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RESEARCH OF DIGESTION OF CATTLE MANURE AND CHICKEN DUNG MIXTURE WITH IRON-BASED ADDITIVES

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Abstract. This study evaluated the anaerobic co-digestion of cattle manure and chicken dung (70/30% ratio on a DS basis) supplemented with iron-based additives (SBGx, SBGx Plus, and BC. Atox Scon) under continuous mesophilic conditions. Two 16 l reactors were operated with an inoculum-to-substrate ratio of 5:1 (on a VS basis) and a daily loading rate of 0.52 l/d (7–10% DS). The experiment was conducted in two phases: Stage I compared a control to BC. Atox Scon, while Stage II compared SBGx Plus to SBGx. Results indicated that while the additives significantly influenced the initial 15 days of digestion, none enhanced total biogas or methane production relative to the control, which achieved the highest overall yields (190 l CH4/31 d). Although BC. Atox Scon yielded the highest mean methane concentration, it resulted in the lowest cumulative methane volume. All additives markedly reduced H_2S levels, with SBGx Plus achieving the most efficient mitigation (mean 1.88 ppm). The study demonstrates that while iron-based additives are highly effective for biogas purification, their impact on total energy yield varies across different experimental stages.

Keywords: anaerobic digestion, iron-based additives, biogas production, VS destruction.

1. Introduction

Anaerobic digestion is a widely used biological process for stabilising biodegradable organic wastes and generating renewable energy in the form of biogas. Through biogas production, energy can be recovered from agricultural and municipal organic waste streams, supporting reductions in greenhouse gas emissions and fostering the development of a circular economy (Jana et al., 2025). Livestock manure is among the most plentiful and consistently produced agricultural feedstocks for anaerobic digestion. However, digestion processes based on manure often suffer from slow hydrolysis, incomplete degradation of volatile solids (VS), and unstable methane generation, all of which reduce the total biogas yield (Kadam et al., 2024; Usman Khan & Kiaer Ahring, 2021).

Cattle manure is rich in lignocellulosic material, which limits hydrolysis efficiency and results in comparatively low methane yields during anaerobic digestion (Sunar et al., 2025). Chicken manure is characterised by a low C/N ratio and high nitrogen content, which promotes ammonia accumulation and inhibits methanogenic microorganisms, which lowers the efficiency of methane production (Song et al., 2023). Co-digestion of cattle manure with nitrogen-rich substrates such as chicken manure is widely applied to improve substrate nutrient balance, dilute inhibitory compounds and enhance process stability and biogas production. Several studies have shown that co-digestion improves methane yields and volatile solids destruction compared to mono-digestion systems (Usman Khan & Kiaer Ahring, 2021). Hydrogen sulphide (H_2S) is one of the most unwanted components of biogas due to its corrosive properties and negative impact on gas quality and energy conversion equipment. High levels of H_2S concentrations significantly increase maintenance costs and reduce the lifetime of biogas utilisation systems (Leonov & Trubaev, 2022).

Iron-based additives are commonly applied to reduce hydrogen sulphide concentration through sulphide precipitation and to stabilise the digestion process. In addition, mineral and commercial additives have been reported to influence microbial activity, methane formation and volatile solids degradation during manure digestion (Dauknys & Mažeikienė, 2023). Although the positive effects of iron-based and mineral additives on anaerobic digestion performance have been reported (Dauknys & Mažeikienė, 2023), most available studies focus on single additives, batch experiments or sewage sludge substrates. A recent meta-analysis demonstrated that iron-based additives significantly increase biogas yield across various organic substrates; however, the magnitude of this effect strongly depends on additive

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type, dosage and substrate characteristics (Ugwu et al., 2020). Different commercial mineral and iron-based additives under identical continuous-flow co-digestion conditions using agricultural substrates remain limited (Kadam et al., 2024). Therefore, the objective of this study was to evaluate the influence of $Fe(OH)_3$, SBGx and SBGx Plus additives on the anaerobic digestion performance of a cattle manure and chicken dung mixture (70/30 by dry solids) under mesophilic continuous-flow conditions. The effects of the tested additives on biogas production, methane concentration, hydrogen sulphide reduction and volatile solids degradation were systematically investigated.

2. Materials and methods

2.1. Reactor configuration and experimental conditions

In this study, two lab-scale anaerobic reactors with an effective volume of 16 l each were employed (Figure 1). The reactors were operated under mesophilic conditions at 37–38 °C. Mixing and settling were cycled, with 15 minutes of mixing followed by 45 minutes of settling to simulate a CSTR digester. The substrate consisted of a mixture of cattle manure and chicken dung without bedding (from egg-laying hens). This mixture contained 70% cattle manure and 30% chicken dung (on a dry solids (DS) basis), resulting in a balanced substrate composition suitable for anaerobic digestion. Digested sludge from a municipal wastewater treatment plant was used as inoculum to ensure the immediate initiation of the anaerobic digestion process. The substrate was mixed with the inoculum at a 5:1 ratio based on VS.

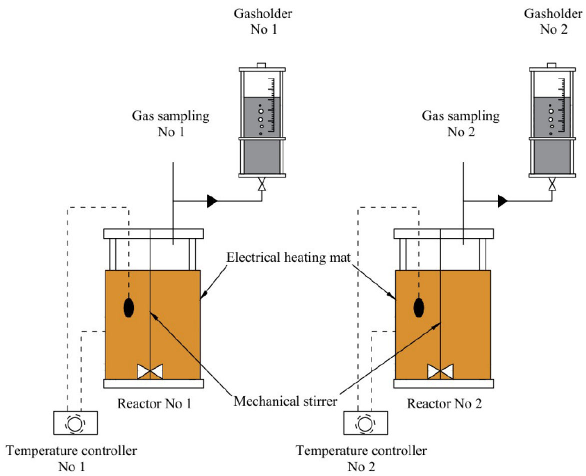

Figure 1. Anaerobic reactors

The prepared substrate was diluted with water to obtain a total solid concentration of 7–10% DS. A single additive dose of 0.2 kg per kg of DS was applied for all tested additives. Feeding was performed once per day with a hydraulic retention time of 30 days and a loading volume of 0.52 per reactor. Substrate was stored at 4 °C to prevent uncontrolled biological activity, then heated to 20–25 °C before loading to minimise thermal shock and maintain stable digestion.

The experiment consisted of two stages:

1. Stage I, in which digestion without additives was compared to digestion in the presence of $Fe(OH)_3$,
2. Stage II, in which digestion supplemented with SBGx Plus was compared to digestion supplemented with SBGx.

Each experimental stage was operated for 34 days, resulting in a total duration of 68 days. This duration was selected based on standard industrial and experimental practices, where a 30-day hydraulic retention time is typically applied for the anaerobic digestion of the substrate used in this study. An additional 4 days were included at the beginning of each stage as an adaptation period to ensure the stabilization of the microbial community and the immediate onset of the digestion process.

2.2. Additives

Three commercial iron-based additives were used: BC.Atox Scon ($Fe(OH)_3$), SBGx and SBGx Plus.

BC.Atox Scon is an iron hydroxide-based additive containing 36–40% trivalent iron hydroxide. It is a brown-red fine powder designed to remove hydrogen sulphide in biogas production by precipitating sulphides and is commonly used in anaerobic digesters treating manure and sewage sludge. $Fe(OH)_3$ works mainly by binding dissolved sulphides with Fe^{3+} ions to form insoluble iron sulphides. Iron hydroxide additives can also improve process stability under high nitrogen and sulphide loads (Schaumann Bioenergy GmbH, 2014).

SBGx is a powdered mineral additive composed mainly of iron oxides. According to the manufacturer's safety data sheet, it contains iron (III) oxide (Fe_2O_3) and iron (II) oxide (FeO), each above 35%, with total iron content over 60%. The additive also contains minor amounts of other metal oxides, including MnO (<1.0%), CaO (<0.5%), Al_2O_3 (<0.5%), MgO (<0.5%), Zn (<0.1%) and trace elements. Supplied as a dark brown to black powder, SBGx Plus is used in anaerobic digestion to reduce hydrogen sulphide, improve process stability and enhance methane production (Autark Investments and Projects AG, 2023a).

SBGx Plus slightly differs from SBGx in its chemical composition. SBGx Plus contains more than 62% iron oxides. In addition, SBGx Plus includes approximately 10% zero-valent iron (ZVI) (Autark Investments and Projects AG, 2023b).

2.3. Monitoring and analytical methods

The anaerobic digestion process was continuously monitored to evaluate substrate degradation, biogas production performance and biogas quality. Dry solids and volatile solids concentrations in the substrate and digestate were analysed to assess organic matter degradation efficiency.

DS concentration was determined according to EN 15934:2012 and VS concentration was determined according to EN 12880:2002. The pH values of the substrate and digestates were measured using a WTW inolab series 720 pH meter to monitor process stability.

Ammonium nitrogen concentration was determined according to ISO/TS 14256-1:2003. Biogas production rate was determined based on the measured volume of produced biogas. Biogas composition, including methane content (%) and hydrogen sulphide concentration (ppm), was analysed using a GasData GFM 406 gas analyser.

Measurements of DS and VS in substrate and digestate were performed every second day. Values of pH and biogas production were monitored daily. Biogas composition was measured once per day, and ammonium nitrogen concentrations were determined four times in substrate and digestates during the experimental period.

3. Results and discussion

3.1. Biogas production rates and yields

As illustrated in Figure 2, following the 4-day adaptation period and the onset of daily substrate loading, the highest biogas production rates were observed in the control (without additives) and the substrate treated with SBGx Plus. However, after 15 days of continuous loading, the biogas production rates stabilized and became comparable across all experimental treatments.

As shown in Table 1, the highest biogas yield throughout the testing period was achieved in the control (without additives). A nearly identical yield was observed using the SBGx Plus additive, with a negligible difference of only 0.8% compared to the control. In contrast, the total biogas production for SBGx and $Fe(OH)_3$ was 4.1% and 17.6% lower than the control, respectively.

3.2. Biogas composition and quality parameters

Methane content

According to Table 2, the highest mean methane content in the biogas (56.5%) was achieved with $Fe(OH)_3$. In the control, the methane concentration was 52.1%, while with SBGx and SBGx Plus, it decreased to 51.4% and 50.9%, respectively. Compared to the control, $Fe(OH)_3$ increased the mean methane concentration by 8.4%, whereas SBGx and SBGx Plus resulted in reductions of 1.3% and 2.3%.

The achieved mean methane concentrations, ranging from 50.9% to 56.5%, are consistent with typical values

Table 1. Comparison of biogas production of Stages I and II during entire test period: CM – cattle manure, CD – chicken dung

No	Substrate composition	Biogas production					
		Total, l/31 d	Average, l/d	Compared to No. 1	Compared to No. 2	Compared to No. 3	Compared to No. 4
1	CM 70% + CD 30%	364	11.7	–	21.3%	4.3%	0.8%
2	CM 70% + CD 30% + $Fe(OH)_3$, 0.2 kg/kg DS	300	9.7	–17.6%	–	–14.0%	–16.9%
3	CM 70% + CD 30% + SBGx, 0.2 kg/kg DS	349	11.2	–4.1%	16.3%	–	–3.3%
4	CM 70% + CD 30% + SBGx Plus, 0.2 kg/kg DS	361	11.6	–0.8%	20.3%	3.4%	–

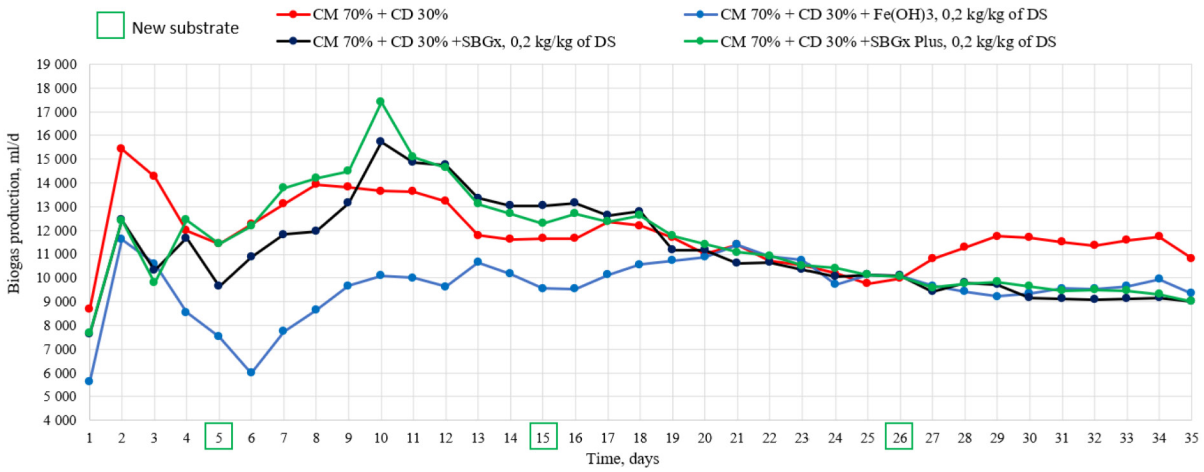

Figure 2. Biogas production, Stages I and II: CM – cattle manure, CD – chicken dung

Table 2. Comparison of methane content of Stages I and II during entire test period: CM – cattle manure, CD – chicken dung

No	Substrate composition	CH_4 content in biogas					
		Max, %/31 d	Average, %	Compared to No. 1	Compared to No. 2	Compared to No 3	Compared to No 4
1	CM 70% + CD 30%	60.8	52.1	–	–7.8%	1.4%	2.4%
2	CM 70% + CD 30% + $Fe(OH)_3$, 0,2 kg/kg DS	74.9	56.5	8.4%	–	9.9%	11.0%
3	CM 70% + CD 30% + SBGx, 0.2 kg/kg DS	63.8	51.4	–1.3%	–9.0%	–	1.0%
4	CM 70% + CD 30% + SBGx Plus, 0.2 kg/kg DS	62.0	50.9	–2.3%	–9.9%	–1.0%	–

reported for the anaerobic co-digestion of cattle manure and chicken dung mixtures (Jana et al., 2025; Song et al., 2023). Biogas with a methane content exceeding 50% is considered suitable for efficient energy conversion in combined heat and power (CHP) units and internal combustion engines.

Methane production rate

As demonstrated in Table 3, the highest total methane yield throughout the testing period was achieved in the control, reaching 190 l CH_4/31 d. The use of additives resulted in lower methane yields of 184 l CH_4/31 d for SBGx Plus, 179 l CH_4/31 d for SBGx, and 170 l CH_4/31 d for $Fe(OH)_3$. Relative to the control, methane production decreased by 3.2%, 5.8%, and 10.5%, respectively. Notably, although $Fe(OH)_3$ yielded the highest mean methane concentration, it resulted in the lowest overall methane yield.

Hydrogen Sulphide concentration

As indicated in Table 4, the lowest mean H_2S concentration (1.88 ppm) was achieved with SBGx Plus, compared to 4.74 ppm for SBGx and 52.2 ppm in the control. The use of $Fe(OH)_3$ lowered the mean hydrogen sulphide concentration to 18.1 ppm, representing a 65% reduction relative to the control. In comparison, SBGx and SBGx Plus resulted in H_2S reductions of 91% and 96%, respectively. These results demonstrate that SBGx Plus was the most efficient additive for enhancing biogas quality by significantly reducing the hydrogen sulphide concentration.

The observed differences in biogas quality improvement can be attributed to the specific functional mechanisms of the additives. While $Fe(OH)_3$ primarily acts as a chemical scavenger for H_2S precipitation, the SBGx-series provides a broader spectrum of essential micronutrients that stabilize the methanogenic community. This explains the superior efficiency of SBGx Plus in simultaneously maintaining high gas yields and achieving near-complete H_2S removal, whereas $Fe(OH)_3$ showed a higher affinity for methane enrichment but resulted in a lower overall methane production rate.

3.3. Volatile solids degradation efficiency

As shown in Figure 3, highly consistent initial volatile solids concentrations were maintained before digestion across both experimental stages. The initial mean VS concentration in Stage I reached 63.4 g VS/l, while in Stage II it was 63.6 g VS/l. The difference between the two stages was only 0.32%; therefore, the VS degradation efficiencies obtained in different experimental stages are directly comparable. The dynamics of VS reduction during digestion are presented in Figure 4, while a comparison of the mean VS reduction values is summarised in Table 5.

As shown in Table 5, the highest mean VS degradation throughout the testing period was recorded in the control (24%). Compared to the control, the mean VS degradation for the $Fe(OH)_3$ and SBGx Plus treatments was 17% lower, while the use of SBGx resulted in a 21% reduction.

3.4. Summary of pH values

Across both experimental stages, the pH values remained stable and conducive to an efficient anaerobic digestion process. During Stage I, the mean loading pH was 7.25 for the control and 7.38 for the $Fe(OH)_3$ treatment. In Stage II, the loading pH values for the SBGx Plus and SBGx treatments were highly comparable, with mean values of 7.33 and 7.35, respectively. Following the digestion process, a slight reduction in pH was observed in all reactors, with mean unloading values ranging from 7.10 to 7.23. Overall, the determined pH levels across all treatments and stages confirmed that the substrate environment remained within the optimal range for effective microbial activity and process stability.

4. Conclusions

1. Biogas production with SBGx Plus remained comparable to the control (364 l/31 d), whereas SBGx and $Fe(OH)_3$ resulted in 4.1% and 17.6% lower yields, respectively.
2. Despite reaching the highest mean methane content (56.5%), $Fe(OH)_3$ yielded the lowest production rate (170 l CH_4/31 d). The control achieved the maximum

Table 3. Comparison of methane production rate of Stages I and II during entire test period: CM – cattle manure, CD – chicken dung

No	Substrate composition	CH_4 production					
		Total, l/31 d	Average, l/d	Compared to No. 1	Compared to No. 2	Compared to No 3	Compared to No 4
1	CM 70% + CD 30%	190	6.1	–	11.8%	6.1%	3.3%
2	CM 70% + CD 30% + $Fe(OH)_3$, 0.2 kg/kg DS	170	5.5	–10.5%	–	–5.0%	–7.6%
3	CM 70% + CD 30% + SBGx, 0.2 kg/kg DS	179	5.8	5.8%	5.3%	–	–2.7%
4	CM 70% + CD 30% + SBGx Plus, 0.2 kg/kg DS	184	5.9	–3.2%	8.2%	2.8%	–

Table 4. Comparison of H_2S concentration of Stages I and II during entire test period: CM – cattle manure, CD – chicken dung

No	Substrate composition	H_2S concentration in biogas					
		Max, ppm/ 31 d	Average, ppm	Compared to No. 1	Compared to No. 2	Compared to No 3	Compared to No 4
1	CM 70% + CD 30%	130	52.2	–	188%	1001%	2677%
2	CM 70% + CD 30% + $Fe(OH)_3$, 0.2 kg/kg DS	50	18.1	–65%	–	282%	863%
3	CM 70% + CD 30% + SBGx, 0.2 kg/kg DS	10	4.74	–91%	–74%	–	152%
4	CM 70% + CD 30% + SBGx Plus, 0.2 kg/kg DS	10	1.88	–96%	–90%	–60%	–

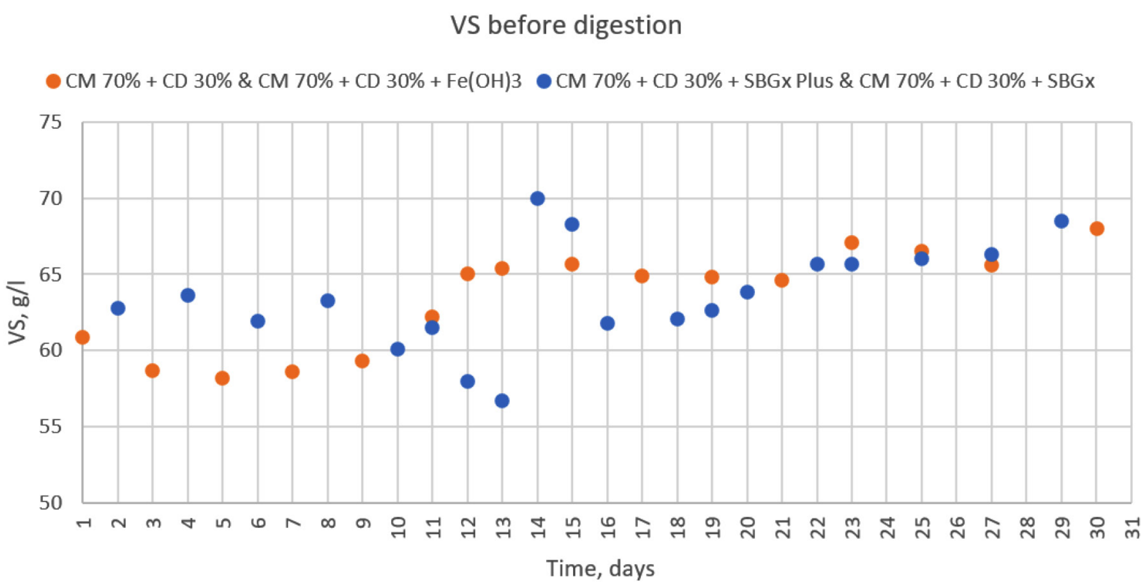

Figure 3. VS values of substrate before digestion, Stages I and II: CM – cattle manure, CD – chicken dung

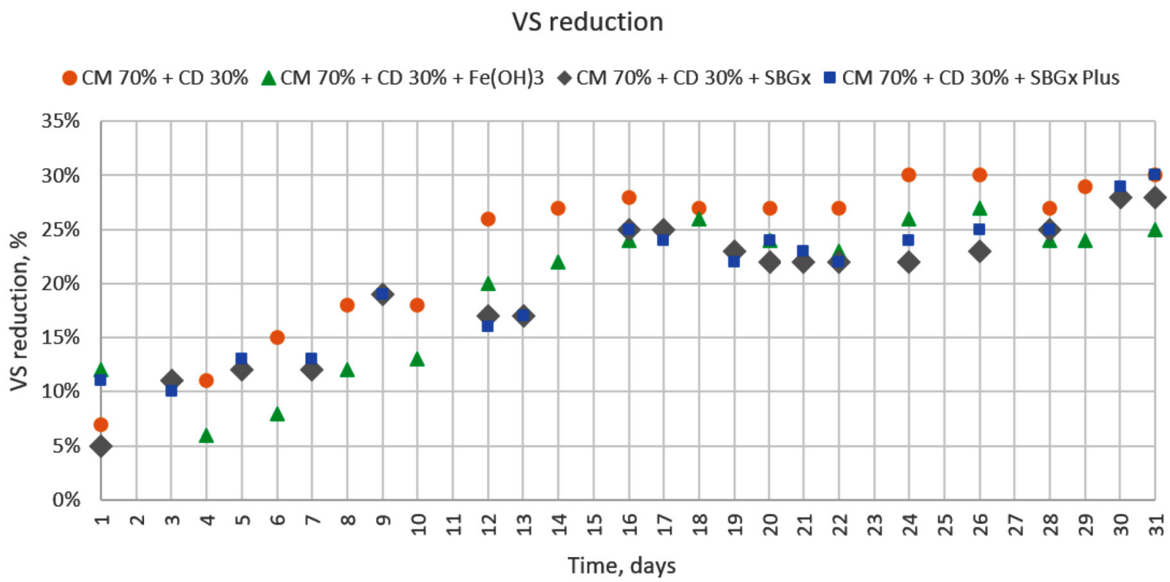

Figure 4. VS reduction during digestion, Stages I and II: CM – cattle manure, CD – chicken dung

Table 5. Comparison of VS reduction of Stages I and II during entire test period: CM – cattle manure, CD – chicken dung

No	Substrate composition		VS reduction				
		Max, %/31 d	Average, %	Compared to No. 1	Compared to No. 2	Compared to No 3	Compared to No 4
1	CM 70% + CD 30%	30	24	–	20%	26%	20%
2	CM 70% + CD 30% + $Fe(OH)_3$, 0,2 kg/kg DS	27	20	–17%	–	5%	0%
3	CM 70% + CD 30% + SBGx, 0,2 kg/kg DS	28	19	–21%	–5%	–	–5%
4	CM 70% + CD 30% + SBGx Plus, 0,2 kg/kg DS	30	20	–17%	0%	5%	–

rate (190 l CH_4/31 d), while SBGx, SBGx Plus, and $Fe(OH)_3$ showed reductions of 5.8%, 3.2%, and 10.5%, respectively.

3. Notably, SBGx Plus outperformed $Fe(OH)_3$ throughout the testing period, achieving a 20% higher biogas production rate and an 8.2% higher methane production rate.
4. Throughout the testing period, the SBGx-series additives demonstrated superior H_2S mitigation compared to the control, with SBGx Plus achieving the lowest mean concentration of 1.88 ppm (a 96% reduction). These varying impacts on biogas quality are attributed to the additives' distinct functional mechanisms: while $Fe(OH)_3$ acts primarily as a chemical scavenger for H_2S precipitation (65% reduction), the SBGx-series provides essential micronutrients that stabilize the methanogenic community. This dual-action effect enabled SBGx Plus to achieve near-complete H_2S removal while maintaining superior biogas production rates throughout the experimental stages.
5. The initial VS concentrations across stages were highly consistent, with only a 0.32% variance between $Fe(OH)_3$ in Stage I (63.4 g VS/l) and the SBGx series in Stage II (63.6 g VS/l). Throughout the testing period, the highest mean VS degradation (24%) was achieved in the control. In comparison, the use of $Fe(OH)_3$ and SBGx Plus resulted in 17% lower degradation, while the SBGx treatment showed a 21% reduction relative to the control.

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