enhance nitritation / denitritation and the denitrifying phosphorus removal from the anaerobic supernatant (Frison et al., 2013). The efficiency of nitrogen removal was in the range of 89 to 92%. The composting of the solid digestate resulted in the production of a final product that had favourable moisture, pH, organic matter and nitrogen content for soil application. Straw was used as an additive, resulting in a feed mixture having adequate moisture (67%) and C/N ratio (25). Table 1 summarizes the feedstock characteristics for which the integrated scheme is designed.

Table 1 Feed stock characteristics

Parameters	Feedstock 1	Feedstock 2
COD (g/l)	72	75
TS (%)	6.15	6.05
TSS (g/L)	43	38.8
VSS (g/L)	40	38
TSS/VSS (%)	93	97.94
TDS (g/L)	20.5	21.7
NH_4-N (mg/L)	2659	2880
TKN (mg/L)	4286	4800
TP (mg/L)	1000	1000
COD/TS	1.20	1.24
TVS/TS	0.85	0.85
TVS (%)	5.03	5.13
TVS (g/L)	50.34	51.3
NH_4-N/TKN	0.62	0.60
Conductivity (mS/cm)	15.1	-

The innovative pilot scale scheme has a design capacity of 247 kg/d of livestock waste. The anaerobic digester will be a continuous stirred tank reactor (CSTR) having a total volume of 10 m^3 and a working volume of 8.5 m^3. Given the feed quantity (247 kg/d), the digester will be able to maintain a hydraulic retention time (HRT) of 35 days in order to allow for effective anaerobic biodegradation. The organic loading rate will be 1.5 kgTVS/m^3d (2.1 kgCOD/m^3d). In this process it is important to maintain an adequate HRT. An HRT of 35 days can provide satisfactory biodegradation and biogas production. Table 2 summarizes the basic design and operating characteristics of the anaerobic digestion unit (Table 2).

Table 2 Basic design and operating characteristics of the anaerobic digestion unit

Parameter	Unit	Value
Total volume	m^3	10.0
Working Volume	m^3	8.5
OLR	kgTVS/m^3d	1.5
Max OLR	kgTVS/m^3d	3.0
Temperature	°C	37.0
Feeding	kg/d	246.6
Loading	kgTVS/d	12.4
Q feed	L/d	246.6
HRT	d	34.5

The SBR unit will receive the UF permeate. Depending the centrifuge solid/liquid separation unit and the UF filtration unit, the quantity of liquid fed to the SBR can range from 137-167 L/d. A reactor working volume of 1.5 m^3 is required. The basic design characteristics are given in Table 3. The struvite crystallization unit has been designed to treat an average flow of liquid fed of 152 L/d, with a phosphate concentration between 500-1000 mg P/L.

Table 3 SBR operating characteristics

Parameter	**Units**	**Value**
Reaction volume	m^3	1.5
Total volume	m^3	2.0
vNLR	kgN/m^3d	0.51
sAUR	mgN/gVSS·h	7
sNUR	mgN/gVSS·h	15
sPUR	mgP/gVSS·h	7
Filling	min/cycle	7.5
Anaerobic	min/cycle	25
Aerobic	min/cycle	160
Anoxic	min/cycle	80
Sedimentation	min/cycle	15
Discharge	min/cycle	7.5
HRT	d	9.9
Nitrogen removal	%	95
Nitrogen effluent	mg/L	180
Phosphorus removal	%	85
Phosphorus effluent	mg/L	75

Two systems are considered to deal with the two challenges considered in terms of gaseous pollutants: i) a biofiltration hybrid system unit (BF+AC) to remove odours and volatile organic compounds (VOCs)

emitted during composting as well as in receiving and buffer tanks; ii) a biotrickling system (BTF) to minimize the content of hydrogen sulphide in biogas in order to use it for combustion. The purpose of the biofiltration hybrid system is to treat the off-gases resulting from the composting process as well as the headspaces collected from the receiving tank and the buffer tanks. The biofiltration unit will comprise an organic packing comprised of pine bark chips, perlite, activated carbon and compost. The selection of a hybrid configuration (BF+AC) ensures a good removal of odours (as well as VOCs), independently of the condition of the biological stage. The biogas produced in the anaerobic reactor will be fed to the BTF unit in which a continuous liquid stream will be recirculated in order to maintain the desired hydrodynamic conditions to ensure the solubilisation of H_2S and its removal inside the unit.

Reference

Frison, N. S., Di Fabio, S, Cavinato, C., Pavan, P., Fatone F. 2013 Best available carbon sources to enhance the via-nitrite biological nutrients removal from supernatants of anaerobic co-digestion. *Chemical Engineering Journal* **215-216**, pp.15–22.