Intermittent Ozonation of Swine Waste Lagoon

Junyu Pan

ASABE Member Number: 1060013

North Carolina State University, Raleigh, NC

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Advisor: Sanjay B. Shah

Department of Biological and Agricultural Engineering

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Introduction

The USDA National Agricultural Statistics Service (2023) reported that North Carolina had 8.0 million hogs and pigs. North Carolina ranks third in the US (NASS, 2023). The two major contributors to animal cash receipts were broilers at 43.5%, and hogs at 28.9%. The US is the second biggest swine producer in the world (NASS, 2023).

The huge commercial pig production has led to a problem – swine waste disposal. Swine waste is the mixture of feces and wastewater. In North Carolina, swine wastewater from pig houses is directly sent to large, open anaerobic lagoons for storage and treatment prior to further application on cropland (Vanotti et al., 2018). Due to the rapid growth of swine farms in the nineties, there were many complaints from neighbors of swine farms about odor. Swine lagoons emit ammonia and odor and degrade water quality (Vanotti et al., 2018). Hence North Carolina evaluated several experimental waste management technologies called environmental superior technologies (ESTs) to see if they could be used on NC swine farms. The EST had to meet five standards: (1) Prevent animal waste from directly getting into the surface and ground water; (2) Prevent ammonia entering the atmosphere; (3) Greatly reducing the odor came from the swine farm; (4) Prevent release of the disease vector and pathogens; (5) Prevent nutrient and heavy metal contamination of underground water (Williams, 2009)

However, the EST have not been widely adopted by farmers. According to the Annual Report to the Environmental Review Commission of the North Carolina General Assembly on the Implementation of the Lagoon Conversion Program in 2010, only two farms that accounted for about 3.1% of the state's hog market improved their waste management system by using the EST. Other farms still use swine waste lagoon to process pig waste. According to NASA, there are 3405 swine waste lagoons in North Carolina (NASA, 2022).

Anaerobic lagoons are extensively utilized for both storage and treatment of diverse waste streams, such as industrial and municipal wastewater, as well as animal manure in livestock farming (Owusu-Twum & Sharara, 2020). The treatment process of anaerobic lagoons depends on a combination of anaerobic, facultative, and aerobic bacteria that work together to decompose organic matter into various gaseous forms such as CO2, nitrogen (N_2), NH_3, hydrogen sulfide (H_2S), CH_4, and volatile organic compounds (VOCs), as well as cellular biomass and residual sludge (Owusu-Twum & Sharara, 2020).

Figure 1 shows that an anaerobic lagoon comprises three distinct layers: the temporary liquid storage zone, the permanent liquid treatment zone, and the accumulated sludge zone. The temporary liquid storage zone contains a large surface area that is in contact with air, promoting strong oxidation. This area is crucial because it facilitates the conversion of CH_e, H_2S, NH_3, and VOCs into CO_2, H_2O, N_2, N_2O, and SO_2. In the permanent liquid treatment zone, anaerobic fermentation occurs. Finally, the accumulated sludge zone serves as a storage area for sludge.

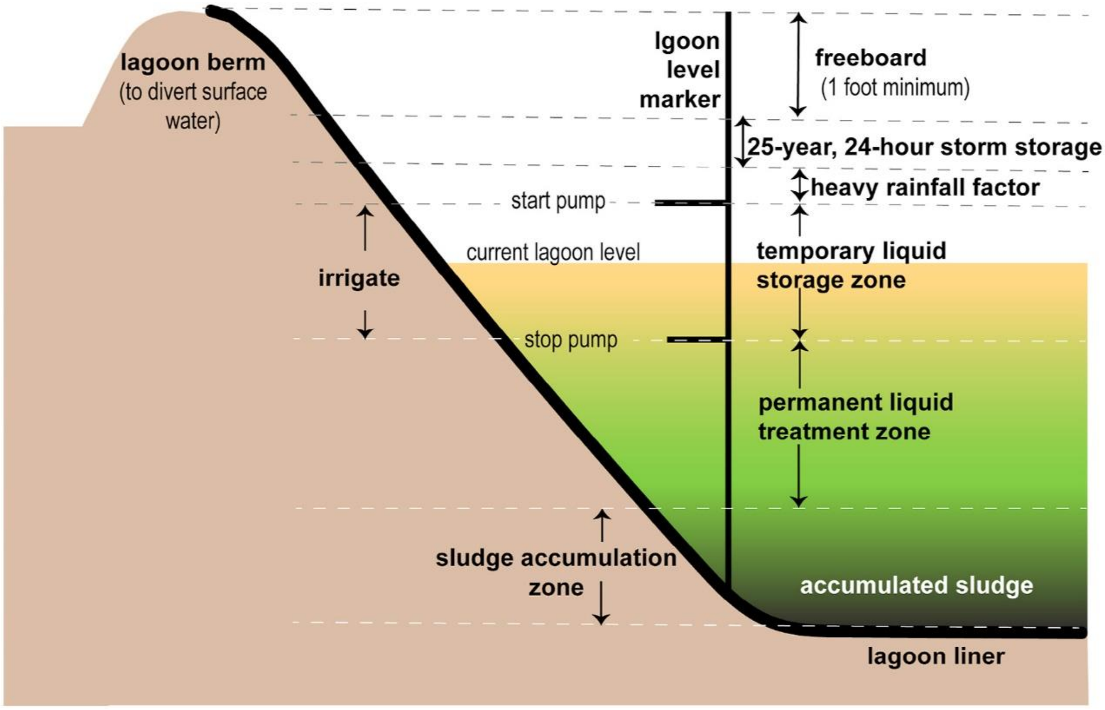

Figure 1. Anaerobic Lagoon Separated Layers (Owusu-Twum & Sharara, 2020)

The sludge in anaerobic lagoons is composed of finely digested solids, mineral salts that have precipitated, enzymes, detritus, and extracellular polymeric substances (EPS). This layer of sludge forms gradually through the sedimentation of digested solid particles caused by gravity. As microbial activity breaks down the manure solids, the particle size distribution decreases significantly (Owusu-Twum & Sharara, 2020).The buildup of sludge is usually more significant in the vicinity of the inlet and gradually decreases towards the outlet in anaerobic lagoons. This increase in sludge concentration at the inlet results from a shift in velocity as the influent passes from the inlet pipe to the lagoon, causing a decline in kinetic energy (Owusu-Twum & Sharara, 2020). The accumulation of excessive sludge in a swine waste lagoon can lead to a loss of its sludge processing capacity. This, in turn, can result in increased production of greenhouse gases and unpleasant odors (Owusu-Twum & Sharara, 2020).

Hamilton (2010) revealed that the rate of sludge accumulation in anaerobic lagoons differs based on the age of the lagoon. In the initial stages of lagoon start-up, there is a temporary surge in the rate of sludge accumulation, which is then followed by a slower rate. However, as the volume of sludge grows and surpasses the designed treatment volume, the rate of sludge accumulation picks up again (Owusu-Twum & Sharara, 2020).

For the most recent data from Chastain (2006), the average sludge accumulation rate was about 1.3×1^{-3} m^3 when 0.7×10^{-3} to 2.3×10^{-3} kilograms of total solid entered the system. To maintain appropriate lagoon treatment and minimize the rate of sludge accumulation, it is crucial to monitor the sludge volume consistently. This can be achieved by determining the depth of the sludge layer (Owusu-Twum & Sharara, 2020).

Regulations impose farmers to clean and remove the sludge when the sludge reaches a depth of 6 ft in an anaerobic lagoon (NRCS,1992). Hence, the farmers need to pay for removal and disposal of the sludge. Managing sludge is a challenging task, and one of the main difficulties is the cost involved in removing it. This is especially true for large lagoons that have accumulated sludge over many years, where the cost of dredging can be very high. Based on estimates, the cost of sludge removal can range between $0.005 and $0.05 per gallon. In the United States, specifically in North Carolina, the estimated cost of removing sludge from 30 inactive lagoons was calculated at rates of $0.01, $0.035, and $0.05 per gallon, resulting in total sludge removal costs of $8,330, $29,150, and $42,650, respectively (Owusu-Twum & Sharara, 2020).

Ozone can help create a better oxidation situation in the environment, on the other hand it means that odor and sludge will be degraded quickly. The utilization of ozone treatment is a widely recognized method for dissolving biological sludge. Ozone, being a highly potent oxidizing agent, can effectively disinfect water. Ozone will break the unsaturated bonds between big molecules of the intricate composition of the sludge. Additionally, ozone produces radicals that can oxidize other organic materials while decomposing. Ozone has a significant potential in treating sludge, with only 5% of sludge being resistant to ozonation, as reported by (Bougrier et al., 2007). Ozone treatment can also modify the physical and chemical characteristics of sludge, resulting in decreased flocculent size, broken membranes that release particulate matter, and solubilization inside the sludge (Bougrier et al., 2007). Hence, ozone treatment can reduce sludge in wastewater.

In addition, ozone treatment can also help solve the odor problems of swine waste lagoons. Odors created by the swine farm are generated by ammonia (NH_3), carbon dioxide (CO_2), methane (CH_4), and sulfur compounds (Febrisiantosa et al., 2020). These compounds are produced by the anaerobic fermentation. One solution for solving the odor problem is to transfer anaerobic fermentation into aerobic fermentation or oxidation. With the oxidation or aerobic fermentation, CH_4 and NH_3 will be transformed into CO_2 and NO_2. This will greatly help solve the odor problem. According to t Wu et al. (1999), using ozone to treat the manure slurry can greatly reduce the odor of the swine wastewater.

The objective of this project is to design and evaluate the potential of e an automatic ozonation system with intermittent ozonation to treat swine waste lagoons.

Principles of ozonation

Ozone

Ozone is a potent disinfectant and oxidant that can have a severe impact on bacteria. It has the ability to penetrate the cell wall, impair the cell membrane of microorganisms, and break down the zoogloeal structures.
Sludge is actually made of two parts: 1. Soluble matter, 2. Particulate matter. When ozone reacts with the sludge, the soluble matter will oxide into gas such as CO^2, H^2O, NH^3; particulate matter will degrade into smaller particles, and finally they will turn into gas like the soluble matter. The whole process is mentioned below in Figure 2.

Consequently, the solid organic elements of sludge are converted into soluble substances that can be further biologically decomposed when the ozonated sludge is reintroduced into the wastewater treatment process. This means that the sludge ozonation technology can effectively decrease the generation of surplus sludge (Zhang et al., 2009).

According to Foladori et al. (2010), the appropriate ozone dosage for the sludge ozonation-cryptic growth technology ranges from 0.03 to 0.05 gO^3/g total solid suspended produced. This dosage strikes a balance between the effectiveness of sludge reduction and the associated costs.

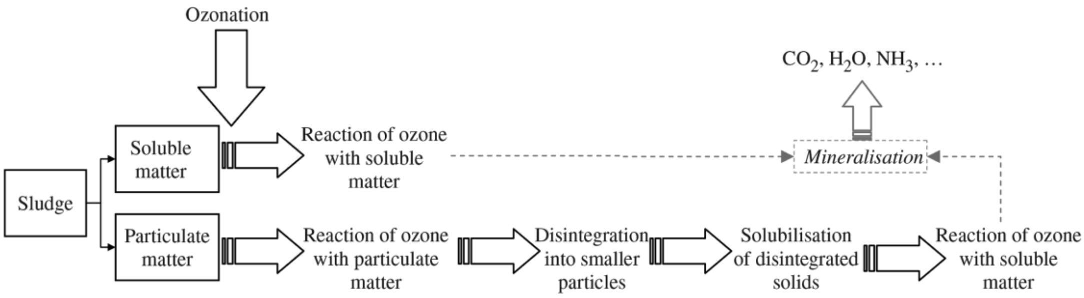

Figure 2. The process of the sludge ozonating (Zhang et al., 2009).

Literature Review

Aeration

Aeration treatment is a highly effective method for processing swine wastewater. This process involves exposing the wastewater to air in a sequencing batch reactor (SBR), which is a fill-and-draw activated sludge system designed for efficient and comprehensive wastewater treatment. By introducing oxygen into the SBR, the aeration process promotes the growth of beneficial bacteria (Kim et al., 2004). In the SBR, there is an air pump and a mixing propeller. The air pump will insert air into the system and the mix propeller will mix both sludge and wastewater. Despite its effectiveness, it's important to note that the SBR system used for aeration treatment operates intermittently, with both anaerobic and aerobic processes working together. During the aerobic phase, ammonia (NH_3) is oxidized into nitrate or nitrite, while in the anaerobic phase, these nitrates or nitrites are converted into molecular nitrogen. This cycle of alternating anaerobic and aerobic processes ensures comprehensive removal of harmful pollutants from the swine wastewater (Nagarajan et al., 2019).

Aeration seems like a reasonable solution and has bright future. However, the energy cost for the whole system is very high, so it seems that farmers cannot afford the cost of the aeration (Yang et al., 2016).

Electrical

To remove impurities in certain effluent, electrocoagulation (EC) is a technique that involves the production of hydroxides by applying an electric current to electrodes made of aluminum, iron, or both (Mores et al., 2016). EC can also be used to remove the phosphorous and turbidity (Mores et al., 2016).

In general, EC solution is too limited and expensive. It is impossible for famers just want to remove phosphorus and turbidity to pay the money to buy them.

Membrane

Anaerobic filter (AF) is a kind of system exactly like anaerobic lagoon, but it has a biological membrane. Organic pollutants become trapped on the surface of filter media such as stone or plastic and are subsequently eliminated by microorganisms that are attached to the filter (Aziz et al., 2019).

While this reactor is well-suited for treating soluble wastewater, its performance can be significantly impeded by clogging of the filtration media. Additionally, the presence of oil can further decrease the performance of the reactor. To maintain optimal performance, farmers must frequently clean the membrane, which can be inconvenient and time-consuming (Aziz et al., 2019).

Materials and Methods

Ozonation Experiment

To gain a deeper understanding of the impact of ozone on swine wastewater, a 44-d lab study was conducted. The study involved collecting swine waste lagoon water and placing them into eight reactors made of PVC pipes. Each reactor was 1.2 in height and 10 cm in diameter. The tubes were filled with 1.1 m of swine wastewater, resulting in a total volume of 10.6 L per reactor. There are four treatments: (1) LOZ (low ozonation): Ozonation was applied at 12 mg/reactor per event, four times a day to provide 0.03 g of total volatile suspended solids (TVSS) over a 1.5-month period (2) HOZ (low ozonation): Ozonation was applied at 20 mg/reactor per event, four times a day to provide 0.05 g of total volatile suspended solids (TVSS) over a 1.5-month period (3) AER (aeration): Aeration was applied at 1 mg/mg of biochemical oxygen demand (BOD) per day, for 1 min with a vacuum pump that moved 0.29 L/min (4)

CON (control): No treatment was provided to this treatment. There were two replicates per treatment. As part of the research, several parameters were measured, including turbidity, oxidation-reduction potential (ORP), dissolved oxygen (DO), nitrous oxide (N2O), carbon dioxide (CO2), and methane (CH4). All these measurements are measured for at least 20 minutes for each tube. Whereas ORP and DO were measured with a DRP-DO probe, concentrations of all four gases were measured in the headspace of all the reactors with a photoacoustic sensor (PAS 1402). Wastewater chemical properties were also measured at the end of the study to compare treatment effects.

At the conclusion of the experiment, three layers of swine wastewater were sent to the NCSU WEAVER LAB, Environmental Analysis Laboratory for water quality testing. The laboratory conducted measurements for Total Kjeldahl nitrogen (TKN), which is the sum of ammonia nitrogen and organic nitrogenous compounds, Ammonia Nitrogen (NH3N), Nitrate Nitrogen (NO3N), Total Solids (TS), Volatile Suspended Solids (VS), and Five-Day Biochemical Oxygen Demand (BOD5), which represents the total amount of oxygen used by microorganisms to decompose organic matter over a five-day period. The three layers of swine wastewater included the top layer, the middle layer, and the bottom layer.

Results and Discussion

Turbidity of the supernatant from the various treatments were compared at the end of the 44-d experiment. The date of the turbidity measurement is 1/4/2023.

Table 1. Comparison of turbidity of the different treatments at the end of the study

Substance	Turbidity (NTU)
Water	19.7
LOZ1	21.8
LOZ2	22.3
HOZ1	33.8
HOZ2	59.8
AER1	81.3
AER2	95.8
CON	138.1

Turbidity is the degree of cloudiness or haziness of a liquid caused by the existence of suspended particles such as microorganisms, sediment, or other substances. This parameter measures the extent to which the water loses its clarity due to the presence of such particles and is quantified using nephelometric turbidity units (NTU), which gauge the amount of light scattered by the particles in the water sample. When the levels of turbidity are high, it suggests poor water quality and can pose a challenge for the survival of aquatic plants and animals. Additionally, it can influence the taste and smell of drinking water. For this reason, monitoring and testing for turbidity is an essential aspect of water quality management.

Turbidty The turbidity results indicate that the LOZ and HOZ groups had lower turbidity values compared to the AER and CON groups. This suggests that treating swine wastewater with ozone results in clearer water than the untreated groups, as indicated by the lower turbidity values in the ozone-treated groups.

For the gas measurement part, the most important element is the methane. The methane figure is shown below.

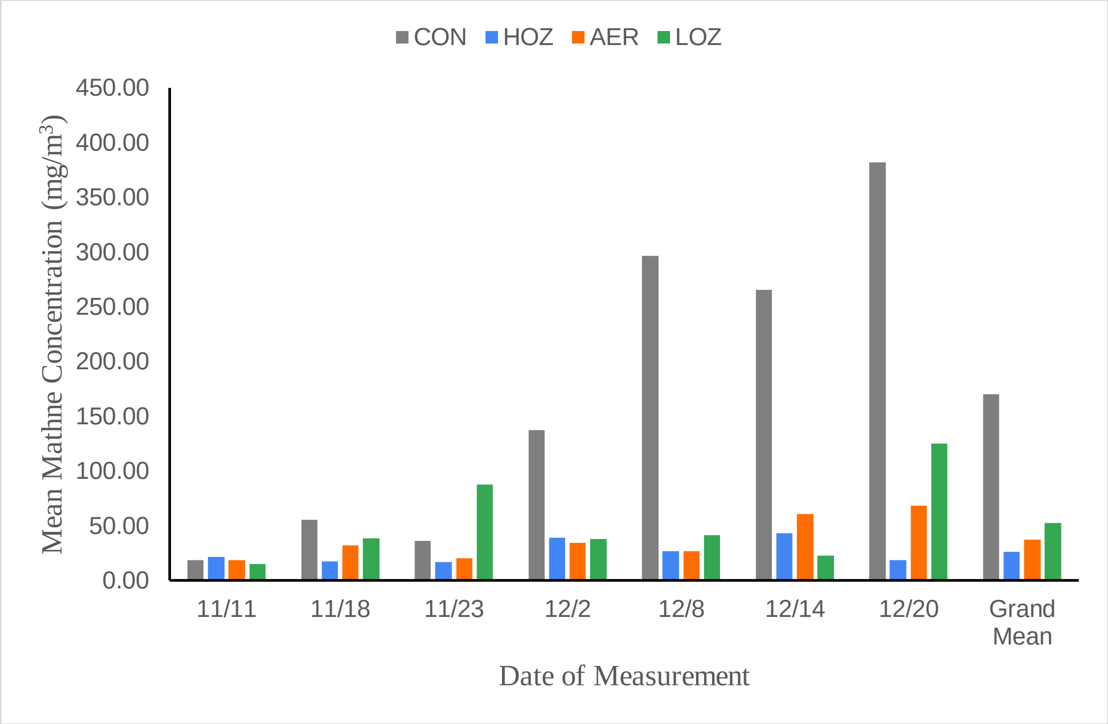

Figure 3 Mean Methane Concentration Level Graph

According to Figure 3, the concentration of CH_4 in the control group increased steadily throughout the experiment, while the other three groups showed much lower CH4 concentration. Notably, the HOZ group demonstrated a decrease in CH_4 concentration over time. These findings suggest that exposure to ozone can significantly decrease CH_4 production, particularly in comparison to the other experimental groups. On November 11th, four groups exhibited similar methane concentrations at the start of the experiment. By December 2nd, which marked the halfway point, the methane concentrations of the CON groups began to rise, while the other groups did not experience an increase. Between December 8th and December 20th, the methane concentration remained consistently high in the CON group, while the HOZ, AER, and LOZ groups maintained low production levels. At the conclusion of the experiment on December 20th, the ozone treatment had reduced methane production by 93.2% when compared to the HOZ group. On the other hand, it improves the oxidizing conditions, and it helps reduce the methane formation. Table 2 shows ORP&DO results.

Table 2. ORP&DO Measurement Results Graph

	HOZ1		**HOZ2**		**AER1**		**AER2**	
Date	**ORP(mV)**	**DO(mg/L)**	**ORP**	**DO**	**ORP**	**DO**	**ORP**	**DO**
11/8								
11/15		0.16		1.85		0.15		0.12
11/17		0.26		2.85		0.17		0.14
11/22	-246.7	0.11	-169.4	0.07	-256.2	0.06	-312.7	0.05
11/29	-317.7	0.05	-55.1	0.49	-251.1	0.09	-336.7	0.05
12/6	12.1	0.12	14.9	0.07	-202.7	0.05	-294.3	0.03
12/14	150	1.46	112.6	0.13	-63.8	0.15	-213.6	0.04
12/20	-16.7	0.16	42.3	0.06	-75.7	0.08	-305	0.05
	CON1		**CON2**		**LOZ1**		**LOZ2**	
Date	**ORP**	**DO**	**ORP**	**DO**	**ORP**	**DO**	**ORP**	**DO**
11/8		0.17		0.13				
11/15		0.17		0.12		0.15		0.1
11/17		0.15		0.11		0.14		0.07
11/22	-335.7	0.22	-283.5	0.08	-219.9	0.07	-242.7	0.05
11/29	-350.6	0.05	-296.7	0.07	-244.9	0.05	-204.5	0.03
12/6	-347.8	0.06	-235.4	0.06	-55.2	0.08	-57.4	0.05
12/14	-326.5	0.12	-219	0.05	84.9	4.17	146.7	4.69
12/20	-334.4	0.21	-283.6	0.05	-30.2	0.54	-42.4	0.1

Analysis of table 2, which compares the HOZ and LOZ groups with the AER and CON groups, indicates that the ozone-treated groups exhibited positive and less negative oxidation reduction potential (ORP) values than the groups that were not treated with ozone. This suggests that the ozone treatment created a more oxidizing environment, which can break down sludge and reduce odor. Specifically, the lower positive and negative values observed in the ozone-treated groups suggest that the ozone treatment was effective in reducing odors and promoting the breakdown of sludge.

Meanwhile the professional lab test was done on the liquid during the experiment at the end of the study.

Table 3. Lab Test of the Swine Wastewater of Each Treatment

Submission Date	Sample ID	TKN	NH3N	NO3N	TS	VS	BOD5
2023/1/4	LOZ1_END_l	18.70	8.94	85.5	0.15	25.96	35.65
	LOZ1_END_s	2368.42	387	2.76	7.28	45.36	885.05
	LOZ1_END_f				0.96	55.95	1055.55
	LOZ2_END_l	21.90	9.9	80.6	0.14	27.04	221.65
	LOZ2_END_s	2465.75	395	2.36	6.90	45.51	919.15
	LOZ2_END_f				0.90	57.65	1133.05
	HOZ1_END_l	11.31	0.329	98.3	0.16	36.81	449.50
	HOZ1_END_s	2622.22	378	2.37	6.96	46.28	1088.10
	HOZ1_END_f				0.33	53.61	886.60
	HOZ2_END_l	15.90	0.272	94.1	0.17	35.59	485.15
	HOZ2_END_s	1858.79	317	3.28	5.16	46.28	1119.10
	HOZ2_END_f				0.49	53.09	759.50
	AER1_END_l	125.4	81.3	5.79	0.15	34.67	137.95
	AER1_END_s	2254.902	385	0.355	6.71	45.25	912.95
	AER1_END_f				0.27	37.50	444.85
	AER2_END_l	157.5	103	1.05	0.19	35.79	235.60
	AER2_END_s	2274.882	329	0.926	6.21	45.80	1023.00
	AER2_END_f				1.09	48.53	1139.25
	CON1_END_l	175.5	96.8	0.872	0.21	35.24	86.80
	CON1_END_s(dil)				3.73	46.73	761.05
	CON2_END_All	739.5288	198	0.555	2.27	47.44	756.40

In the result table, the labels "l," "s," and "f" refer to the different layers of liquid in the PVC tube, with "l" indicating the upper layer. Upon comparison, the results show that ozone treatment resulted in lower NH3N (ammonia-N) levels and higher NO3N (nitrate-N) levels in the upper layer liquid (sample ending with "l") compared to the other treatments. These findings suggest that ozone treatment created a more oxidizing environment in the upper layer, leading to increased nitrate-N levels and decreased ammonia-N levels. In general, it will reduce the ammonia production and ammonia production is considered as one of major atmosphere pollutant.

Conclusions & Future Work

In the study of ozone's impact on swine sludge and odor, ozone reduced turbidity. Intermittent ozone and aeration treatments likely caused oxidizing conditions, which reduced methane emissions. Furthermore, it decreased the concentration of ammonia in the liquid, which is a pollutant and odorant. Moving forward, and ozonator will be assembled and tested.

For the future’s work, the ozone system will be designed into an automatic robot that can use intermittent ozone to treat the swine waste lagoon. For the body of the robot was a commercially available RC boat powered by an 11.1 V battery. The ozone generator will be ozone production system from the Ivation Portable Ozone Generator and the ozone production rate is 600 mg/h.

There are two key components of the robot: one is the navigation system and the other is the controlling system. For the navigation system, ultra-wide band (UWB) location module MDEK1001 will be used. With the MDEK1001, developers can easily create and test indoor and outdoor location-based applications, such as asset tracking, wayfinding, and geofencing, with high precision and low power consumption. Five MDEK1001 modules will be utilized, with four of them acting as anchors and one serving as the tag on the robot. The tag will be connected to the controlling system on the boat and four anchors will be placed on the four corners of a rectangular section of the swine lagoon that covers the area where the waste from the swine houses is released into the lagoon. The four anchors will continuously measure the position of the tag at one-second1-s intervals and transmit this information to the tag. The tag will then relay this information to the control system, which will analyze the data and determine the appropriate course of action for the robot to take. With this setup, the system can accurately and continuously track the location of the robot, allowing for efficient and precise navigation.

The control system will utilize a Raspberry Pi 3B+ to manage various components. It will control the on/off functionality of the ozonation system, navigation system, and power system.

Moving forward, efforts will continue to automate the process, and the final assembly will be completed.

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