Optimization of Volatile Fatty Acids Production Through Anaerobic Digestion for the Valorisation of Chicken Manure

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Abstract:
The short-chain, volatile nature of volatile fatty acids (VFAs) distinguishes them as organic molecules. They are essential in organic chemistry, environmental science, microbiology, and many other natural processes. Here are some key details regarding VFAs: they are organic acids that typically have a carbon backbone with functional groups called carboxyls (COOH). The three most prevalent VFAs are butyric acid (C4), acetic acid (C2), and propionic acid (C3). VFAs are produced when organic matter, especially complex chemical compounds and carbohydrates, is fermented by microorganisms.

1.1 Introduction
The human digestive tract, soil, and anaerobic digestion systems are just a few of the environments where this fermentation process takes place. The applications for volatile fatty acids (VFAs) are numerous; they serve as a source of energy in animal feed, as food additives, and in the manufacturing of biodegradable polymers. According to environmental scientists, VFAs are crucial for anaerobic digestion, which converts organic waste into biogas.
An extensive amount of research was conducted, including a review of relevant literature, an examination of internet resources, and a variety of data sources. The study investigated anaerobic digestion processes, material properties, and chemical characteristics, as well as various conversion techniques for chicken manure and the biodigester system. The project's objectives were supported by the gathered parameters and materials, such as chicken manure, necessary components for the biogas system, and instruments for modifying the drum. Drum assembly, sample preparation, and chicken manure experiments were all carried out methodically. The pre- and post-digestion physicochemical characteristics of chicken dung were examined, along with variations in volatile fatty acid content and biogas production. The study included the characterization of sludge digestate and macronutrients, a thorough analysis of VFA profiles, the determination of optimal conditions, and the creation of a predictive quadratic model for VFA optimization. The model demonstrated strong predictive power and accuracy.

1.2 Objective

Optimizing the volatile fatty acids from anaerobic digestion for the value-adding of chicken manure was the primary objective of this study. Other subsidiary aims were:

- To increase the production rate of biogas and volatile fatty acids using appropriate environmental conditions.
- To utilize chicken manure for the volatile fatty acid.

1.2.1 Work Nature

I embarked on an extensive research journey to investigate the conversion of chicken manure into volatile fatty acids (VFAs) through anaerobic digestion. For this project, I meticulously gathered materials and parameters, including chicken manure, 200-liter drums designated for anaerobic digestion, a comprehensive biogas digester system, and a variety of reagents such as acetic acid and lactic acid. Within the experimental framework, I conducted two sets of experiments, systematically altering key variables like pH, temperature, and loading rate to enhance biogas and VFA production. Throughout these experiments, I engaged in constructing the biogas digester using PVC pipes and metal sheets, diligently prepared chicken manure samples for digestion, and carefully observed and analyzed the results.

1.3 Literature Review

Before commencing a venture, I did extensive research regarding the endeavor of converting chicken manure into volatile fatty acids through anaerobic digestion through different pieces of literature such as books, the internet, journal papers, researched articles, etc. I investigated the general knowledge about the procedures of anaerobic digestion. I also studied the characteristics of fatty acids and their applications in different fields. Similarly, I gained knowledge of different chemicals and reagents that were necessary for the proposed project. I also learned the properties of sludge digestate and the influence of time of retention, pH, and rate of loading, temperature, moisture, and micronutrients on fatty acids. I also browsed the different methods for the conversion of chicken manure into volatile fatty acids through previous papers. For the effective running of the venture, I studied the biodigester system.

1.4 Methodology

I collected the essential parameters and materials to enhance the production of gas and volatile fatty acids. Initially, I obtained chicken manure from the SLJ poultry farm. I also selected and installed 200-liter drums at ITCH in Lipa City, Batangas, for anaerobic digestion. For the biogas digester system, I allocated a biogas desulfator, burner, gas and water separator, and storage drums. To cut the drum appropriately, I chose an angle grinder and a power drill. As reagents, I selected acetic acid, propanoic acid, lactic acid, phosphoric acid, dimethyl carbonate, and their respective masses. I decided to conduct two sets of experiments, using 40 kg of chicken manure for the first test and 45 kg for the second. For these, I prepared 100 liters of water in a properly sealed storage drum. I set the trial period to 7–12 days to produce effective biogas and VFAs, with pH levels of five, seven, and nine at a loading rate of one. Additionally, I selected a temperature range of 35 to 40 degrees Celsius for optimal anaerobic digestion.

1.4.1

After that, I began conducting an experiment using the available parameters and materials. To do this, I used an angle grinder and a power drill to cut off the side and top cover of the drum according to the provided specifications, which served as the biogas digester. I fastened a 3-inch diameter PVC female threaded adaptor (FTA) to the side hole of the drum, connecting it to the end of a male threaded adaptor

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(MTA). I used an epoxy A and B combination to seal the joint. I then connected the other pipe sections inside the biogas digester, ensuring they were tightly bonded with PVC solvent cement. I aligned and cut two metal sheets according to the diagram, bored eighteen screw holes in them, and positioned them above the biogas digester. I gathered broiler chicken excrement from SLJ poultry farms, keeping 40 kg for the first experiment and 45 kg for the second to prepare the samples. After acclimating the samples for 5 days at 37°C in open storage to remove dirt and impurities, I ensured they were clean and stable for use in the biodigester. Finally, I observed the results and analyzed the optimization of volatile fatty acid production through anaerobic digestion for the valorization of chicken manure.

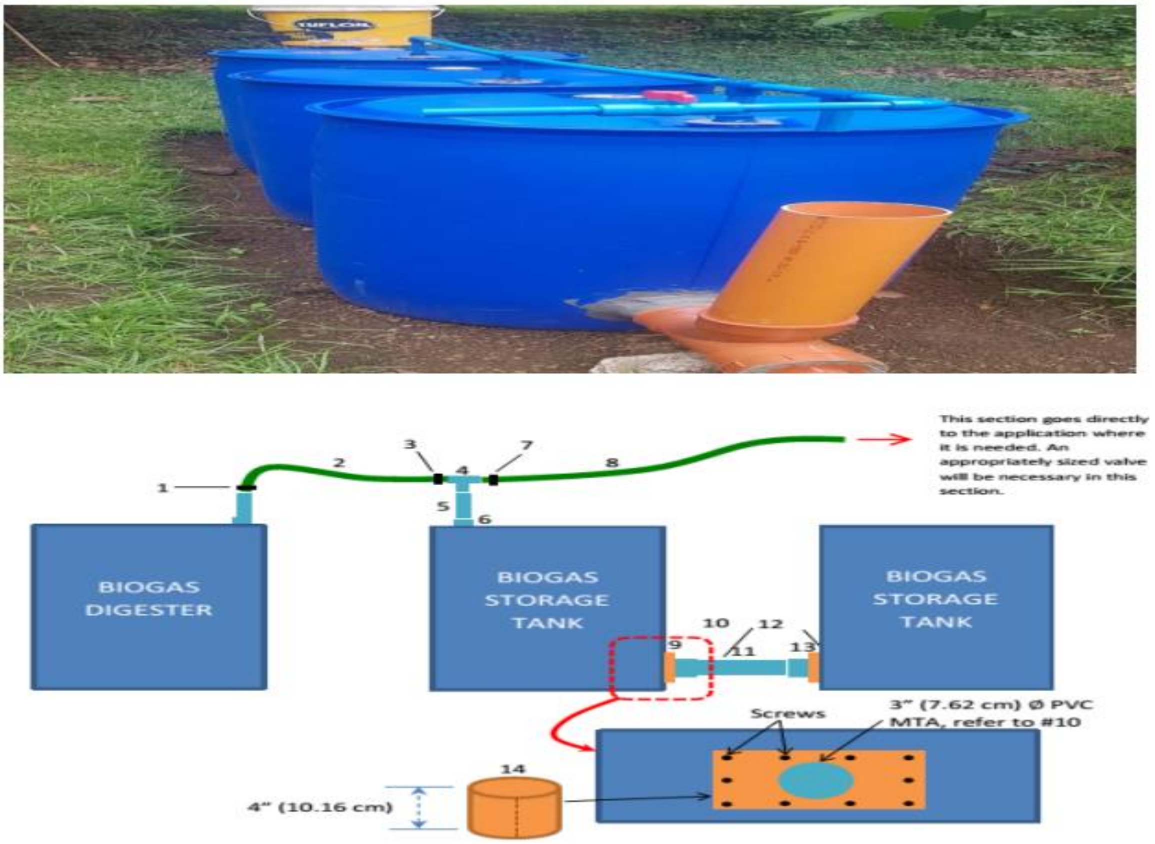

Figure 1 Bio-digester system

1.4.2

Prior to its anaerobic digestion, I carried out the physicochemical property characterization of chicken manure. For the biogas production, I added 45 kg and 40 kg of chicken manure and water of 100 ml to the biogas digester at various trials. Then I placed water in the storage drum and the level of water was arranged similarly with 2nd storage drum. I stirred the biogas digester regularly for 1 week and the experiment was completed if the level of water matched in both drums. After completing this, I connected the biogas pipeline and collected the sludge and liquid from the digester according to VFA and fertilizer manufacturing. I dried the sample at 70^{0}C before crushing it at a 2 mm thickness for Ad testing and chemical analysis. I repeated the process 6 times. I also determine the biogas and VFA average production rate. I also implemented the task of a mathematical model.

$$\text{Average gas produced} = \frac{n}{\frac{1}{X_1}+\frac{1}{X_2}+\frac{1}{X_3}\cdots\frac{1}{X_n}}$$

Table 1. An operating condition during VFA

Parameters	Unit	Value (Variations)
pH	--	5 – 9
Temperature	°C	35 – 45
HRT	Days	7 – 12
Loading Rate	Kg COD/L d	40 – 45

1.4.3

I noted the properties of Chicken manure for the anaerobic process and found all physicochemical characteristics, except for moisture content, showed an increase before drying. With 11.90% crude protein, 0.38% crude fat, 31.31% ash, 9.87% crude fiber, and 12.68% nitrogen-free extract, I got the chicken dung initially included 66.13% dry matter and 33.87% moisture. When the material had dried, I saw that the greatest physicochemical contents were 99.01% for dry matter, which contained 18.98% nitrogen-free extract, 0.57% crude fat, 14.77% crude fiber, 17.82% crude protein, and 46.87% ash. I saw that the output of biogas varied every day, averaging 151 mL/kg-day, with daily fluctuations occurring from 100 mL/kg-day on day 7 to 500 mL/kg-day on day 12. I discovered that the total amount of biogas produced was 1270 mL/kg-day. While digesting the chicken manure, I found that volatile fatty acids (VFA) were generated, and their values varied from 0.607 g/Vs on day 7 to 4.25 g/Vs on day 12. Additionally, after characterizing the sludge digestate's physicochemical characteristics, I discovered that it had an 8.5 pH, 97.37% moisture content, and 0.19% soluble salts. Additionally, I found that the sludge had macronutrients such as 0.11% P, 0.17% sulfur, 0.082% N, 0.10 mg/g of NH3, and 3.6 mg/L of potassium.

Table 2 Physicochemical properties of Chicken manure

Properties	As Received or Fresh Basis	After Drying at 70°C
pH	7.4	
Moisture Content, %	33.87	0.99
Dry Matter, %	66.13	99.01
Ash, %	31.31	46.87
Crude Protein, %	11.90	17.82
Crude Fibre, %	9.87	14.77
Crude Fat, %	0.38	0.57
Nitrogen Free Extract, %	12.68	18.98
C/N Ratio	4:1	

Table 3 Biogas production rate

HRT (days)	Biogas Produced (mL)	Cumulative Gas Produced (mL)
7	100	100
8	120	220
9	125	345
10	125	470
11	300	770
12	500	1270
Average	151 mL/kg^{-1}day	

Table 4 VFA production

HRT(days)	Biogas Produced (mL)	VFAs Produced (g/Vs)
7	100	0.607
8	120	0.622
9	125	0.559
10	125	0.603
11	300	1.950
12	500	4.25

Table 5 Physicochemical Characteristics of Sludge Digestate

Properties	Results
pH	8.5
Moisture %	97.37
Macronutrients	
Potassium (Mg/L k)	3.6
Nitrogen (Total %)	0.082
Ammonia (Mg/g)	0.10
Phosphorus (%)	0.11
Sulfur (%)	0.17
Soluble Salt (Total %)	0.19

1.4.4

In a similar vein, I conducted a thorough examination of the (VFA) generated by the anaerobic digestion process. I divided the VFAs into three groups: tartaric, lactic, and acetic acid. At the beginning of the digestion period, I saw that acetic acid was predominant and had a noteworthy concentration of 2.9 mg/L, however, this concentration progressively fell to 0.10 mg/L at the conclusion of the time. I noted that the production of tartaric acid remained relatively low with values fluctuating between 0.03 mg/L and 1.15 mg/L. I detected 4.61 mg/L of acetic acid, 4.03 mg/L of lactic acid, and 0.48 mg/L of tartaric acid overall during the 7–12-day retention period with acetic acid emerging as the main fatty acid. I found that the total VFA production during this period reached 9.12 mg/L In my work, I also disclosed the ideal parameters for the manufacture of VFA, which were 45°C, 9.5 days for the hydraulic retention time (HRT), 45 kg/L of organic loading rate (OLR), and a pH of 7. I developed a quadratic model for VFA optimization and I was pleased to find that it displayed impressive predictive capability and precision by achieving a predicted R2 of 0.9086 and an adjusted R2 of 0.9640.

The reduced quadratic model for the optimization of VFA production is: *VFA*

$$= -136.94150 + 2.28833*Temperature + 8.08554*pH + 5.28043*HRT + 1.19010*OLR + 0.116500*pH*HRT - 0.152500*pH*OLR - 0.080800*HRT*OLR - 0.014033*Temperature^2 - 0.251146*pH^2 - 0.067733*HRT^2.$$

Table 6 VFA extracted from the digestate of sludge

HRT (days)	Acetic Acid	Lactic Acid	Tartaric Acid	Volatile Fatty Acids (mg/L)
7	2.9	0.23	0.03	3.16
8	0.84	0.5	0.03	1.37
9	0.4	0.3	0.08	0.78
10	0.2	0.63	0.09	0.92
11	0.17	1.17	0.10	1.44
12	0.10	1.2	0.15	1.45
Total	4.62	4.03	0.48	9.12

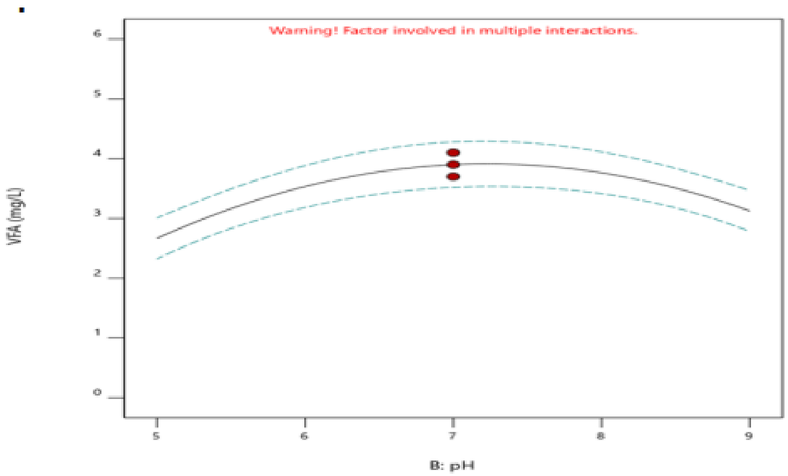

Figure 2 pH level's impact on VFA

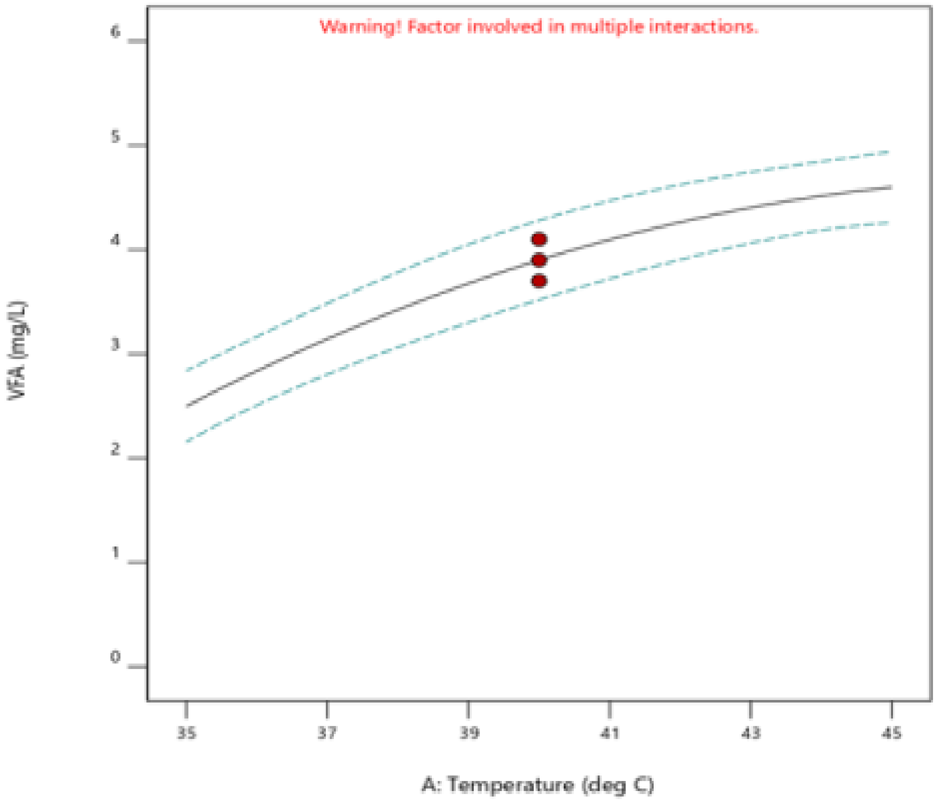

Figure 3 Impact of Temp on VFA

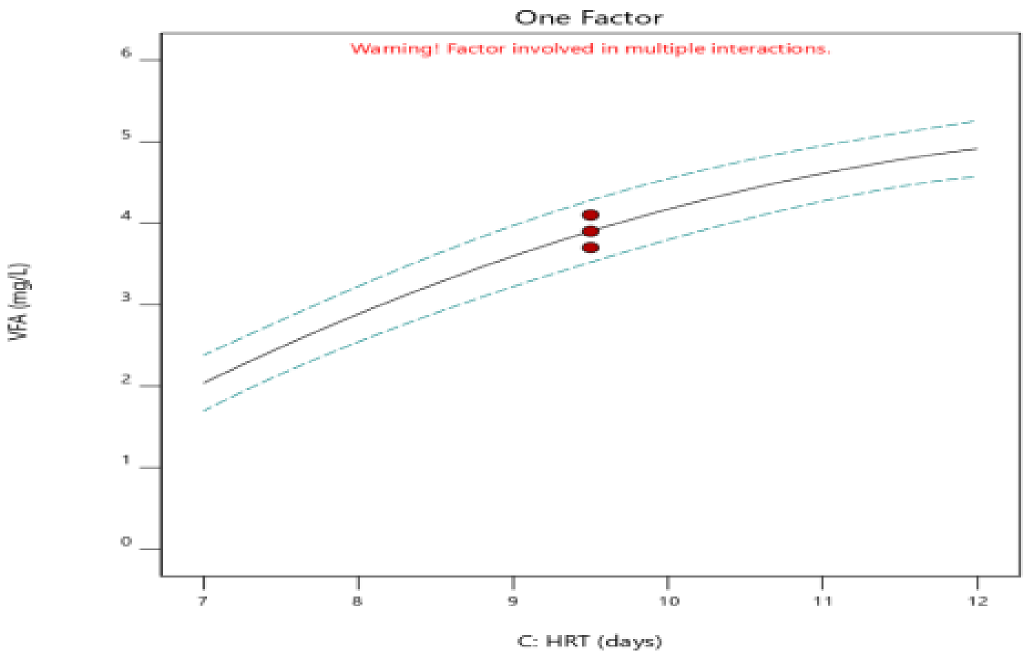

Figure 4 Effect of HRT on VFA

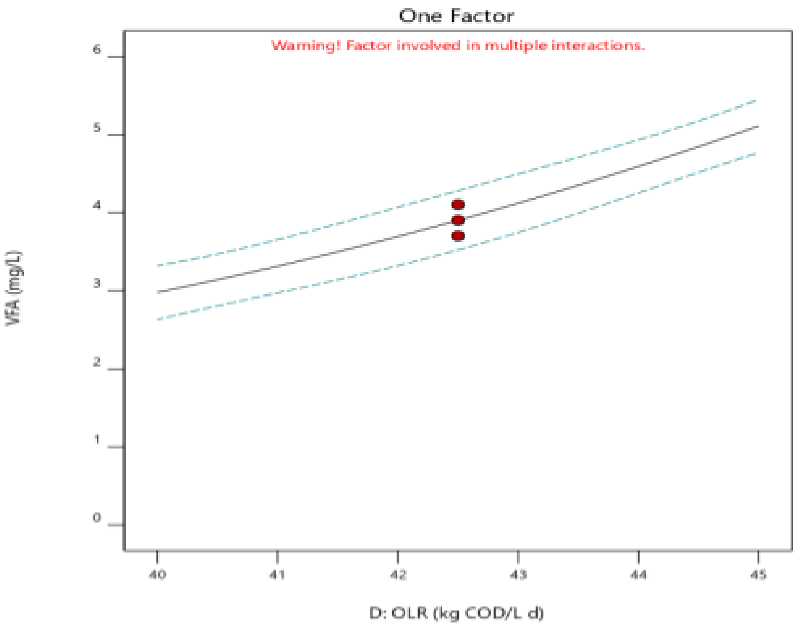

Figure 5 Effect of OLR on VFA

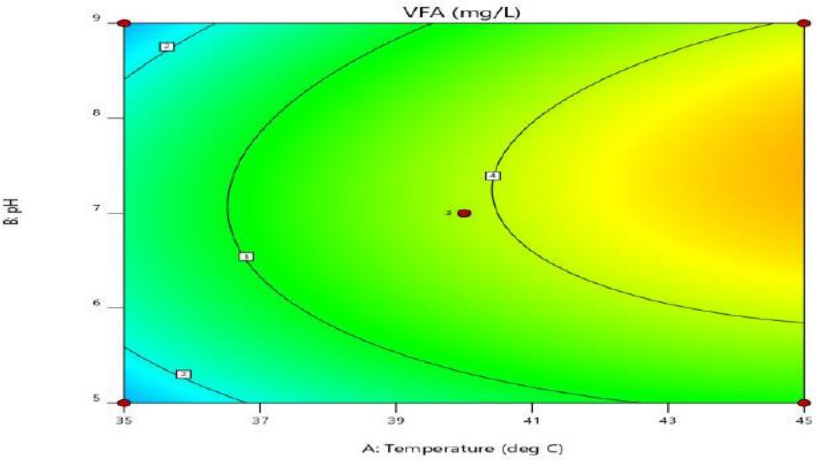

Figure 6 Plot of VFA, pH, and temperature

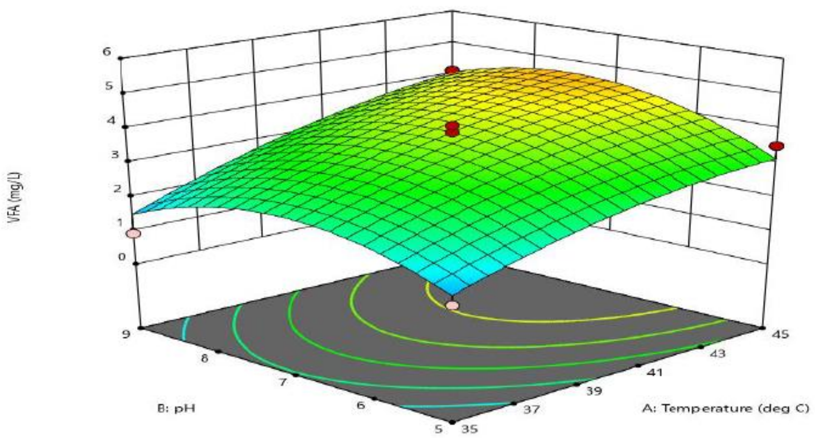

Figure 7 Surface 3D plot of VFA, pH, and temperature

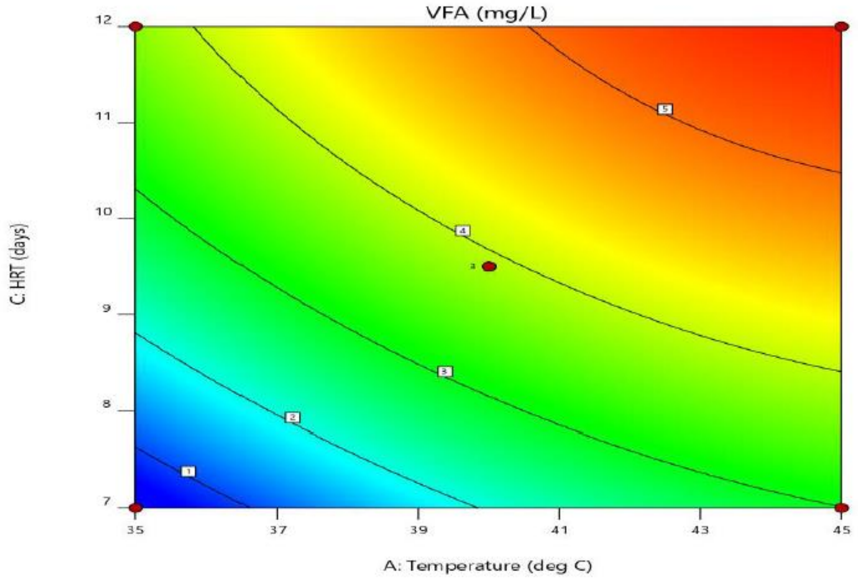

Figure 8 Plot of VFA, OLR and temperature

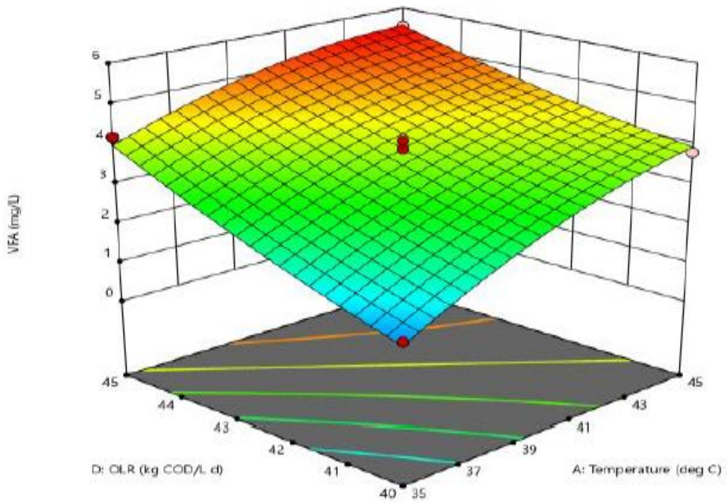

Figure 9 Surface 3D plot of VFA, OLR and temperature

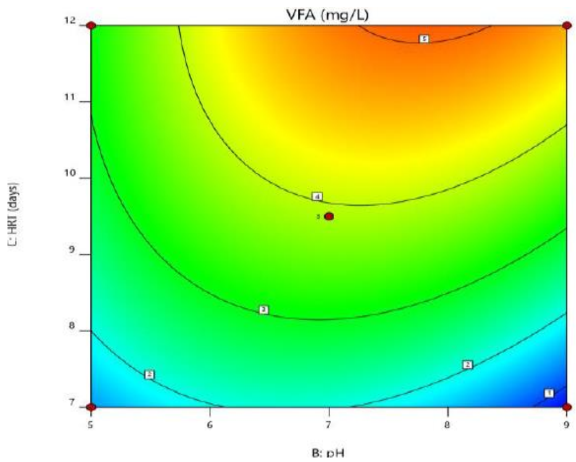

Figure 10 Plot of VFA, HRT, and pH

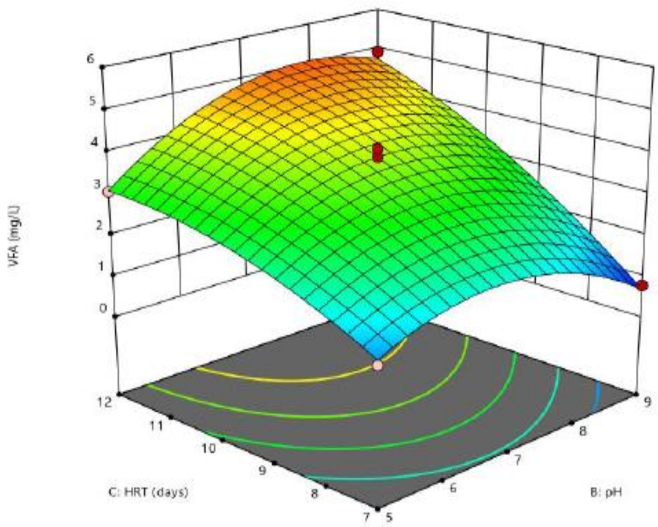

Figure 11 Surface 3D plot of VFA, HRT, and pH

1.4 Problems and Solutions

1.4.1

I reviewed the conclusions of the work, which included information on volatile fatty acid (VFA) composition and production. Following the production of the VFAs, I investigated how several factors including pH, temperature, hydraulic retention time, and organic loading rate affected VFA synthesis. Maximizing VFA output was a challenge I needed to overcome. I had to fully understand how these factors influenced VFA production to complete my task. It was my responsibility to determine the ideal conditions for VFA synthesis. To find a solution, I studied the impact of pH, temperature, hydraulic retention time, and organic loading rate on the VFA synthesis process. This research was essential to the project's goals and improved the precision and efficiency of the planned VFA synthesis process, allowing me to identify the optimal conditions for maximum VFA production.

1.4.2

In my work, I encountered a unique technical challenge with the mathematical model used to determine how different factors affected VFA generation. This arose from the need to find a suitable mathematical model that could accurately capture the complex interactions among the factors influencing VFA formation. I concluded that the wide range of correlations between the variables and VFA output made the search for this model a difficult endeavor. Therefore, I dedicated significant effort to researching how various combinations of pH, temperature, hydraulic retention time, and organic loading rate impacted VFA production. Believing it was crucial to the project's success, I aimed to identify the precise parameters that would yield the highest VFA production. My goal was to solve this challenge and provide a more accurate and effective method for predicting and regulating VFA production, ultimately enhancing the project's overall effectiveness and optimizing the process.

1.5 Creative Work

I designed a bio-digester system to help break down organic waste and produce biogas which was a valuable byproduct. To cut the drum appropriately, I selected an angle grinder and power drill.

1.6 Project Management

To maximize the production of volatile fatty acids (VFAs) through anaerobic digestion for valorizing chicken manure, I oversaw all related documentation. I conducted regular management, updated reports, and facilitated cross-functional cooperation. Additionally, I prepared a Gantt chart for proper task allocation. Using pilot-scale research and small-scale trials, I supervised the testing and validation of process improvements before considering scaling up VFA production for commercial or industrial purposes. To ensure the proposed project ran smoothly, I collaborated with the project manager. I also participated in various training sessions related to the endeavor. I completed the comprehensive report within the specified timeframe.

1.7 Codes and Ethics

I followed the code ISO 15985:2004 to use the guidelines for anaerobic digestion. I also came through the code of the University for Further Inspection.

1.8 Conclusion

The anaerobic digestion of chicken manure was investigated in detail to determine its potential for producing volatile fatty acids (VFAs). Data were acquired from various sources, including books, websites, journal articles, and research papers. The study covered the characteristics of VFAs, the anaerobic digestion process, and the selection of appropriate chemicals and reagents. To complete the project, a biogas digester system, 200-liter anaerobic digestion drums, chicken manure, and reagents such as lactic and acetic acid were gathered. To maximize the generation of VFA and biogas, two sets of trials were conducted with varying loading rates, temperatures, and pH levels. PVC pipes and metal sheets were used to construct the biogas digester. Samples of chicken manure were prepared for anaerobic digestion, and the outcomes were tracked and evaluated to determine how to enhance VFA production. After anaerobic digestion, the moisture content of the sludge digestate increased, and its composition included macronutrients like potassium, nitrogen, ammonia, phosphorus, and sulfur, with potassium being the most abundant. Additionally, a relatively low concentration of soluble salts was observed. Three types of volatile fatty acids were produced: tartaric, lactic, and acetic acids, with acetic acid having the highest concentration. Elevated temperature, hydraulic retention time (HRT), and organic loading rate (OLR) were found to enhance VFA production. Moreover, raising the pH to neutral conditions optimized VFA yield, while increasing the pH beyond neutral caused a decline in VFA production. I developed the concept of optimizing VFA production from chicken manure and improved my skills in supervising, managing, directing, and leading throughout the project.

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