

Enhancing anaerobic digestion efficiency of dried fish waste through C/N ratio adjustment and additive application

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1. Introduction

As the fisheries and aquaculture industries continue to expand, the global production of fish waste has increased rapidly. Fish waste, including viscera, bones, scales, heads, skin, and deceased fish, is primarily managed through incineration or landfilling in Korea. However, these disposal methods are highly energy-intensive and contribute to greenhouse gas (GHG) emissions and environmental pollution. Therefore, an effective treatment strategy for fish waste is essential to address both environmental and economic concerns. Anaerobic digestion (AD) is a sustainable biological process in which microorganisms degrade organic matter to produce biogas, primarily methane. AD has been widely applied to food waste, livestock manure, and agricultural residues. Similarly, fish waste can serve as an energy source through AD while also mitigating environmental pollution.

However, several challenges hinder the direct AD of fish waste. Prolonged storage of fish waste accelerates decomposition, leading to odor formation and energy loss. Additionally, fish waste has a low carbon-to-nitrogen (C/N) ratio and high protein and lipid contents, which can result in excessive volatile fatty acid (VFA) and ammonia accumulation, thereby compromising process stability. Therefore, optimizing the C/N ratio and implementing appropriate pretreatment strategies are crucial for ensuring stable operation.

This study aimed to mitigate spoilage and odor associated with fish waste through drying, which also facilitates storage. To achieve this, fish meal was utilized as a model substrate to simulate dried fish waste, offering advantages such as enhanced homogeneity and prolonged preservation. The study evaluated the biogas potential of dried fish waste and investigated strategies for enhancing anaerobic digestion efficiency through C/N ratio optimization and additive supplementation.

2. Materials and Methods

This study was conducted in three phases. Phase 1 involved characterizing fish meal and starch (carbon source) through physicochemical analyses, including pH, VFAs, VS, TS, COD, and elemental composition. Additionally, a BMP test was performed to assess the anaerobic digestion potential of fish waste.

In Phase 2, fish meal and starch were mixed at ratios of 1:1, 2:1, and 3:1, and batch experiments were conducted at organic concentrations ranging from 2.5 to 30 g VS/L. Methane production and VFA accumulation were analyzed to determine the optimal substrate ratio for the continuous stirred tank reactor (CSTR) experiment.

Phase 3 consisted of semi-continuous anaerobic digestion experiments using a CSTR system. Fish meal alone and mixtures of fish meal and starch at ratios of 1:1 and 3:1 were used as substrates. The reactor was operated with a hydraulic retention time (HRT) of 21 days and an organic loading rate (OLR) of 1 g VS/L/day. pH, methane production, TS, VS, and VFA levels were monitored regularly. The experiment was conducted for a total of 168 days, with additional treatments implemented to enhance process stability, including the addition of 50 g/L oyster shell powder (R1, R2: 68 days; R3: 52 days) and 1.6 g/L magnetite (R1, R2, R3: 101 days).

3. Results and Discussion

The characteristics of the fish meal used in the experiment are presented in Table 1. According to the elemental analysis results, the C/N ratio of fish meal was 3.5, which is considerably lower than the optimal C/N ratio of 20–35 typically required for anaerobic digestion. Therefore, anaerobic digestion of fish meal alone was expected to be limited, and increasing the carbon ratio was considered necessary to ensure a stable anaerobic digestion process. To evaluate the biogas production potential of fish meal, a BMP test was conducted, and the results were obtained by averaging three replicates. The reported BMP value of fish waste generally ranges from 350 to 650 mL CH₄/g VS, while the fish meal used in this experiment showed a value of 419 mL CH₄/g VS.

Table 1. Characteristics of fish meal

	pH	TS g/kg	VS g/kg	COD g/L	C %	H %	O %	N %	S %	BMP CH ₄ NL/kg VS
Fish meal	6.99	792	598	608	38	5	44	11	2	419

Figure 1 shows the batch test results for fish meal and starch. For starch alone, methane gas production was highest in the following order: 10, 5, 2.5, 20, and 30 g VS/L. After the batch test, the organic acid concentration was measured in the final samples. At 2.5, 5, and 10 g VS/L, the organic acid concentration was below 30 mg/L. However, at 20 and 30 g VS/L, the values were 486 and 1,248 times higher, respectively, indicating a significant accumulation of organic acids. These results suggest that, in the case of starch alone, organic acid accumulation negatively affected the batch digestion process starting from 20 g VS/L.

For fish meal alone and the 1:1 and 1:2 fish meal-to-starch ratios, methane gas production was highest in the following order: 30, 20, 10, 5, and 2.5 g VS/L, indicating that higher organic concentrations led to greater methane gas production. In contrast, for the 1:3 fish meal-to-starch ratio, methane production was highest in the order of 20, 10, 30, 5, and 2.5 g VS/L. The highest methane gas production values across all conditions were 562 mL CH₄ at 30 g VS/L for the 1:1 ratio, 497 mL CH₄ at 30 g VS/L for the 1:2 ratio, and 475 mL CH₄ at 30 g VS/L for fish meal alone. At a 1:1 ratio, the C/N ratio was 12, which was four times higher than that of fish meal alone and resulted in the highest methane gas production. This confirms that increasing the C/N ratio with an additional carbon source enhances methane gas production. Additionally, in all conditions except for 30 g VS/L, more than 90% of total methane gas was produced within 10 days, whereas at 30 g VS/L, it took 30 days to reach 90% methane gas production. This suggests that when fish meal and starch are co-digested, starch, which has a high carbohydrate content, decomposes first, whereas fish meal, which is rich in protein, decomposes more slowly. Furthermore, it was confirmed that fish meal contains trace elements necessary for anaerobic digestion, allowing it to generate a certain amount of gas even when digested alone. However, as observed in the batch test results, adding an additional carbon source demonstrated a greater synergistic effect on methane gas production.

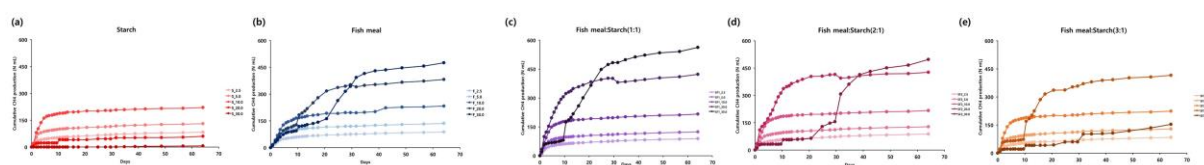


Figure 1. Methane production across different conditions in batch tests

Figure 2 shows the methane gas production and pH variations monitored during CSTR reactor operation. R1 consisted of fish meal alone, R2 contained fish meal and starch at a 1:1 ratio, and R3 was the substrate alone at a 1:3 ratio. Over time, methane gas production decreased, with a sharp decline observed after 42 days. During this period, R3 showed almost no gas production, and pH levels also dropped significantly, indicating that operating the reactor with only the supplied substrate was ineffective.

To regulate pH and provide an alkalinity buffering effect, 50 g/L of oyster shell powder was added on Day 52 for R3 and on Day 68 for R1 and R2. Although some recovery was observed after the addition of oyster shells, the improvement was temporary due to the single application.

Therefore, on Day 101, 1.6 g/L of magnetite was added to all reactors (R1, R2, and R3) to promote electron transfer and enhance microbial activity during anaerobic digestion. Following the addition of magnetite, methane gas production increased compared to pre-addition levels, and pH remained stable, demonstrating that magnetite played a role in enhancing methanogenesis efficiency and process stability.

This study investigated the anaerobic digestion potential of dried fish waste. The results demonstrated that stable operation could be achieved by co-digesting fish waste with a carbon source to establish an appropriate C/N ratio and by utilizing additives. This study explored the efficient valorization of dried fish waste, which may contribute to the development of a sustainable waste management system for fish waste.

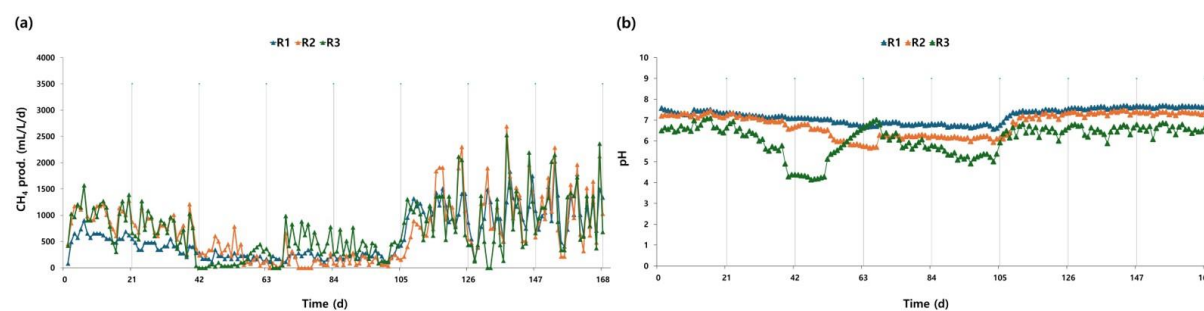


Figure 2. Operational profiles of bioreactors over 168days (methane production and pH)

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