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Research paper

Recovery of Fatty Waste from Wastewater Treatment Plants through Anaerobic Codigestion: Improvement of the Agronomic Potential of Digestates

Modou Dieng [a,*], Fatou Kiné Toure [b], Ndèye Adiara Ndiaye [c], Alé Kane [d], Abou Abdallah Malick Diouara [e], Mamadou Faye [f], Falilou Mbacke Sambe [f]

[a] *Analysis and Testing Laboratory, Graduate School Polytechnique (ESP)- Cheikh Anta Diop University, Dakar*
[b] *National Office of Sanitation of Senegal (ONAS), Dakar, Senegal*
[c] *Laboratory of Microbiology, Graduate School Polytechnique (ESP)-UCAD, Dakar, Senegal*
[d] *Laboratory of Biological, Agronomic and Food Sciences and Complex Systems Modelling (LABAAM), University Gaston Berger (UGB), Saint-Louis, Senegal*
[e] *Applied Biotechnologies & Environmental Bioprocesses Research Group (GRBA-BE), Graduate School Polytechnique (ESP)-UCAD, Senegal*
[f] *Electrochemistry and Membrane Processes Laboratory (LEPM), Graduate School Polytechnique (ESP)-UCAD, Senegal*

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ABSTRACT

In the context of increasing effluent production, anaerobic digestion has been identified as a promising solution for waste treatment in a sustainable development approach. This study developed a process for treating fats from wastewater treatment plants, which are mainly composed of triglycerides and free fatty acids. Anaerobic co-digestion of these fats with suitable sludge dilutes the toxic substances and optimizes the carbon/nitrogen ratio, thereby increasing biogas production. The best yields are obtained with an addition of 30% fat for fresh sludge and 45% for biological sludge. From an agronomic point of view, the digestates obtained are rich in ammonium and phosphorus, but low in potassium, suggesting a potential use for crops, but requiring further study. The digestates have interesting average concentrations of ammonium (NH4+) ranging from 322.5 mg/L to 530 mg/L, and total phosphorus (TP) from 159.99 mg/L to 677 mg/L, but low levels of potassium (K+) from 0 mg/L to 1.03 mg/L. Effluent management presents several complex challenges. Anaerobic digestion is a sustainable solution that captures and converts methane into biogas, a renewable energy source that reduces the impact on the climate. This biogas can be used to produce electricity or heat. What's more, this process is part of a circular economy, recovering organic waste to produce energy and compost to improve the soil.

[*] *Corresponding author, E-mail address: modouabsadieng@gmail.com / modou.dieng@ucad.edu.sn*
Tel.: +221 776304607

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1. INTRODUCTION

Emissions of substances, the production of waste, and various nuisances are major causes of environmental degradation, particularly in developing countries (Bourouis, 2015). Effluent is also a major source of pollution, compromising the safety of our environment. However, thanks to scientific and technological progress in the field of renewable energies, effluents can also be recovered as an alternative source of energy, notably through the anaerobic digestion of sewage plant sludge. In recent years, strategies for developing renewable energies in Africa have become increasingly important (Berahab, 2019). In Senegal, several challenges, particularly those relating to financing and public policy, continue to hold back the growth of investment in this area (Toure et al., 2023). Biogas is becoming a major alternative energy source, particularly industrial biogas, with the creation of production units at the Cambérène wastewater treatment plant in Dakar, Senegal (Toure et al., 2023).

Wastewater generates various forms of pollution, including physical, organic, mineral, and biological, and can cause serious illnesses and toxic contamination, as well as damaging natural ecosystems. Large quantities of effluent are frequently discharged into public sewage systems without prior treatment. This practice poses a serious threat to the environment, generating pollution risks and compromising public health (Sanaa et al., 2019). Pre-treatment of domestic wastewater in wastewater treatment plants gives rise to various by-products, including greasy waste (Toure et al., 2023). The main management method currently adopted by the National Office of Sanitation of Senegal (ONAS) wastewater treatment plants consists of spreading residues on drying beds, followed by landfilling. This practice presents risks for humans and the environment (Obriot, 2016). In addition, these residues are not considered to be final waste because of their treatability, low dryness and high organic matter content (Canler, 2001). Anaerobic digestion is considered a promising technology for producing bioenergy from biowaste, generating a large quantity of digestate as residual waste (Wang and Lee, 2021). The residual manure resulting from biogas production contains a rich source of plant nutrients and is an alternative to mineral fertilizers (van Midden et al., 2024). The grease from the flotation process has good potential for methanization, with a methanogenic capacity of around 600 Nm³ of CH_4 per tonne of organic matter (Ngoma et al., 2015). Energy recovery from fatty waste is a solution that can help solve some of the environmental problems associated with landfilling (Bousbaa et al., 2016). The methanization process is thus at the crossroads of several issues, namely energy production, waste management, the environment, and agriculture.

The general aim of this work is to recover effluent from wastewater treatment plants in Senegal by producing a soil improver for agricultural use.

Specifically, this will involve:

- Characterising fats from wastewater treatment plants;
- Assessing the co-digestion of sludge produced with fat-rich waste;
- Maximising energy recovery from organic biomass;
- Characterise the final digestate resulting from these treatments.

2. MATERIALS AND METHODS

2.1 Study area

The Cambérène wastewater treatment plant (WWTP) is located in Dakar, the capital of Senegal (Fig. 1). It helps to improve public health and the quality of the environment by reducing surface water pollution. The Cambérène WWTP was commissioned in the 1990s to treat wastewater from the rapidly expanding city of Dakar and to combat pollution of the Bay of Hann and surrounding waters. It has a treatment capacity of around 92,000 m³ of wastewater per day, covering much of the city. It uses modern wastewater treatment technologies, including primary, secondary, and tertiary treatment. This type of treatment allows treated water to be reused in agriculture and for other purposes, thereby contributing to the sustainable management of water resources. A modernization and extension project is currently underway to increase the plant's capacity to around 123,000 m³ per day to cope with the growth in Dakar's population.

Fig 1. Location of the Cambérène wastewater treatment plant

2.2 Biological materials

The sludge and grease used in the experiments were collected from the Cambérène, Niayes, and Sénégalaise de l'Habitat Social (SHS) wastewater treatment plants. The primary sludge was obtained after decantation of the wastewater collected at the end of the pre-treatment stage. Biological sludge was recovered from the extractor connected to the clarifier, while grease was taken from the grease trap (figure 2).

Fig 2. Sampling of primary sludge (1), grease (2), biological sludge (3)

2.3 Methods

After anaerobic digestion, the digestate undergoes phase separation, resulting in two parts: a liquid part (around 3 to 7% dry matter) in which the ammoniacal part of the nitrogen is concentrated, and a solid part (around 25% dry matter) rich in organic matter and phosphorus. Phase separation provides both a solid product that can be used as a soil improver and a product that is rich in nitrogen so that inputs can be optimized according to crop needs (Ballerini, 2011). The main fertilizing elements (N, P, K) present in sludge give it an agronomic value, enabling it to be used as a soil improver. This is why it seems essential to assess the levels of these fertilizing elements. A 600 g load is prepared and introduced into each digester. The inoculum accounts for two-thirds, or 400 g, while the substrates (sludge and fats) make up one-third or 200 g. The substrates are distributed according to the ratios shown in Table 1.

Table 1. Breakdown of substrates: percentage of sludge and grease

Tests with primary sludge mixed with grease		Tests with biological sludge mixed with grease	
Primary Sludge PS (%)	Addition of Fatty Waste FW (%)	Biological Sludge BS (%)	Addition of Fatty Waste FW (%)
100	0	100	0
90	10	85	15
80	20	75	25
75	25	65	35
70	30	55	45

The proportion of added grease is higher in the tests with biological sludge, as this contains less organic matter than primary sludge. In fact, biological sludge is more mineralised due to the aerobic degradation processes that have taken place in the aeration tanks (Berahab, 2019).

2.4 Experimental set-up and operating conditions

The method consists of introducing 600 g of experimental substrate into the fermenters and then monitoring the cumulative production of gas under predefined incubation conditions. After introducing the substrate, the temperature of the reactors was raised to 37°C using a water bath (VWR brand, MX06S135, temperature range up to +100°C). The choice of the mesophilic regime adopted was justified by the optimum bacterial activity sought at this temperature. The biodigestion trial was carried out in a batch system over 21 days, with two replicates for each substrate sample. The digestate was racked on day 21 because the Biological Methanogenic Potential (BMP) value corresponds to the total quantity of gas produced cumulatively after this incubation period.

2.5 Characterization of substrates

Several physicochemical parameters were measured to assess the progress of the effluent treatment process. These parameters included:

- Ammoniacal nitrogen) determined to assess water quality and its impact on the environment. (NS 05-063 June 2001;
- Total nitrogen (NT) (NS 05-061, July 2001), total phosphorus (PT) (NS 05-065, July 2001), and potassium (K+) (NS 05-061, July 2001) were determined to assess their impact on crop yields.

3. RESULTS AND DISCUSSION

The volume of biogas produced was measured throughout the experiment. The cumulative amount of biogas produced throughout the experiments is shown in Table 1. It can be seen that the volume of biogas produced during mono-digestion is significantly lower than that of anaerobic co-digestion (Table 2).

Table 2. Cumulative biogas production by blend: PS/FW and BS/FW.

Blends / PS and FW			Blends / BS and FW		
Primary Sludge PS (%)	Addition of Fatty Waste FW (%)	Volume Biogaz (ml)	Biological Sludge BS (%)	Addition of Fatty Waste FW (%)	Volume Biogaz (ml)
100	0	1110	100	0	560
90	10	3400	85	15	3090
80	20	4880	75	25	4770
75	25	6968	65	35	9030
70	30	7125	55	45	10290

This confirmed that adding fat significantly enhances digestion and accelerates the development of methanogenic bacteria. During these 21 days, we produced 3400, 4880, 6965 and 7125 ml of biogas respectively for the PS90%FW10%, PS80%FW20%, PS75%FW25% and PS70%FW30% cases, and only 1110 ml in the case of primary sludge digestion alone.

The BS55%FW45% blend is the most productive, followed by the BS65% FW35%, BS75% FW25%, and BS85% FW 15% blends respectively, and the BS100% biological sludge substrate alone, which is the least productive. Greasy waste, by its very nature, is very rich in carbon, which is a highly methanogenic component. With up to 45% addition of fatty residues to sludge, the increase in biogas production appears linear and proportional.

These results clearly show that biogas production increases with the amount of grease added. The addition of greasy waste improved the methanogenic potential by up to 18 times the amount of biogas obtained from the fermentation of biological sludge alone and 10 times that of fresh sludge at 45% and 30% respectively. According to (Ruiz et al., 2023), a significant increase in methane production is observed after introducing 10% fat. At 40%, a decrease in methane production appears, which seems to correlate with the presence of fat beads in the reactor.

The biodigestion of grease, mixed with primary sludge on the one hand and with biological sludge on the other, produced the results shown in Table 3.

Table 3. Agronomic values of Primary Sludge (PS) alone and Primary Sludge / Addition of Fatty Waste mixtures (PS/FW)

Parameters	$PS_{100\%}$	$PS_{90\%}$ $FW_{10\%}$	$PS_{80\%}$ $FW_{20\%}$	$PS_{75\%}$ $FW_{25\%}$	$PS_{70\%}$ $FW_{30\%}$
NT (mg/l)	1197,2 ± 1381,43	682,1 ± 220,48	1287 ± 195,16	1920,5 ± 54,45	1450,5 ± 738,93
NH4+ (mg/l)	376 ± 93,34	322,5 ± 3,54	413,25 ± 195,52	378,5 ± 78,49	381,5 ± 197,61
PT (mg/l)	265 ± 122,13	217,41 ± 64,65	252,69 ± 20,37	366,58 ± 62,25	343,6 ± 42,99
K (mg/l)	0,5	-	-	0,59	0,6 ± 0,01

The soluble major elements such as ammonium (NH4+), total nitrogen (NT), total phosphorus (PT), and potassium (K+) determine the fertilizing value of the digestates. On average, NH4+ concentrations range from 322.5 mg/l to 413.25 mg/l, NT concentrations from 682.1 mg/l to 1920.5 mg/l, and TP concentrations from 217.41 mg/l to 366.58 mg/l. Potassium (K+) concentrations ranged from 0 to 0.6 mg/l.

Table 4. Agronomic values of Biological Sludges (BS) alone and Biological Sludge (BS) / Fatty Waste (FW) mixtures

Parameters	$BS_{100\%}$	$BS_{85\%}FW_{15\%}$	$BS_{75\%}FW_{25\%}$	$BS_{65\%}FW_{35\%}$	$BS_{55\%}FW_{45\%}$
NT (mg/l)	1844,65 ± 934,72	799,92 ± 82,14	570,6 ± 482,59	2383,10 ± 120,77	3139,3 ± 424,41
$NH4^{+}$ (mg/l)	309,43 ± 147,89	338,85 ± 29,91	335,15 ± 11,10	530 ± 110,31	525,5 ± 207,18
PT (mg/l)	458,2 ± 390,61	159,99 ± 16,43	196,68 ± 2,40	609,25 ± 72,48	677 ± 78,91
K (mg/l)	0,19	-	0,2 ± 0,06	0,42 ± 0,17	1,03 ± 0,29

Average NH4+ concentrations in the digestates varied from 309.43 mg/l to 530 mg/l. For total nitrogen (TN), average concentrations ranged from 570.6 mg/l to 3139.3 mg/l, while those for total phosphorus (TP) varied from 159.99 mg/l to 677 mg/l. Average potassium concentrations range from 0 to 1.03 mg/l. However, the methanization reaction modifies the form of fertilizing elements such as nitrogen, phosphorus, and potassium (Martin et al., 2022). During this process, some of the organic nitrogen is converted into mineral nitrogen, in the form of ammonium (NH4+) and ammonia (NH3). This change can make nitrogen more readily available to plants when they need it (Berahab, 2019). However, the mineralization of organic nitrogen has one drawback: it makes the nitrogen in the digestate more volatile (Launay et al., 2020). Mineral nitrogen can be found in the form of ammonia and ammonium. The balance between these two compounds depends on the pH. As the pH of the digestate is higher or lower than that of the raw manure, a large proportion of the nitrogen is found in the ammoniacal form, which is the most volatile form (Mansaly, 2018). Precautions therefore need to be taken to prevent evaporation and reduce significant losses during storage and spreading.

Digestate does, however, have the advantage of being highly viscous, which makes it less aggressive for the soil, facilitating infiltration and reducing the time it takes to evaporate after spreading (Launay et al., 2020).

From the results in Tables 3 and 4, it can be seen that the amount of ammonium is very high in digestates from sludge/fat. This is due to the high NH4+ content of fatty waste compared with primary and biological sludge. Fats therefore improve the quality of the digestate. The non-biodegraded carbonaceous organic matter and nitrogen present in the digestate contribute to its amending and fertilizing properties respectively. The fertilizing power is thus linked to the quantity of ammonium, biodegradable organic nitrogen in the soil, and the carbon/nitrogen ratio of the digestate (Duru and Bras, 2020). Like nitrogen, organic phosphorus is partially mineralized during the destruction of fermentable organic matter. Bacteria assimilate the substrate and release phosphorus, thereby increasing its availability through methanization (Glénisson, Caillet and Regnier, 2022). In addition, the phosphorus contribution from the fat added as a co-substrate could explain this increase.

Unlike mineral forms of nitrogen, which are mainly soluble, mineral phosphorus binds mainly to particles in the solid fraction and can be found in various mineral chemical forms. During anaerobic digestion, only a third of the phosphorus is released and rendered soluble in the supernatant, while the remaining two-thirds is fixed in the digested sludge in the form of struvites (MAP: Magnesium Ammonium Phosphate) and hydroxyapatites (HAP: Calcium Phosphates) (Carretier, 2014). Digestion does not affect potassium levels. Nevertheless, very low concentrations of potassium were observed in the digestate, ranging from 0 to 1.23 mg/L in both experiments. Sludge is low in potassium, as this element is found in dissolved form, so it is more concentrated in the liquid phase after separation and is not retained to any great extent in the sludge (Besson et al., 2019).

4. CONCLUSION

In the current context of increasing effluent production, anaerobic digestion appears to be a promising solution for waste treatment with a view to sustainable development. This study has enabled us to develop a method for treating grease from wastewater treatment plants. Greasy waste is mainly composed of biodegradable organic matter, mainly triglycerides and free fatty acids. These substrates are rich in nitrogen, and anaerobic digestion alone could cause inhibition problems due to the accumulation of nitrogen products and volatile fatty acids (VFAs). Anaerobic co-digestion of the fatty waste diluted the toxic elements and better balanced the carbon/nitrogen ratio of the organic matter. Co-digestion of grease with primary sludge and extended aeration of biological sludge increased biogas production compared with anaerobic digestion of the sludge alone. For primary sludge, the percentage of added grease varied from 10 to 30%, and from 15 to 45% for biological sludge. It was found that the higher the amount of added fat, the higher the biogas production. The best yields were obtained with a 30% addition of fats for fresh sludge (11.88 m^3/t DM) and 45% for biological sludge (17.15 m^3/t DM). This type of co-digestion opens up new prospects for the anaerobic digestion of biological sludge, whose degradation by anaerobic digestion is generally low. From an agronomic point of view, the digestates have interesting average concentrations of ammonium ($NH4^+$) ranging from 322.5 mg/L to 530 mg/L, and total phosphorus (TP) from 159.99 mg/L to 677 mg/L, but low levels of potassium (K^+) from 0 mg/L to 1.03 mg/L. The effect of these concentrations on crop yields needs to be assessed. Given the low potassium content of digestate from the biodigestion of fatty waste, it could be enriched by adding other potassium-rich digestates to improve agricultural yields. However, because Senegal has two seasons, the dilution of effluent by rainwater could lead to variations in the data obtained.

AUTHOR CONTRIBUTIONS

Conceptualization and methodology: (MD, FKT, and NAD); Data analysis and discussion: (MD, FKT, NAD, AAMD, and AK); Manuscript preparation (MD, and FKT); Manuscript review and editing (MD, FKT, NAD, AAMD, AK, MF, and FMS).

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