



Case Study

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Treatment of Kitchen Wastewater with High Ammonia Nitrogen, COD, and Alkalinity: A Case Study

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Abstract

The treatment process at a kitchen-waste processing plant generally comprises sorting of kitchen waste, anaerobic digestion of kitchen waste containing approximately 3% solids by high-efficiency anaerobic microorganisms, production of waste-cooking-oil biodiesel, and spray absorption of workshop exhaust gas. During production, three wastewater streams are generated: high-ammonia-nitrogen biogas-slurry wastewater, with an ammonia-nitrogen concentration of approximately 1,500–2,300mg/L, high-COD wastewater, with a COD concentration of approximately 10,000–100,000mg/L, and high-alkalinity wastewater, with alkalinity exceeding 5,000 mg/L (as NaOH) and a pH of approximately 11. Combined with domestic sewage, these streams form a composite influent containing approximately 4,000–6,000mg/L COD, 400–1,000mg/L ammonia nitrogen, and a pH of approximately 9.0. The treatment objective is compliance with the discharge-to-pipeline limits: COD ≤ 500mg/L, ammonia nitrogen ≤ 15mg/L, and pH 6–9. The treatment process first applies physicochemical pretreatment, followed by an A²/O process, and the effluent is then treated by a Membrane Bioreactor (MBR) before discharge. COD was relatively easy to bring within the required limit, whereas ammonia nitrogen was more difficult to control. The main problem is high alkalinity, which can easily lead to free-ammonia poisoning and system collapse. This project combined engineered nitrifying-bacteria bioaugmentation with free-ammonia control to achieve stable compliance for COD, ammonia nitrogen, and pH, providing a reference for similar projects.

Keywords: Kitchen waste, Food waste, Biogas slurry, High ammonia nitrogen, Free ammonia

Introduction

The treatment of kitchen waste plays an important role in improving the environment and preventing waste cooking oil from returning to the food chain. Kitchen waste is highly biodegradable and, if not collected and treated in a timely manner, can readily ferment and generate unpleasant odors, it may also promote the growth and spread of harmful microorganisms, posing serious risks to human health. Waste cooking oil has repeatedly attracted public concern because it may contain dozens of toxic and harmful organic compounds, and if such oil re-enters the food chain, it can

pose a significant but often hidden threat to consumers. Therefore, converting waste cooking oil into biodiesel provides an effective route for its safe utilization while helping to prevent it from being reused for food preparation.

At one company, the food and kitchen waste treatment project has a daily treatment capacity of more than 2,000 t and is reported to be the largest integrated organic solid-waste treatment project constructed at one time in China [1-5], the maximum treatment capacity of the waste-cooking-oil facility is 400 t/d. The process

is generally as follows: after entering the plant, kitchen waste first undergoes ultra-high-pressure separation, with the solid fraction (moisture content below 65%) sent to an incinerator for power generation, while the liquid fraction is combined with food-service waste and subjected to oil-water separation. The recovered oil is transferred to the biodiesel workshop, and the organic slurry containing approximately 3% solids is sent to the anaerobic fermentation unit, where, under the action of high-efficiency anaerobic microorganisms, organic matter is converted to methane, anaerobic digestion is widely used for the valorization of food waste through biogas production, while a considerable amount of digestate is generated and requires appropriate downstream management [6]. After purification, the methane is used for power generation, and a portion is liquefied for sale. The residual anaerobic digestate contains approximately 1.5–2.5% solids, and after chemical conditioning to improve dewaterability, solid-liquid separation is performed using an ultra-high-pressure plate-and-frame filter press, the separated liquid, containing approximately 2,000–3,000 mg/L COD and 1,500–2,300 mg/L ammonia nitrogen with suspended solids on the order of several tens of mg/L, is sent to the wastewater treatment station, while the separated solids are transported for farm composting or incineration. Externally collected waste cooking oil and waste oil recovered by on-site oil-water separation are sent to the biodiesel workshop, where oils are hydrolyzed into higher fatty acids and glycerol by lipase and a superacid catalyst, purified glycerol is used as a chemical raw material, while the higher fatty acids react with methanol under enzymatic catalysis to produce biodiesel for sale. Equipment cleaning and condensate streams generate high-COD wastewater, part of which is recycled and the remainder discharged to the wastewater treatment station. Because workshop production is carried out in a relatively enclosed environment, odor-control systems are required to minimize odor emissions, and these systems mainly use acid/alkali scrubbing, sodium hypochlorite solution absorption, biofilm absorption, and deodorant absorption, generating strongly alkaline deodorization wastewater with a pH of approximately 11–12 during the process. These three wastewater streams are combined with workshop floor-washing water, first-flush stormwater, and domestic sewage and then conveyed to the centralized wastewater treatment station, forming the wastewater source for this project.

The main operational problems observed at the wastewater treatment station were as follows: ammonia nitrogen frequently exceeded the required limit, mainly because large fluctuations in the different influent streams created shock loads that made it difficult for nitrifying bacteria to survive, pH fluctuated substantially and was often high in the effluent, with high acid consumption associated with poor ammonia-nitrogen removal, the MBR permeate production rate was low, cleaning was frequent, and membrane fouling was severe, the microbial community in

the biological tanks was poor, functional microorganisms became inactive, and inoculated activated sludge was repeatedly subjected to shock loading, and a pungent ammonia odor could be detected around the biological tanks, indicating that free-ammonia toxicity had not been eliminated. Therefore, in this study, we conducted a detailed investigation of a method for efficiently treating the wastewater.

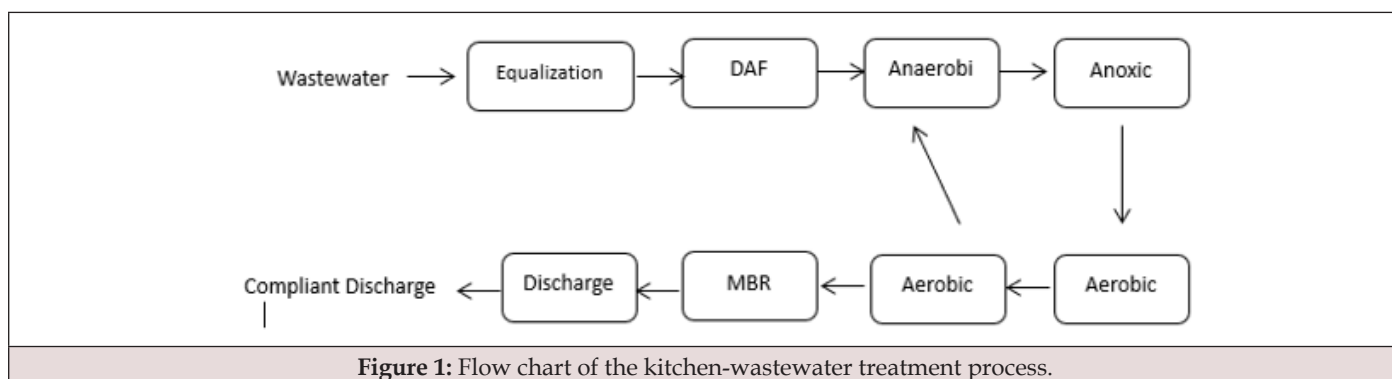
Preliminary Testing and Cause Analysis

Preliminary Characterization of the Wastewater Streams

Digestate wastewater is mainly the effluent from anaerobic biological treatment. A large proportion of the suspended solids has already been removed by pressure filtration, but the water still contains high concentrations of residual organic matter, including low-molecular-weight and high-molecular-weight organics, sulfides, nitrogen compounds, and organic phosphorus. Its pH is approximately 8.5, alkalinity is approximately 3,000 mg/L, and ammonia nitrogen is approximately 1,500–2,300 mg/L, while its overall biodegradability remains relatively good. This stream is the main source of ammonia nitrogen at the wastewater treatment station, and high-strength kitchen-waste digestion liquid generally requires further treatment because of its substantial organic and nitrogen loads [7]. Biodiesel wastewater is readily biodegradable but highly concentrated, with COD generally above 10,000 mg/L and capable of reaching 100,000 mg/L, the main pollutants include methanol, glycerol, fatty acids, oils and fats, and suspended solids. Deodorization wastewater is generated mainly from the absorption of odorous components in the workshop, including hydrogen sulfide, organosulfur compounds, and ammonia, as well as from chemicals used to prepare the scrubbing solutions, such as sodium hydroxide, hydrochloric acid, sulfuric acid, sodium hypochlorite, and deodorants, this stream is mainly characterized by high alkalinity and high salinity, with COD approximately 1,000–2,000 mg/L, ammonia nitrogen approximately 100 mg/L, salinity approximately 10,000–30,000 mg/L, and sulfide approximately 100 mg/L. Domestic sewage and first-flush stormwater have relatively low pollutant concentrations and are comparatively easy to treat, with typical influent concentrations of approximately 500 mg/L COD, 280 mg/L BOD, 70 mg/L total nitrogen, 40 mg/L ammonia nitrogen, 5 mg/L total phosphorus, and 100 mg/L suspended solids, and a pH of approximately 6.7, making its characteristics similar to those of ordinary municipal sewage. In summary, the wastewater streams have complex compositions, and with the exception of domestic sewage, all can be regarded as difficult-to-treat wastewater.

Cause Analysis

The treatment process and operating indicators of the wastewater treatment station were monitored and analyzed over a one-week period. The process flow is shown in Figure 1.



The biological hydraulic retention times were 72 hours in the anaerobic tank. The monitoring results are presented in Table 1. aerobic tanks, 24 hours in the anoxic tank, and 48 hours in the

Table 1: Influent and effluent wastewater quality during one-week monitoring.

No.	Sampling point	Date	COD	Total N	Ammonia N	Total P	pH
1	EQ tank	Jun-02	4300	721	648	45	8.11
2		Jun-03	3605	611	565	37	7.29
3		Jun-04	4682	856	711	58	6.93
4		Jun-05	3852	527	479	41	7.14
5		Jun-06	3459	501	463	42	6.32
6		Jun-07	3206	733	610	29	7.47
7		Jun-08	3739	480	412	35	7.52
8	Aerobic-tank influent	Jun-02	901	520	496	35	8.81
9		Jun-03	834	499	430	29	8.56
10		Jun-04	865	530	396	26	8.42
11		Jun-05	930	527	479	34	8.14
12		Jun-06	856	501	463	39	8.32
13		Jun-07	809	601	526	29	8.47
14		Jun-08	739	480	412	35	8.52
15	MBR	Jun-02	128	347	310	0.25	8.91
16		Jun-03	150	287	276	0.38	8.93
17		Jun-04	147	301	225	0.28	9.02
18		Jun-05	166	398	301	0.14	8.89
19		Jun-06	124	401	359	0.17	8.94
20		Jun-07	151	433	399	0.29	8.99
21		Jun-08	256	380	353	0.35	8.96

The data show that ammonia nitrogen was the main parameter exceeding the required limit, and this load had to be further treated by the downstream receiving wastewater treatment plant, thereby imposing an additional burden on subsequent treatment. In addition, the membrane effluent had a relatively high pH and elevated turbidity. Although the system removed approximately 200 mg/L of ammonia nitrogen, it was tentatively inferred that

part of the removal resulted from ammonia stripping and part from assimilation associated with COD removal. The average influent C/N ratio was approximately 6, indicating high-nitrogen wastewater, therefore, total nitrogen and ammonia nitrogen could not be removed sufficiently through assimilation alone. On-site observations also showed that the dissolved-air-flotation unit operated relatively steadily, while a distinct ammonia odor could be

detected from the top of the biological tanks, suggesting that free-ammonia toxicity was occurring in the biological treatment system.

Microscopic examination of the microbial community in on-site samples is shown in Figure 2.

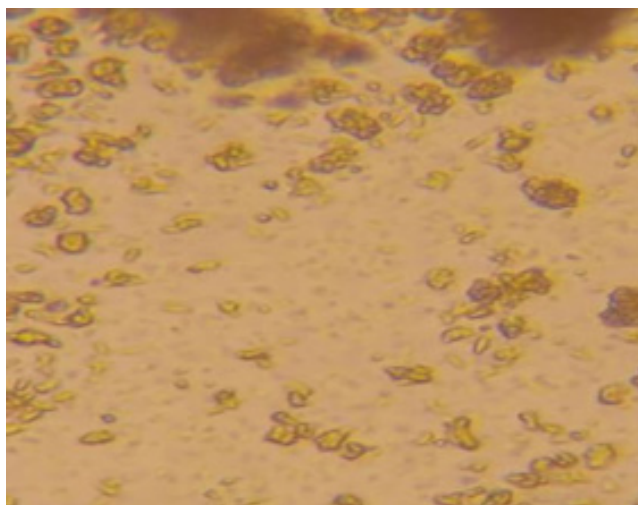


Figure 2: Process flow diagram of the kitchen-wastewater treatment system.

According to literature reports on the inhibition of nitrification by free ammonia, when the Free-Ammonia (FA) concentration reaches 13.4 mg/L, the Nitrite Accumulation Rate (NiAR) in the system gradually increases while the Nitrate Accumulation Rate (NaAR) gradually decreases, and when the NiAR/NaAR ratio exceeds 1, stable partial nitrification is achieved, at this FA concentration, FA inhibits the activity of both Ammonia-Oxidizing Bacteria (AOB) and Nitrite-Oxidizing Bacteria (NOB), but NOB are more sensitive to FA inhibition than AOB [8]. Quantitative studies of the effect of free ammonia on nitrification further indicate that FA is one of the key factors affecting biological nitrogen removal, and its concentration depends on $\text{NH}_4^+\text{-N}$ concentration, pH, and temperature [9]. It can therefore be concluded that free ammonia is an important factor affecting and inhibiting the nitrification process [10], and overcoming this inhibition is the key issue addressed in this project.

Preliminary Testing

To identify a feasible solution, laboratory-scale exploratory tests were first conducted, with the aim that a successful method would later be scaled up for on-site application to provide technical support for project implementation. The experimental equipment and consumables included one 10-L plastic bucket, an aquarium aeration pump, a PHSJ-3F laboratory pH meter manufactured by Shanghai INESA (Rex brand), and consumables such as concentrated sulfuric acid, soda ash, engineered nitrifying bacterial inoculum, and wastewater samples from the aeration tank. In the experimental method, approximately 10 L of aeration-tank wastewater was collected and placed in the plastic bucket, and diluted sulfuric acid (1+10) was added to adjust the pH to approximately 7.8, after which engineered nitrifying bacteria were added for inoculation and

cultivation to allow simultaneous carbon removal and nitrification for ammonia-nitrogen reduction, since pH decreases during nitrification, soda ash was added as needed to readjust the pH and maintain favorable conditions, as nitrifying bacterial communities are strongly affected by pH, ammonium concentration, and oxygen availability [11]. In the bench-scale results, two parallel experimental runs were conducted, but after the pH had been adjusted to 7.8, it gradually increased to approximately 8.5 after about 4 hours of aeration, with the same trend observed in both the parallel test and the control, and an ammonia odor could still be detected above the water surface, indicating that the experimental approach was not feasible, after approximately 3 days of aeration, COD remained similar to the on-site level, while ammonia nitrogen was slightly higher and pH was slightly lower, at approximately 8.7. The possible reasons for the failure of the bench-scale test were analyzed as follows: first, the wastewater had high alkalinity and therefore required a large amount of acid, but the acid dose used in the test was insufficient, so as organic acids were consumed, the pH increased again and the inhibitory condition reappeared, second, the salinity of the wastewater was high, making it difficult for non-acclimated engineered nitrifying bacteria to adapt to the system [12], and third, acid addition lowered the pH and was unfavorable for ammonia stripping, which is why the effluent ammonia-nitrogen concentration was higher than that observed on site.

Measures Proposed After the Initial Test

In response to the failure of the initial bench-scale test, the next step was to use wastewater streams discharged directly from the workshop to the wastewater treatment station, rather than wastewater from the aeration tank, and to blend them according to their respective flow rates. This would allow better pH control,

reduce free-ammonia toxicity, and create favorable conditions for nitrification. Once nitrification was initiated, complete mixing with a high recycle ratio would be used to avoid localized ammonia toxicity. Further experiments were therefore arranged for the next stage.

Further Experiments and On-site Commissioning

Further Experimental Plan

The system was started in a controlled manner, with full consideration given to the characteristics of each wastewater stream. Digestate and biological wastewater were first mixed at an appropriate ratio, and engineered nitrifying bacteria supplied by Qingtai were added to shorten the start-up period [13]. Depending on the pH and C/N ratio, alkaline wastewater from exhaust-gas deodorization was added as needed to compensate for the alkalinity consumed during nitrification, thereby preventing an excessive pH

decrease. After nitrification was established, biodiesel wastewater was introduced at an appropriate ratio. Under anaerobic and anoxic conditions, nitrite and nitrate were denitrified to nitrogen gas, while the COD introduced with the biodiesel wastewater was concurrently degraded. The key to this strategy was to facilitate pH control and avoid free-ammonia toxicity.

Further Experimental Setup

The experimental equipment and materials were the same as those used in the preliminary test, with the addition of a stirred vessel to simulate anaerobic or anoxic conditions. Several liters of each wastewater stream were collected directly from the workshop, including digestate, biodiesel-workshop wastewater, alkaline wastewater discharged from exhaust-gas scrubbing, and sewage from the domestic-sewage collection tank. The corresponding analytical results are presented in Table 2.

Table 2: Wastewater characteristics used in the further experimental plan.

No.	Wastewater sample	COD (mg/L)	pH	Ammonia N (mg/L)	Total N (mg/L)
1	Digestate	2356	8.21	1359	1578
2	Domestic sewage	527	7.14	39	72
3	Biodiesel-workshop wastewater	40036	7.53	28	49
4	Alkaline wastewater from exhaust-gas scrubbing	1469	11.64	869	950

Record of the Further Experiments

Two rounds of experiments were conducted. In each round, 1.5 L of digestate and 1.5 L of domestic sewage were first mixed. The pH values of the two mixtures were 7.72 and 7.85, and their ammonia-nitrogen concentrations were 689 and 705mg/L, respectively. Engineered nitrifying bacteria, supplied by Yixing Qingtai Purification Agent Co., Ltd., were added at a concentration of 200 mg/L. After 3.5 days of continuous aeration, alkaline wastewater was added dropwise to maintain the pH within the range of 7.5–

7.9. Under these conditions, ammonia nitrogen decreased to 53 and 61mg/L in the two tests, respectively. Subsequently, biodiesel wastewater was added at approximately one-tenth of the mixture volume, and a stirred vessel was used to simulate an anaerobic denitrification reactor. Biodiesel-derived wastewater can provide readily available organic carbon for heterotrophic denitrification [14]. After 2 days under anaerobic conditions, the effluent contained approximately 862 mg/L COD, 15mg/L ammonia nitrogen, and 28 mg/L total nitrogen, demonstrating a favorable treatment effect.

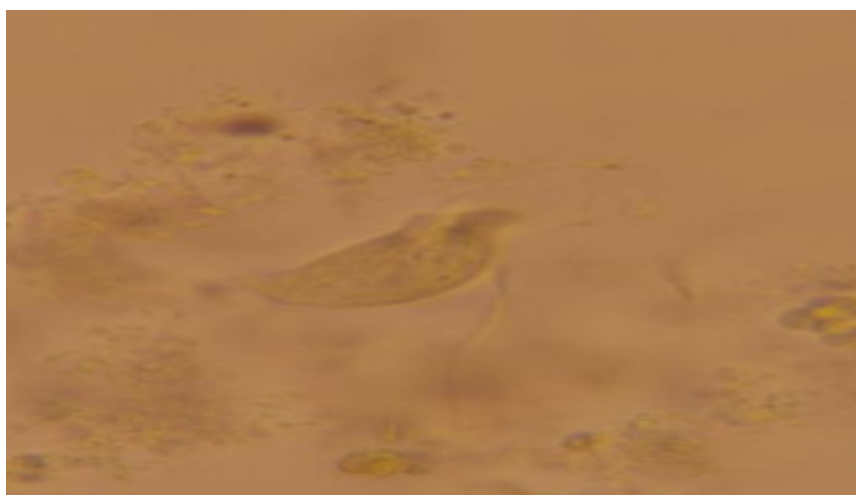


Figure 3: Microscopic observation of the microbial community under stable operating conditions.

On-site Commissioning Test

Following on-site discussion and analysis, the commissioning and operating procedure was established as follows: First, adjust the pH of the on-site aeration tank. Although this step requires substantial acid consumption initially, it is necessary to initiate the system and break the existing inhibitory cycle. Temporarily control the shock discharge of exhaust-gas scrubbing wastewater by rotating the discharge from the dozens of absorption towers, thereby reducing instantaneous hydraulic and pollutant loads. Maintain continuous high-rate aeration in the aeration tank and temporarily stop the recycle flow to the anaerobic zone, as nitrate recirculation has little value before nitrification is established. Once the pH has been adjusted and no longer rises, add engineered nitrifying bacterial inoculum to the aeration tank at a concentration of 200 mg/L. Bioaugmentation with nitrifying bacteria has been shown to improve nitrification performance during full-scale wastewater treatment system upgrades [15]. After three days of continuous aeration, stop acid addition to the aeration tank. If the

pH begins to drop below 7.0, this indicates that nitrification has been successfully initiated. At this stage, appropriately supplement the aeration tank with alkaline wastewater recovered from exhaust-gas scrubbing to regulate alkalinity. Simultaneously, gradually begin recycling from the end of the aeration tank to the anaerobic tank. Increase the proportion of biodiesel wastewater progressively to provide sufficient carbon for denitrification, thereby promoting the removal of total nitrogen and COD. As loading conditions stabilize and the functional microbial community recovers, treatment performance improves. The digestate influent can then be increased appropriately to enhance the overall treatment capacity of the system. After approximately 14 days of biological commissioning, all monitored indicators met the discharge requirements. The experimental and commissioning activities were thereby completed, and the treatment capacity of the wastewater system was successfully restored. The discharge indicators are presented in Table 3, and the microbial community observed under stable operating conditions is shown in Figure 3.

Table 3: Effluent quality during on-site commissioning.

No.	Date	COD (mg/L)	pH	Ammonia N (mg/L)	Total N (mg/L)
1	Jul-15	169	7.58	5.8	14.3
2	Jul-20	156	7.32	4.9	14.8
3	Aug-01	124	7.27	3.6	13.4
4	Aug-10	115	7.25	0.5	10.5

Conclusions

In this study, a control strategy was established to address the rate-limiting effect of free ammonia on ammonia-nitrogen removal from kitchen wastewater. The respective roles of nitrification and denitrification were clarified. The recommended optimum pH range for nitrification is 7.5–7.8. When multiple complex wastewater streams are present, the interrelationships among them should be clearly understood in order to avoid adverse interactions and to beneficially utilize the characteristics of each stream to support stable compliance. The use of a suitable bacterial inoculum can facilitate rapid system start-up. Given that acclimation may require an extended period, engineered bacterial cultures can provide crucial support for successful project operation. Overall, this project was successfully implemented from laboratory testing through to full-scale operation and can serve as a useful reference for similar projects. For high-strength wastewater of a comparable nature, proper control of treatment sequence and dosage can prevent treatment indicators from exceeding limits or becoming unmanageable.

Acknowledgments

None.

Conflicts of interest

None.

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