Applying circular strategies to the food industry: slaughterhouse solid waste valorization in a pilot demonstration plant

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INTRODUCTION

Circular economy is becoming a reality as new strategies are starting to being implemented in industries. At the present time, in view of the objectives to be achieved concerning the reduction of greenhouse gas emissions by 2030, the focus of action is mainly on industries. In this sense, the food and beverage industry is the EU's biggest manufacturing and the most water and energy intensive industries. Consequently, it is a sector which produces a substantial amount of waste. Thus, circular economy strategies and resource recovery from agri-food by-products and waste are a feasible alternative to reduce the environmental impacts derived from their productive activities (Mishra et al., 2023).

AccelWater project (Accelerating water circularity in food and beverage industrial areas around Europe, GA 958266) aims to develop and transfer this circular bioeconomy concept, boosting the water-waste-energy nexus by introducing beyond state-of-the-art technologies on industries. In this context, the aim of the current study is to assess the feasibility of implementing a set of biological technologies (anaerobic digestion, solid-state fermentation, and biodrying process) to recover energy (biogas and biomass fuel) and high value agronomic products (biostimulants) from animal by-products (ABPs, category 3) generated in a slaughterhouse located in Manresa, Spain.

METHODOLOGY

Waste and by-products selected to be treated were pig guts and viscera, and the industrial sewage sludge from the slaughterhouse MAFRICA S.A. (Barcelona, Spain). Pig viscera and guts were grinded (8 mm) and hygienized (70ºC, 1h) to follow the Regulation EC 1069/2009 requirements. Waste characterization is shown in Table 1.

Table 1 Characterization of wastes generated in MAFRICA slaughterhouse.

	TS [%]	VS [%, db]	pH	C/N	TKN [g N kg^{-1} TS]
Viscera	23 ± 2.3	88 ± 0.6	6.36	6.5	83.8 ± 1.7
Guts	35 ± 4	96 ± 1	6.96	19.9	33.1 ± 1.5
Sewage sludge	23.4 ± 0.1	89.2 ± 0.1	6.2	9.4	50.2 ± 1.7

The technological treatment train consists of a 1 m^3 anaerobic digestor (AD) operating under mesophilic conditions (37ºC), which was started up in November 2022. The AD pilot is fed 3 times per week using a mixture of 50:50% (VS basis) of pig guts and pig viscera by-products. The initial organic loading rate was set at 0.23 kg VS m^{-3} d^{-1}, and it was progressively increased to improve the treatment capacity and biogas production. The solid fraction of digestate is further valorized through a solid-state fermentation (SSF) process to stabilize and enrich the solid matrix with free amino acids, which act as biostimulants in plant roots and leaves. Several fermentation strategies were tested and developed at a laboratory scale, where 0.5 L reactors were connected to a dynamic respirometric system (Ponsá et al. 2010). Those strategies included the inoculation of the solid matrix with bacteria (*Bacillus licheniformis* and *Bacillus subtilis,* 10% v/w) and the use of co-substrates (viscera and blood). These tests were performed under two ranges of temperature: a first mesophilic stage to promote biomass growth and enzyme production, and a second thermophilic stage to activate enzymes and increase hydrolysis yield. Best results were scaled-up to a 100-L pilot reactor. In all fermentations carried out, the improvement of free amino acids release was targeted.

On the other hand, sewage sludge was valorized through biodrying process, to remove as much water as possible from the solid matrix using the biogenic heat generated by the present aerobic microorganisms. An aeration strategy control loop based on Guerra-Gorostegui et al. (2021) was applied, setting different airflow rates depending on the packed bed temperature.

RESULTS

As shown in Figure 1, the biogas production raised while increasing the OLR from 0.23 to 0.5 kg VS m^{-3}d^{-1}, reaching a maximum specific biogas production of 62.17 NL kg^{-1} VS d^{-1}. Apparently, during the AD operation over the first year, an increase of OLR had not adverse impact on the generation of biogas. However, it was stated a progressive accumulation of ammonia in the digestate, reaching 4.24 g kg^{-1} of total ammonia nitrogen at an OLR of 0.5 kg VS m^{-3}d^{-1}. Those concentrations are reported as inhibitory. Thus, mitigation strategies using absorbent materials are currently being studied to reduce the effect of ammonia nitrogen on methanotrophic bacteria and consequently, on biogas production.

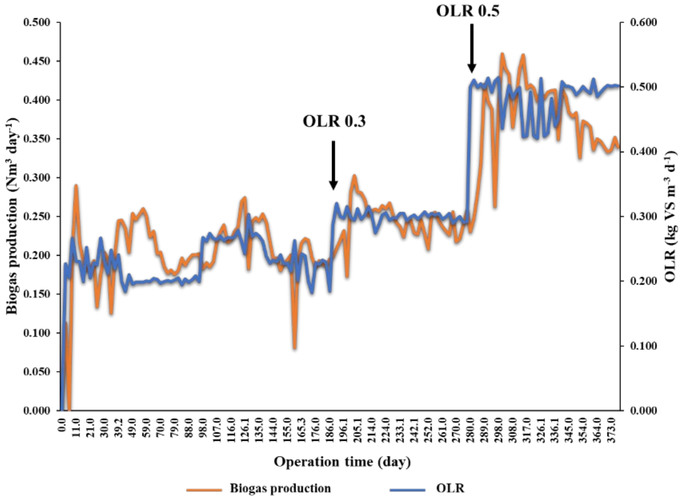

Figure 1: Biogas production and OLR of the 1 m^3 AD at MAFRICA facilities.

For the valorization of the solid fraction of digestate, the addition of bacteria strains known for their proteolytic enzymes-producing ability (Contesini et al., 2017) boosted a slight increase in total amino acids concentration; however, the concentration of free amino acids at the end of the fermentation was lower than initial concentrations. The process was enhanced by adding protein-rich co-substrates (30% viscera w/w and 20% blood v/w) and tested with or without external inocula. Best results were obtained when fermenting a mixture of solid digestate and viscera (70:30 w/w) without external inoculum, suppling an airflow of 0.2 mL min^{-1} g^{-1} fresh solid, applying mesophilic (30ºC, 28h) – thermophilic (50ºC, 40h) – mesophilic (30ºC, 70h) temperature ranges. Under these conditions, a total amount of 150.7 µg of free amino acids g^{-1} VS were obtained, where hydroxyproline was the most abundant amino acid (96% of relative abundance). The process in currently being scaled-up to a 100 L.

The last technology tested was the biodrying process to valorize the produced sludge from the wastewater treatment plant of the slaughterhouse. In this operation run in batch, similar to a composting process, the aim is to stabilize and dry as much as possible the solid matrix, concentrating the nutrients and carbon content, and explore both fertilizing and energetic valorization pathways. For these experiments, 24 kg of sludge (ρ: 0.72 kg L^{-1}) were mixed with 15.2 kg of bulking agent (ρ: 0.21 kg L^{-1}) per batch. From these studies, a water removal of a 40% was obtained, reducing the sludge moisture from 77-79% to 46-48% in 15 days. From the characterization shown in Table 2, and after a deep fertilizing regulation analysis, it was concluded that the best way to valorize dried sludge was through energy valorization (pelletized biomass fuel), as nowadays the use of sludge for fertilizer formulations is not included in the European fertilizing regulations (EU 2019/1009), and the minimum threshold regarding nutrient composition was not achieved.

Table 2: Biodryied sludge characterization.

TN (%, wb)	P_2O_5 (%, wb)	K_2O (%, wb)	C_{org} (%, wb)	TS (%)	DRI_{24} (mmol O_2 h^{-1} kg_{VS}^{-1})	LHV (MJ kg^{-1})
2.25±0.16	0.95±0.01	0.44±0.11	11.97±0.57	52.86±0.58	105.13±10.25	8.2±0.1

CONCLUSIONS

A demonstration of different biological technologies to valorize solid organic waste and by-product derived from a slaughterhouse activity has been performed, approaching these technologies to a close-to-real environment, and transferring the knowledge and experience with the industry. Biogas and biomass fuel can be internally consumed and consequently, external energy demand would decrease, while biostimulants could be introduced into the fertilizer market.

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