Evaluation of Anaerobic and Aerobic Treatment for Tds, Cod, and Bod Reduction in Meatball Wastewater

Vinashinee Ravindran[1], Nuramidah Hamidon[2], Nur Aini Mohd Arish[3] ,Mariah Awang[4]

[1]Faculty of Engineering Technology, University Tun Hussein Onn Malaysia (UTHM), Higher Education Hub, Pagoh, 84600, Malaysia

[2,3]Focus Group Advanced Environment Engineering and Green Technology (AEEGTech), University Tun Hussien Onn Malaysia, Higher Education Hub, 84600, Pagoh, Johor, Malaysia

[4]Building Environment and Maintenance, Faculty of Engineering Technology, University Tun Hussien Onn Malaysia, Higher Education Hub, 84600, Pagoh, Johor, Malaysia

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ABSTRACT

Meatball production is rising due to convenience, global cuisine trends, health awareness, and food delivery services. This growth increases wastewater, requiring effective treatment to manage pollutants like COD, BOD, and TDS. This study presents an evaluation of anaerobic and aerobic treatment methods for the reduction of TDS, COD, and BOD in meatball wastewater. A wastewater treatment plant is crucial for preventing environmental harm, ensuring regulatory compliance, and promoting sustainability through water recycling and pollution reduction.

Keywords: Meatball wastewater, anaerobic treatment, aerobic treatment, COD, BOD, TDS, food industry.

INTRODUCTION

General

Meatball production has increased both in our country and worldwide due to a surge in demand driven by several factors. Firstly, the convenience of ready-to-cook and ready-to-eat meals has made meatballs popular for busy consumers seeking quick and satisfying options. (Romans *et al*, 1994; Sloan, 2003). Additionally, the growing popularity of international cuisines has introduced diverse meatball variations, appealing to a broader audience (Fulton, 1983; Serdaroglu & Degirmencioglu, 2004). Health trends also play a significant role as people become more aware of nutrition, seek protein-rich foods, and meatballs offer a versatile option that can be customized with lean meats or plant-based alternatives. (Widyastuti, 1999; Purnomo, 1999) Furthermore, the rise of meal delivery services and food trucks has spotlighted meatballs, making them accessible to more consumers than ever before.

This increased production reflects changing consumer preferences and drives innovation within the industry, encouraging the development of new flavours, healthier formulations, and sustainable practices. (Utami, 2004; Utami et al., 2007) As a result, the meatball market continues to expand, meeting today's consumers' evolving tastes and needs.

The increase in meatball production necessitates establishing effective wastewater treatment systems for several reasons. As production scales up, the volume of wastewater generated from cleaning processes, ingredient preparation, and cooking also rises significantly. This wastewater often contains organic matter, fats, oils, and proteins that can harm the environment if released untreated. To address this challenge, companies are increasingly investing in advanced wastewater treatment systems to manage their environmental impact. (Hermanianto & Andayani, 2002) These systems are designed to filter and treat wastewater before it is discharged into local water bodies, ensuring compliance with environmental regulations and protecting ecosystems. Parameters that focus on COD, BOD, and SS because these three parameters are very harmful to the ecosystem. By implementing these systems, meatball producers can minimize pollution, reduce water usage through recycling processes, and demonstrate a commitment to sustainability. (Rahardiyan, 2002; Widyastuti, 1999). Wastewater treatment systems are vital infrastructures designed to manage and purify water used in various processes, including industrial, agricultural, and domestic activities. As populations grow and industries expand, the volume of wastewater increases, leading to significant environmental challenges. Untreated wastewater can contaminate natural water bodies, posing risks to public health and ecosystems. A wastewater treatment system employs a series of physical, chemical, and biological processes to remove contaminants from wastewater, transforming it into clean water that can be safely discharged or reused. These systems are essential not only for complying with environmental regulations but also for protecting aquatic life and maintaining the quality of drinking water sources. (Birke M., Rauch U., Harazim B.2010).

Modern wastewater treatment facilities can efficiently process large volumes of water while minimizing their environmental footprint by incorporating advanced technologies, such as membrane filtration and biological treatment methods. As industries like food production, including meatball manufacturing, continue to grow, implementing effective wastewater treatment solutions becomes increasingly crucial in promoting sustainable practices and safeguarding our natural resources.

LITERATURE REVIEW

Electrocoagulation

The extensive literature review was done by referring to standard journals and conference proceedings. The major work carried out by different researchers is summarized below.

Wastewater treatment is essential for improving water quality to meet the standards required for various applications, such as drinking, industrial use, irrigation, or safe environmental discharge. It involves removing impurities, contaminants, and harmful substances to protect human health, prevent environmental pollution, and support resource conservation (UN Environment Program - Water Treatment). Among the diverse methods available for wastewater treatment, two prominent techniques include electrocoagulation and anaerobic treatment systems. Electrocoagulation is a physicochemical process that utilizes sacrificial electrodes, typically aluminum or iron, to generate coagulants by applying an electric current. This process induces the formation of hydroxyl ions and hydrogen gas at the cathode, separating suspended particles from water. Critical parameters such as potential, pH, residence time, and electrode configuration significantly influence the efficiency of electrocoagulation. It has been effectively applied to reduce Total Dissolved Solids (TDS), Chemical Oxygen Demand (COD), and turbidity in meatball wastewater by optimizing variables like current density, number of electrodes, and retention time.

Anaerobic treatment

On the other hand, anaerobic treatment systems are widely used for treating food-industry effluents due to their high content of biodegradable organic matter, which can be converted into biogas under anaerobic conditions. This process involves the breakdown of organic pollutants by anaerobic microorganisms without oxygen, producing biogas (primarily methane and carbon dioxide) and digestate, which can be used as a biofertilizer. Anaerobic digestion is particularly effective in reducing high concentrations of Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Suspended Solids (SS), making it ideal for treating organic-rich industrial wastewater. Additionally, it aligns with circular economy principles by promoting energy recovery, reducing greenhouse gas emissions, and supporting nutrient recycling.

In this study, a combination of anaerobic and aerobic treatment systems has been employed to enhance the overall efficiency of the wastewater treatment process. While the anaerobic system effectively handles high organic loads and generates renewable energy in biogas, it may not fully eliminate certain pollutants such as ammonia nitrogen and residual COD. To address this, the treated effluent from the anaerobic reactor is further subjected to aerobic treatment, where oxygen is introduced to promote the activity of aerobic microorganisms. These microbes degrade remaining organic matter, oxidize ammonia to nitrate (nitrification), and further reduce

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COD and BOD levels, resulting in a cleaner effluent suitable for discharge or reuse.

The integration of anaerobic and aerobic processes offers several advantages. It combines the energy efficiency and biogas production of anaerobic digestion with aerobic treatment's high pollutant removal capacity. This hybrid approach ensures more comprehensive treatment, effectively reducing organic pollutants, nutrients, and suspended solids while supporting sustainable practices. Moreover, the sequential use of both systems minimizes operational costs, maximizes resource recovery, and achieves higher treatment efficiency, making it a robust solution for complex wastewater like meatball processing effluent.

Membrane Bioreactor

A Membrane Bioreactor (MBR) is an advanced form of the activated sludge process where the traditional secondary clarifier is replaced with a membrane filtration unit. This membrane unit, often consisting of microfiltration or ultrafiltration membranes, separates treated water from suspended solids and microorganisms, producing high-quality effluent suitable for reuse or discharge. The MBR process is characterized by a long solids retention time (Θc), which refers to the extended period that biomass is retained in the system. This promotes the growth of slow-growing microorganisms, enhancing the degradation of organic matter and nutrient removal. Additionally, MBR systems operate with a high mixed liquor suspended solids (MLSS) concentration, typically 8,000-15,000 mg/L, compared to conventional systems (2,000-4,000 mg/L). The high MLSS allows for compact reactor sizes, improved biological treatment efficiency, and reduced sludge production. By integrating biological treatment with membrane separation, MBR systems eliminate issues like sludge bulking in secondary clarifiers and achieve superior effluent quality, making them ideal for applications requiring stringent discharge standards or water reuse.

Aerobic treatment

The Sequencing Batch Reactor (SBR) is a batch-mode activated sludge process that treats wastewater in discrete cycles, combining equalization, aeration, and clarification in a single reactor. Unlike continuous systems, SBR operates in timed phases: the fill phase, where wastewater is introduced into the reactor; the react phase, during which aeration allows microorganisms to degrade organic matter and remove nutrients; the settle phase, where solids settle to separate treated water from sludge; the draw phase, where clarified effluent is discharged; and sometimes an idle phase for adjustments before the next cycle. This non-steady-state operation eliminates the need for secondary clarifiers, offering flexibility in handling variable flows and pollutant loads, making SBR ideal for municipal and industrial wastewater treatment in space-constrained or performance-focused settings.

Table 1 shows parameters and their limits for drinking water quality in Malaysia (technical guidance document series number –DOE-IETS-9)

Parameter Type	Parameter	Limit	Unit
Physical Parameters	pH	6.5–9.0	-
	Turbidity	≤ 5	NTU
	Colour	≤ 15	TCU
	Taste and Odor	Not objectionable	-
	Total Dissolved Solids (TDS)	≤ 1000	mg/L
Chemical Parameters	Ammonia (NH3-N)	≤ 1.5	mg/L
	Arsenic (As)	≤ 0.01	mg/L
	Cadmium (Cd)	≤ 0.003	mg/L
	Chloride (Cl)	≤ 250	mg/L
	Copper (Cu)	≤ 1.0	mg/L

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	Fluoride (F)	≤ 1.5	mg/L
	Lead (Pb)	≤ 0.01	mg/L
	Nitrate (NO3 as nitrogen)	≤ 10	mg/L
	Sulfate (SO4)	≤ 250	mg/L
	Iron (Fe)	≤ 0.3	mg/L
Organic Chemicals	Pesticides (e.g., Atrazine)	≤ 0.003	mg/L
	Trihalomethanes (THMs)	≤ 0.1	mg/L
Microbiological Parameters	Total Coliforms	0	counts/100 mL
	Escherichia coli (E. coli)	0	counts/100 mL
	Heterotrophic Plate Count (HPC)	≤ 500	CFU/mL
Radiological Parameters	Gross Alpha Activity	≤ 0.1	Bq/L
	Gross Beta Activity	≤ 1.0	Bq/L

Difference Between Biological and Chemical Treatment System

Biological Treatment Plant

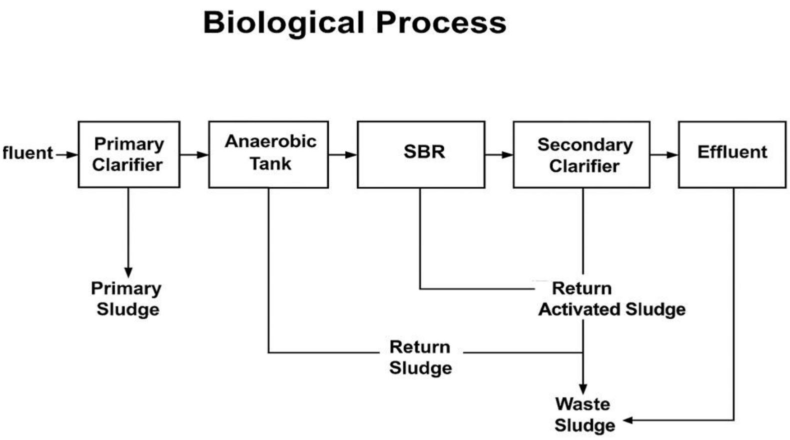

Figure 1 shows the biological process treatment

Biological wastewater treatment relies on the activity of microorganisms, such as bacteria, fungi, and protozoa, to break down organic matter and nutrients present in wastewater. These microorganisms consume organic pollutants as their primary food source, converting them into biomass, carbon dioxide, and water through natural metabolic processes. This eco-friendly approach effectively reduces the concentration of organic pollutants, making the treated water safer for discharge or reuse. Standard biological treatment methods include the Activated Sludge Process, where microorganisms are aerated in a suspended growth system; Trickling Filters, which use biofilms on media to treat wastewater; Anaerobic Digestion, where organic matter is broken down in the absence of oxygen to produce biogas; and Sequencing Batch Reactors (SBRs), which treat wastewater in timed cycles, allowing for flexibility and efficiency in treatment. Biological treatment is particularly suitable for wastewater with high organic content, such as municipal sewage and food industry effluents. One of its main advantages is its cost-effectiveness in treating biodegradable waste while being environmentally friendly. However, the process requires careful control of operational conditions—including oxygen levels, pH, and temperature—to maintain optimal microbial activity. Additionally, biological treatment is less effective for wastewater containing non-biodegradable or toxic pollutants, which can inhibit microbial processes (EQA, 1974; Mutamim et al., 2013). Therefore, selecting the appropriate biological treatment method depends on the specific characteristics of the wastewater and the desired treatment outcomes.

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Chemical Treatment Plant

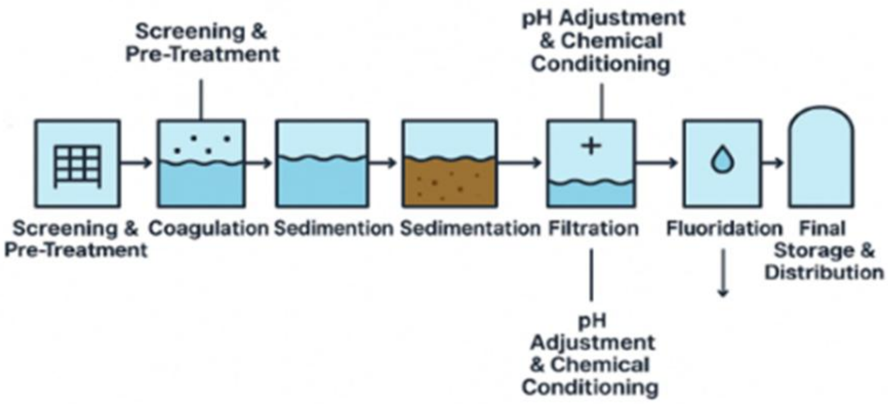

Figure 2 shows the Chemical process treatment

Chemical wastewater treatment is based on chemical reactions that transform contaminants into forms that can be more easily separated or neutralized. The core principle involves altering the chemical properties of pollutants to enhance their removal through physical or chemical processes. One of the primary objectives of chemical treatment is destabilizing and removing suspended solids that cannot be effectively separated through conventional filtration or sedimentation alone. This is commonly achieved through coagulation and flocculation processes. Coagulants such as alum (aluminum sulfate) or ferric chloride are added to the wastewater to neutralize fine particles' surface charges, preventing them from repelling each other. Once neutralized, these particles can clump together during the coagulation phase and further aggregate into larger flocs during flocculation. These flocs can then settle at the bottom or float to the surface, making them easier to remove through sedimentation or skimming. To ensure optimal treatment efficiency, chemical reaction stoichiometry is carefully managed. This involves calculating and adding the correct amounts of chemicals to fully react with the contaminants without leaving excess residues in the treated water. Additionally, phase separation techniques are applied to convert dissolved contaminants into solid or gas phases, simplifying their extraction. The treatment process also relies on effective energy and mass transfer to enhance contact between the wastewater and the added chemicals, thereby maximizing reaction rates and overall treatment efficiency (EQA, 1974; Mutamim et al., 2013). Chemical treatment removes a wide range of pollutants, including suspended solids, heavy metals, and certain organic compounds. However, careful control of chemical dosages and reaction conditions is required to avoid secondary pollution and ensure the treated effluent meets environmental discharge standards.

The comparison between biological treatment and Chemical treatment

Table 2 shows the comparison between biological treatment and chemical treatment

Aspect	**Biological Treatment**	**Chemical Treatment**
Mechanism	Microbial action	Chemical reactions
Target Pollutants	Organic and biodegradable	Non-biodegradable, toxic
Environmental Impact	Generally eco-friendly	Potential secondary pollution
Cost	Low to moderate	High
Maintenance	Requires expertise in microbiology	Requires expertise in chemistry

METHODOLOGY

Flowchart below shows the overall Industrial Effluent Treatment System (IETS) flow for the site, beginning from the raw effluent collected from production. The system consists of several key units: the Oil/Solid Trap, Anaerobic Tanks (AN1 & AN2), Flocculation Tank, and Sequencing Batch Reactors (SBR1 & SBR2). The effluent undergoes both biological and chemical treatments before reaching final discharge. Sludge generated during the process is directed to sludge holding and conditioning tanks, followed by a filter press for proper dewatering and disposal. This setup ensures effective pollutant removal and compliance with discharge standards.

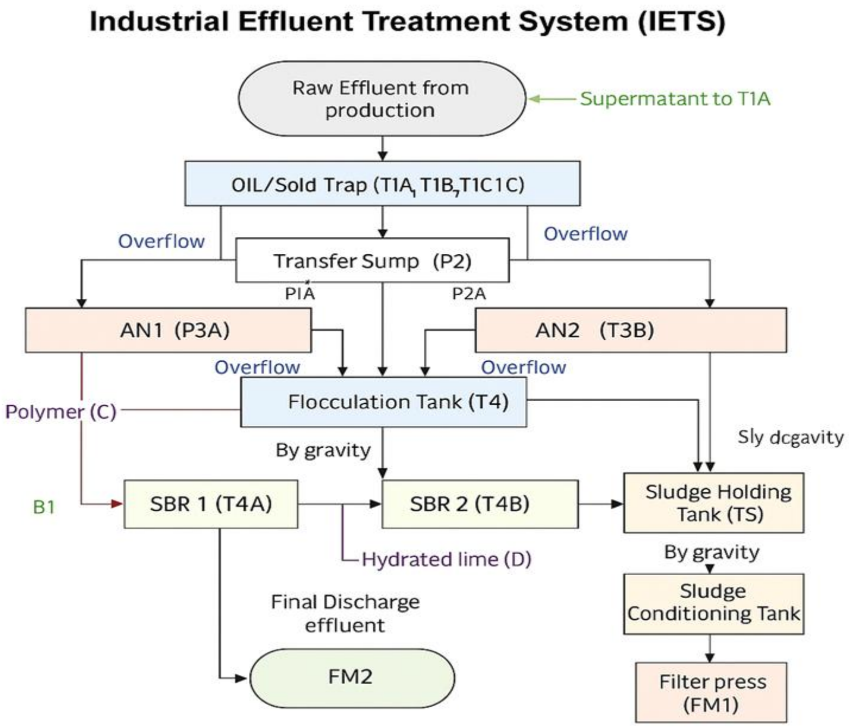

Figure 3: Flowchart of Treatment system

This study was conducted through a pilot-scale experiment to evaluate the effectiveness of a combined anaerobic and aerobic treatment system for meatball processing wastewater. Due to the large scale and operational constraints of the existing treatment plant at the site, it was not feasible to carry out testing directly on-site. Therefore, a lab-scale pilot plant was designed and operated at the research facility to replicate the key processes used at the actual wastewater treatment plant. The objective was to simulate real-world treatment conditions in a controlled environment and to measure the performance of biological treatment in reducing critical wastewater parameters such as COD, BOD, TDS, and DO.

The treatment system followed the design of an Integrated Effluent Treatment System (IETS), which consists of several components functioning in sequence. These include an oil and solid trap, anaerobic (AN) tank, a flocculation tank, a Sequencing Batch Reactor (SBR), and a filter press for sludge handling. The oil and solid trap were used as the initial step to remove large particles, oils, and suspended solids through physical separation. Following this, the anaerobic tank facilitated the breakdown of organic pollutants in the absence of oxygen, enabling microbial digestion under anaerobic conditions. The effluent from the anaerobic tank was then directed to the flocculation tank, where hydrated lime and polymer were added to initiate the coagulation and flocculation process, forming heavier sludge that could be easily separated from the water. This step helped in improving the clarity of the effluent and supported downstream treatment. The biologically treated water was subsequently fed into the SBR for further aerobic treatment.

The SBR was operated using a fixed 24-hour cycle: 16 hours of aeration, followed by 8 hours for settling, decanting, and idle phases. Aeration was provided using a blower system to ensure sufficient oxygen supply for aerobic microbial activity. The dissolved oxygen (DO) levels were monitored during this stage to assess whether aerobic conditions were consistently maintained. Daily feeding of the SBR was done using effluent treated from the anaerobic tank to simulate the continuous flow as it would occur at the site. This approach ensured that the pilot plant truly represented the full-scale system's flow pattern and treatment sequence.

Throughout the experiment, various parameters were regularly monitored to evaluate treatment performance.

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These included pH, COD, BOD, TDS, SV30 (sludge volume after 30 minutes), ORP (Oxidation-Reduction Potential), and DO. Measurements were taken daily, and results were recorded and plotted to observe trends over time. No chemicals were used in the oil trap, anaerobic tanks, or sludge holding tanks, maintaining a purely biological approach in these stages. However, hydrated lime and polymer were selectively applied in the flocculation tank to aid in sludge formation and settling. The final sludge was transferred to a sludge holding tank and later dewatered using a filter press system, minimizing solid waste volume.

Flowrate was recorded manually, and mass balance calculations were used to estimate influent and effluent volumes. A schematic diagram of the pilot plant setup and a process flowchart were included to illustrate the treatment stages clearly. By using a pilot plant to mimic site-scale operations, this methodology enabled detailed monitoring of treatment performance in a manageable and controlled setting. It provided valuable insight into how combined anaerobic and aerobic biological treatment can effectively treat high-strength food industry wastewater.

RESULTS AND DISCUSSIONS

Treatment Process and Removal Efficiency

Chemical Oxygen Demand (COD) Reduction

The graph illustrates the reduction in Chemical Oxygen Demand (COD) over time, reflecting the efficiency of the treatment system in breaking down organic pollutants. Initially, COD levels were high, exceeding 500 mg/L, indicating a significant presence of organic matter in the wastewater. However, as the treatment progressed, COD levels dropped substantially, stabilizing around 150 mg/L towards the end of the process.

This downward trend in COD demonstrates the system's ability to effectively degrade organic pollutants through biological and chemical processes. The steep decline at the beginning suggests rapid decomposition of easily degradable organic matter, while the gradual decrease later indicates the breakdown of more complex compounds. The sustained decrease in COD confirms that microbial activity, aeration, and settling processes were successfully reducing pollutant levels.

As a result of this COD removal, the treated water becomes significantly clearer and cleaner, meeting environmental discharge standards. By the end of the process, the water is sufficiently purified and can be safely released into the public drainage system without posing a risk to the environment. This highlights the system’s effectiveness in wastewater treatment, ensuring that organic pollutants are efficiently removed before discharge.

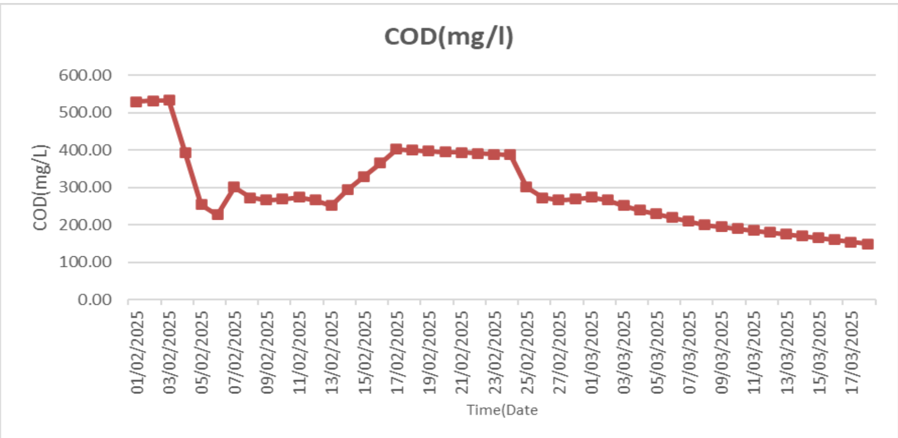

Figure 4: COD Reduction Over Time: Organic Pollutant Degradation in Wastewater Treatment Biological Oxygen Demand (BOD) Removal

Before treatment, the Biochemical Oxygen Demand (BOD) levels were significantly high, starting at approximately 210 mg/L on February 1, 2025. This indicates a high concentration of organic pollutants in the wastewater, making it heavily contaminated and unsuitable for direct discharge. Similarly, the Chemical Oxygen Demand (COD) was also very high, around 540 mg/L at the beginning, confirming the presence of a high organic

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load. Such elevated BOD levels suggest that microorganisms require a large amount of oxygen to break down organic matter, which can lead to oxygen depletion in natural water bodies, harming aquatic life.

After treatment, the BOD levels significantly declined, reaching approximately 80 mg/L by March 17, 2025. The COD also followed a downward trend, reducing to around 150 mg/L by the same period. This reduction indicates that the treatment process effectively removed organic pollutants from the wastewater. However, while the overall trend is downward, a sudden increase in BOD after March 10, reaching around 200 mg/L, suggests possible recontamination or inefficiencies in the treatment system that require further investigation. COD remained more stable but exhibited some fluctuations, especially around mid-February, when it temporarily increased to nearly 400 mg/L before resuming its decline.

A reduction in BOD generally means the wastewater contains fewer organic pollutants, making it safer for discharge. Lower BOD levels help maintain oxygen levels in receiving water bodies, preventing environmental degradation and harm to aquatic ecosystems. However, the effluent can only be discharged into public drains if the BOD is within permissible limits set by environmental regulations, typically below 30 mg/L for most municipal wastewater discharge standards. Since the final BOD in this case is still above 80 mg/L, additional treatment may be necessary before discharge. Furthermore, ensuring compliance with other parameters such as COD and Total Suspended Solids (TSS) is crucial before considering the effluent safe for disposal.

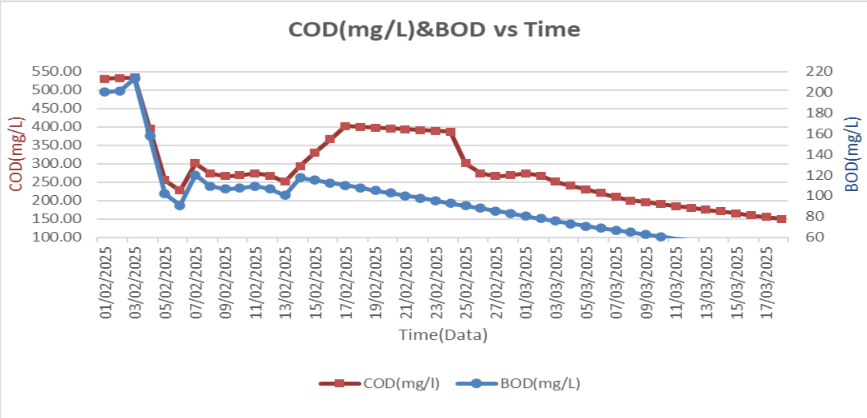

Figure 5: Variation of COD and BOD Levels Before and After Wastewater Treatment

Total Dissolved Solids (TDS) Removal

The treatment system effectively reduces suspended solids in the effluent by breaking down organic matter and removing particulate contaminants through physical, chemical, and biological processes. Initially, the wastewater contains high suspended solids, contributing to elevated Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD). As the treatment progresses, suspended solids are removed through processes like sedimentation, filtration, and coagulation, which help separate solid particles from the liquid phase. Additionally, biological treatment methods further break down organic matter, converting it into simpler compounds either removed as sludge or dissolved as Total Dissolved Solids (TDS).

The graph shows COD levels decreased significantly from 540 mg/L on February 1, 2025, to around 150 mg/L by March 17, 2025. This drop indicates a substantial portion of suspended and dissolved organic matter was removed. However, the increase in TDS levels from 200 mg/L to over 7000 mg/L suggests that while suspended solids were reduced, some organic matter was broken down into finer, soluble components. This is a typical outcome in wastewater treatment, where larger solid particles are removed, but dissolved substances remain in the effluent.

By effectively reducing suspended solids, the treatment system helps improve water clarity and lowers COD and BOD, making the effluent safer for discharge. Although TDS levels increased, the effluent may still be safe for disposal if regulatory standards primarily focus on COD and BOD reduction. If necessary, further treatment, such as advanced filtration or reverse osmosis, can help manage TDS levels before final discharge into the environment.

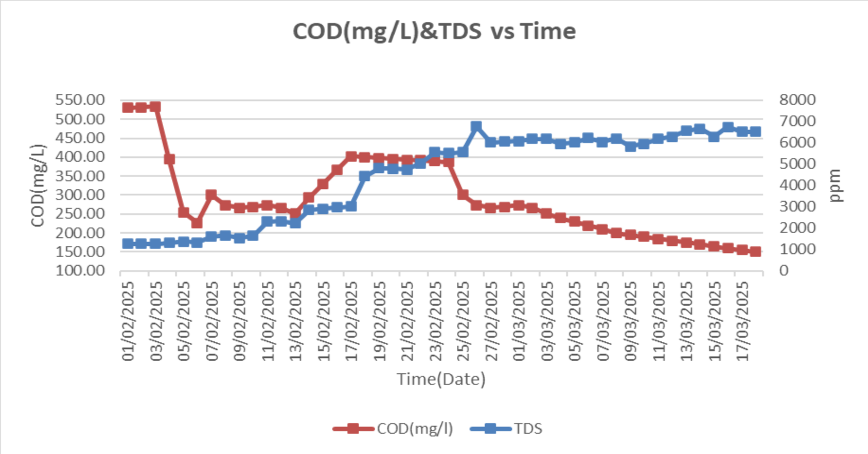

Figure 7 : Correlation Between COD and TDS During Wastewater Treatment

Treatment Efficiency of Anaerobic and Aerobic Processes

The effectiveness of the combined anaerobic and aerobic (SBR) treatment system was evaluated by comparing influent and effluent concentrations for key wastewater parameters. The influent values represent the output from the anaerobic tank, while the effluent corresponds to treated water from the aerobic SBR tank.

Significant reductions were observed across several parameters. BOD_5 levels decreased from 2013.0 mg/L to 20.0 mg/L, achieving a removal efficiency of 99.0%, indicating excellent organic matter degradation. COD was reduced from 7092.0 mg/L to 96.0 mg/L (98.6% efficiency), reflecting effective oxidation of both biodegradable and non-biodegradable compounds. Suspended Solids (SS) dropped from 1100.0 mg/L to 8.0 mg/L (99.3% efficiency), suggesting efficient solid-liquid separation and microbial activity.

For inorganic compounds, Iron (Fe) and Boron (B) showed removal efficiencies of 90.7% and 93.8%, respectively, indicating that the SBR process contributed to the removal of trace metals and metalloids. Colour was reduced by 88.5%, although the final effluent still contained 121.0 Pt-Co units, which may require polishing treatment if regulatory standards are stringent.

Notably, Ammonium Nitrogen (AN) showed no reduction (0.0% efficiency), suggesting that nitrification did not occur or was ineffective during the aerobic phase. This could be due to insufficient aeration time, lack of nitrifying bacteria, or inhibition effects. This indicates a need for process optimization if nitrogen removal is required.

Overall, the combination of anaerobic pre-treatment and aerobic SBR treatment proved highly effective in removing organic and particulate pollutants from meatball processing wastewater.

Table 3: Comparison of in-influent (from the anaerobic tank) and out-effluent (after the aerobic SBR tank)

Parameters	Efficiency (%)	Reference	Concentrations (mg/L)		Mass Load (kg/day)	
			In (Q= 9.693m³/d)	Out (Q=9.693m³/d)	In (Q=9.693 m³/d)	Out (Q=9.693m³/d)
pH	-	-	Monitored to be between 5.5-9.0		-	-
BOD_5	99.0	JBH Analysis	2013.0	20.0	19.51	0.19
COD	98.6	JBH Analysis	7092.0	96.0	68.74	0.93
SS	99.3	JBH Analysis	1100.0	8.0	10.66	0.08
Iron, Fe	90.7	JBH Analysis	1.0	0.1	0.01	0.00
Boron, B	93.8	JBH Analysis	162.0	10.1	1.57	0.10
AN	0.0	JBH Analysis	NA	NA	NA	NA
Color	88.5	JBH Analysis	1050.0	121.0	10.18	1.17

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CONCLUSION

This study successfully evaluated the performance of an aerobic Sequencing Batch Reactor (SBR) system following anaerobic treatment for the removal of ammonium nitrogen and organic pollutants in industrial effluent. A pilot plant was established to simulate full-scale treatment conditions in a controlled lab setting. This setup allowed for detailed monitoring of influent and effluent quality, with a clear focus on comparing parameter levels before and after treatment.

Significant improvements were observed across key parameters. The SBR system effectively reduced COD from 7092.0 mg/L to 96.0 mg/L, BOD_5 from 2013.0 mg/L to 20.0 mg/L, and TDS (represented by SS) from 1100.0 mg/L to 8.0 mg/L. These reductions resulted in high removal efficiencies, bringing the final effluent concentrations within acceptable discharge limits. The performance highlights the efficiency of the aerobic SBR process in polishing effluent from the anaerobic stage.

Operationally, the pilot system emphasized the importance of consistent aeration, proper cycle timing, and sludge management. Monitoring parameters such as pH and dissolved oxygen confirmed that the biological conditions were well-maintained to support microbial degradation of pollutants.

In conclusion, the combined anaerobic and aerobic (SBR) treatment demonstrated strong potential for industrial application. The process achieved significant pollutant removal and ensured that COD, BOD_5, and TDS values were within environmental regulatory standards, making the system a viable and sustainable solution for industrial wastewater treatment. Future work can focus on enhancing nitrogen removal and optimizing system design for full-scale implementation.

RECOMMENDATIONS

Consideration of Future Treatment Challenges:

As wastewater composition changes or volume increases, the system may face challenges related to varying organic loads or seasonal fluctuations. To address this, it is recommended that periodic system audits and performance evaluations be conducted to ensure that the treatment capacity can meet future demands while maintaining compliance with environmental discharge standards.

The combined anaerobic and aerobic treatment system will produce waste sludge, which needs to be managed appropriately. It is recommended to explore options for sludge treatment, such as dewatering or anaerobic digestion for biogas recovery, to minimize environmental impacts and potentially generate value from waste byproducts.

In conclusion, the combined anaerobic-aerobic treatment system has shown promising results in reducing pollutants in meatball wastewater, and with proper scaling, monitoring, and optimization, it can serve as an effective solution for treating food industry wastewater in compliance with environmental discharge standards

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