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Evaluation of the Effect of Biological Nutrient Removal (BNR) on Wastewater Quality

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Abstract

Industrial wastewater, particularly brewery wastewater contains high-strength organic, inorganic, and biological compounds which are harmful to the environment. Different technologies such are employed towards treating brewery wastewater before discharge into water bodies, but biological method has proven to be more environmental-friendly, cost-effective and easier to operate. This research project assessed the impact of biological nutrient removal (BNR) on wastewater quality, and it involved laboratory scale sequencing batch reactor (SBR), operated in a cyclic aerobic-anaerobic set-up inoculated with activated sludge to remove orthophosphates and nitrate compounds. Raw brewery wastewater samples were collected from Awo-Omama brewery plant of Nigerian Breweries Plc, Imo State, Nigeria. They were analyzed using standard methods described by American Public Health Association (APHA) to determine the removal efficacies of orthophosphates (PO_4^{3-}), ammoniacal-nitrogen (NH_3-N), total Kjeldahl nitrogen (TKN), total nitrogen (TN), total organic nitrogen (TON), total inorganic nitrogen (TIN) and NO_3-N+NO_2-N. Results revealed that 69% $PO_4^{3-,}$ 69% NH_3-N, 59% TKN, 60% TN, 64% TON, 67% TIN and 56% NO_3-N+NO_2-N. These removal efficacies were attained for a hydraulic retention time of 18 hours for both SBRs with a solids retention time of 5 days for SBR-1 and 7 days for SBR-2. Findings of this study showed that the cyclic aerobic-anaerobic set-up on a laboratory scale SBR, inoculated with activated sludge for treatment of brewery wastewater for biological nutrients was feasible. It is recommended that investigation on BNR using brewery wastewater with a well-balanced C: N: P ratio should be done to improve BNR efficacies.

***Keywords**: Biological Nutrient Removal (BNR), Nitrogen removal (organic and inorganic), Phosphorus removal, dissolved oxygen (DO), Chemical oxygen demand (COD), Biological oxygen demand (BOD)*

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1. Introduction

The burgeoning global population and industrial activities have significantly increased the generation of wastewater laden with nutrients, posing severe environmental and public health concerns. The discharge of industrial wastewater with a high-concentration of biological nutrients (i.e. nitrogen and phosphorous compounds) and organic matter pollutants into receiving water bodies stimulates the growth of algae, which promotes eutrophication, thus destroying aquatic life and resulting in environmental pollution.

Nutrient pollution in wastewater has become a pressing environmental concern worldwide due to its detrimental effects on water quality and ecosystem health. Traditional wastewater treatment methods often fall shorts in effectively removing nutrients such as nitrogen, phosphorous, carbon, etc, leading to eutrophication of water bodies and endangering aquatic ecosystems. In response, emerging technologies for nutrient removal in wastewater treatment have gained traction in recent years, offering innovative and efficient solutions to mitigate nutrient pollution.

Effective nutrient removal in wastewater treatment is crucial for several reasons. Firstly, excessive nutrients in effluent can cause imbalances in aquatic ecosystems, leading to the depletion of oxygen levels and the loss of biodiversity. Secondly, nutrient pollution poses risks to human health, as contaminated water sources can harbour pathogens and toxins associated with algal blooms. Additionally, nutrient-enriched effluent discharged into receiving waters can impair recreational activities and compromise aesthetic value of natural environments. Therefore, ensuring efficient nutrient removal in wastewater treatment processes is essential for safeguarding both environmental and public health.

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2. Materials and Methods

2.1 Study area

Industrial wastewater samples were collected from Nigerian Brewery (NB) Plc, located at Awo-Omamma, Oru East Local Government Area of Imo State, Nigeria. NB Plc, Awo-Omamma is located within the coordinates of 5°39'23"N and 6°56'4"E, along Njaba River bank, Imo State, Nigeria. It was formerly Consolidated Breweries Plc, becoming a subsidiary of the independent global brewer, managed by NB Plc in December, 2014.

2.2 Sample collection

Samples were mainly collected for characterization and operation of the two laboratory scale SBRs to assess the impact of biological nutrient removal on wastewater quality. The following parameters were measured before and after treatment: orthophosphates, ammonical nitrogen, nitrate and nitrite, total Kjeldhal nitrogen, total nitrogen, total nitrogen, total inorganic nitrogen and total organic nitrogen removal from industrial wastewater generated from the brewery.

Collected samples were transported to the laboratory in a cooler box full of ice, to avoid biological activities, thus maintaining sample's biological condition from the sampling point to the laboratory.

2.3 Sample preparation

At the laboratory, samples were allowed to warm up to room temperature to conduct physicochemical analyses, thereafter charged to the reactors (i.e. SBR-1 for nitrogen removal and SBR-2 for orthophosphates removal) to commence treatment immediately. Where it was not possible to conduct all analyses immediately, samples were stored in a refrigerator at 4 °C and analyses carried out within 48 h from time of sampling.

2.4 Sludge sampling and preparation

Activated sludge (microorganisms) was harvested from an anaerobic digester at the wastewater treatment plant (WWTP) at the brewery plant. Sludge was harvested using a 5-L bowl and then transported to the Microbiology Laboratory of Chukwuemeka Odumegwu Ojukwu University, Uli Campus, Anambra State. The sludge as collected is presented in **Figure 1**. In preparing the harvested sludge for treatment, no chemicals were added in brewery wastewater or to the microorganisms to balance the N: C: P ratio as recommended. This is to say the sludge was not acclimated. Only the condensed, almost granular sludge was used for treatment since granular sludge is associated with good settleability, which is important for optimum treatment efficacy.

Figure 1: Activated sludge sample harvested from an anaerobic digester.

2.5 Experimental methods

2.5.1 *Equipment design*

The laboratory scale sequencing batch reactor consists of two identical reactor tanks made of transparent polyvinyl chloride, each calibrated to 18 L with a conical bottom having a slope of 60° for easy drainage of bio-solids. Each reactor had a diameter of 35 cm and a height of 45 cm, with a theoretical total volume of 22 L. The working volume of the experimental set up was set at 13 L, with the microbial population occupying 4 L and a brewery wastewater occupying 9 L. Both reactors were not utilized to their maximum working volume to accommodate sludge bulking, since the bacterial growth rate is proportional to the substrate utilization rate. The conical bottom of the reactor tanks allowed an easy gravitational settling mechanism.

2.5.2 Experimental approach

Cyclic aerobic-anaerobic sequencing batch reactor operation

Wastewater treatment in sequencing batch reactor systems is accomplished over a series of steps, all taking place in a single reactor vessel which operates in time, rather than space. The following procedures are a series of operational steps:

- *Filling phase*: This is the first operational phase of the sequencing batch reactor system. Both reactors were first seeded with 4 litres of activated sludge under anaerobic conditions. Brewery wastewater was fed into the reactor holding tank, where suspended solids were allowed to settle by gravitational force for a period of 2 h. After the settling phase, 9.0 L of the brewery wastewater supernatant was pumped to each reactor. The filling phase took place under anaerobic conditions, but the stirrer was switched on and set to operate at 350 rpm to allow mixing. A mix only during the filling stage promotes filamentous growth control and improves settling and thickening. The agitation speed of stirrer was set to be 350 rpm, because it was observed that higher agitation speed resulted in sludge bulking, thus compromising solids settle ability. The filling period on average for all experimental runs lasted for 5 minutes.

- ***Aeration phase***: After filling both reactors (i.e. SBR-1 and SBR-2) to their maximum working volume, the aeration phase was instigated for SBR-1. This phase was done by adopting cyclic aeration and continuous mixing to promote biological nitrification and denitrification for ammoniacal nitrogen, nitrates and nitrites removal. In the case of SBR-2, the aeration phase was initiated after the system had undergone the anaerobic stagein which polyphosphorus accumulating organisms are favoured. During this phase, microorganisms in activated sludge consume substrates (ammonia and orthophosphate) under controlled environmental conditions. Therefore, the pH inside the reactor was monitored and maintained between the range of 4.0 and 9.0, and the temperature inside the reactor was also monitored and left unadjusted at mesophilic temperature conditions. Hydrochloric acid (HCl) was added into the reactor if pH levels were above 9, and sodium hydroxide (NaOH) pellets were added into the reactor at pH levels below 4. Aeration was carried out by means of a diaphragm air pump mounted on the **SBR** frame beneath the reactor tanks. Air from the diaphragm pump was transported by means of rubber pipelines connected to a copper pipelines, which descended from the top of each reactor tank down to the central height for optimum reaction and mixing. The aeration phase lasted for 4 hours for SBR-1 and 14 hours for SBR-2.

- ***Settling phase*****:** During this phase, bio-solids were allowed to separate gravitationally from the treated liquid, resulting in a clear clarified supernatant. During this phase, the stirrer was switched off as well as the aeration system and no influent was charged into the reactor tanks, or effluent drawn. This phase lasted for 2 hours, to enhance optimum settling of bio-solids containing biodegradable organic and biological pollutants, thus resulting in a clear clarified supernatant with minimum suspended solids.

- ***Decanting phase*****:** This phase was considered as the final treatment operational stage for the sequencing batch reactor system. Here, the clarified supernatant was sampled as the treated reactor effluent, by tapping the reactor effluent into a 500 mL sterile glass bottle for laboratory analysis. The drawing period lasted for 3 minutes on average for all experimental runs. After each run, an observation was made on the increase in quantity of iomass inside the reactor tanks, since the substrate utilization rate is directly proportional to the microbial specific growth rate. In preparation for the next run, treated wastewater was drawn from each reactor tank together with "new biomass" to avoid further sludge bulking and improve bio-solids settlebility, thus improving the system treatment efficacy. This process is called the idling phase, and lasted for 1 hr on average for all batches.

2.5.3 Analysis of physicochemical parameters

Some parameters were analyzed on raw brewery wastewater and treated brewery wastewater. Analysis was conducted in accordance with the *Standard Methods for the Examination of Water and Wastewater* standard methods. For data credibility, all samples were analyzed in triplicates.

2.5.3.1 pH and oxidation reduction potential (ORP)

The pH is an important parameter in biological wastewater treatment system, because it affects the microbial metabolic process, thus compromising wastewater treatment efficacy as well as the environment. Microorganisms in their nature are pH dependent, such that at pH levels less than 4 and pH levels more than 9.5, they do not perform well. The pH was analyzed during characterization of reactor influent and treated effluent, in accordance with the APHA (2012) standard methods. A calibrated Thermo Scientific Orion A215 pH/Conductivity meter was used to measure the pH, by directly dipping it inside the reactor tanks.

2.5.3.2 Conductivity

This is a measure of the ability of water to pass an electric current. Conductivity is greatly affected by the presence of inorganic dissolved solids such as nitrate, phosphate, anions, etc. Organic compounds like alcohol and sugars do not conduct electrical current effectively, and therefore, they have low conductivity in water. Conductivity was used to give a quantitative measure of the total dissolved solids in water, given in micro Siemens per centimeter (µS/cm).

2.5.3.3 Chemical oxygen demand (COD)

The COD measures the capacity of water to consume dissolved oxygen during the decomposition of organic matter and the oxidation of inorganic chemicals, such as ammonia and nitrite. The COD was used to quantify organic pollutants concentration in industrial wastewater, generated from the brewery which was considered to be a quick indicator of organic pollutant in brewery wastewater. COD was measured in milligrams of oxygen per litre (mg O_2/L), which is the amount of oxygen consumed per litre of solution. In other words, it was the amount of oxygen consumed per litre of brewery wastewater. Both the reactor influent and treated effluent were characterized for COD. COD was measured using the spectrophotometer (DR 3900), using the colorimetric method as described by Abimbola *et al*. (2015). Samples were heated for 2 hours at 150 ºC in the presence of sulphuric acid and a strong oxidizing agent, potassium dichromate.

2.5.3.4 Orthophosphates (PO_4^{3-})

Phosphorus in wastewater is found in different forms, including the dissolved (orthophosphates), inorganic (reactive plus condensed or acid hydrolysable phosphate) and organically bound forms. Phosphorus concentration was measured as orthophosphates, since industrial wastewater from the brewery is characterized by a high fraction of inorganic orthophosphates. Orthophosphates concentration was measured colorimetrically using a Hach DR 3900 spec, by adopting the molybdovanadate method. In this method, orthophosphate reacts with molubdate in an acid medium to produce a mixed phosphate/molybdate complex. In the presence of vanadium, a yellow molybdovanadophosphoric acid is formed. The intensity of the yellow colour is proportional to the phosphate concentration. Samples were measured at a wavelength of 430 nm.

2.5.3.5 Ammoniacal-Nitrogen (NH_3-N)

Nitrogen pollutants exist in different forms in wastewater. In this study, ammoniacal nitrogen (ammonia) was used to evaluate the treatment efficacy of the SBR system in treating industrial wastewater for nitrogen pollutants (i.e. ammonia). Ammonia, a toxic pollutant in wastewater, is considered to be highly soluble in water and exists as ammonium ions. This parameter was measured to give an approximate concentration of nitrogen pollutants in the form of ammonia contained in brewery wastewater.

The concentration of NH_3-N was measured colorimetrically using a Hach DR 3900 spectrophotometer. Ammonium ions reacted with hypochlorite ions and salicylate ions in the presence of sodium nitroprusside as a catalyst to form indophenols. The amount of colour formed is directly proportional to the ammoniacal nitrogen present in the sample. Samples were measured at a wavelength of 494 nm, using test vials.

2.5.3.6 Total Kjeldahl nitrogen (TKN)

Wastewater is characterized by a variety of organic compounds containing nitrogen, which cannot be analyzed by a single test, which will allow each compound to respond in an equal manner. TKN is basically the combination of organically bound nitrogen and ammonia in wastewater. TKN analyses were conducted to quantify the amount of nitrogen contained in the organic form. Nitrogen pollutants in wastewater exist as both organic and inorganic forms. The reactor influent and effluent samples were analyzed for TKN, and their differences used in evaluating the SBR system for organic nitrogen removal.

The TKN was measured colorimetrically using a Hach DR 3900 spec. Inorganic and organic nitrogen were oxidized to nitrate by digestion with peroxodisulphate. The nitrate ions reacted with 2, 3-dimethylphenol in a solution of sulphuric and phosphoric acids to form a nitrophenol. Oxidized forms of nitrogen, i.e. nitrate and nitrites are also determined. Samples were measured at a wavelength of 345 nm. Total organic nitrogen (TON) and total inorganic nitrogen (TIN) concentrations were estimated using the equations [3.1] and [3.2] respectively.

$$TON = TKN - (NH_3N + NH_4N) \qquad [3.1]$$

$$TIN = (NH_3N + NH_4N) + (NO_3N + NO_2N) \qquad [3.2]$$

2.5.3.7 Dissolved oxygen (DO)

Biological treatment is defined as an aerobic activated-sludge process in the aeration zone for treating wastewater. DO is measured in mg O_2/L, and was considered an important parameter in this study. This is because the microbial communities in the aerobic zone needs enough DO for degradation. During the experimental runs, air was supplied to both reactors by means of a diaphragm air pump, to maintain a DO minimum concentration of 2 mg/L for the survival of the microbial community in the zone. DO was measured during the aerobic phase for process monitoring purposes.

2.5.3.8 Total solids (TS) and total dissolved solids (TDS)

According to APHA (2012), TS are total dissolved solids plus suspended and settleable solids in water. Dissolved solids in brewery wastewater contain nitrate, phosphorus and other particles. On the other hand, suspended solids include fine organic debris and other particulate matter. The difference between dissolved solids and suspended solids is that dissolved solids can pass through a filter with pores around 2 microns (µ) and suspended solids cannot pass through a 2 µm filter. DO was measured to quantify the amount of solids in both the influent and effluent streams.

TS and TDS were measured gravimetrically in mg/L. A well-mixed sample was dried at 105 °C for 24 hours. The TS fraction was given by the weight of the residue after drying.

3. Results and Discussion

3.1 Characteristics of brewery wastewater composition

Table 1 presents a summary of results on the characterization of brewery wastewater composition used in conducting this experimental research study. The findings of the study on brewery wastewater characterization are presented in terms of the mean expressed in standard deviation and range, which are statistically analyzed at a 95% confidence level.

Table 1: Results of the characteristics of brewery wastewater composition

Parameters	Mean (±SD)	Range
Temperature (°C)	31±3.7	25.3 – 37
pH	6.5±2.4	4.4 – 12.2
Conductivity (µS/cm)	2718±1020	1893 – 6017
TCOD (mg/L)	7687±2030	3447 – 11813
PO^{3-}_4 (mg/L)	343±64	229 – 424
NH_3-N (mg/L)	12.2±7.5	12.2 – 27.8
TKN (mg/L)	29.3±25.6	6.24 – 94.7
Total nitrogen (mg/L)	38.6±29.0	13.7 – 106
Total organic nitrogen (mg/L)	8.92±11.1	0 – 39.1
Total inorganic nitrogen (mg/L)	34.4±22	7.78 – 93
Total solids (mg/L)	5951±3387	2942 – 14981
Total dissolved solids (mg/L)	4121±1503	2198 – 7400

Key: TKN = Total Kjeldahl nitrogen, TCOD = Total chemical oxygen demand, NH_3-N = Ammoniacal-nitrogen, PO^{3-}_4 = Orthophophates

The findings presented in Table 1 indicated that brewery wastewater composition fluctuates significantly. As indicated in the literature, the sudden changes in brewery effluent composition results from the activities taking place inside the brewery plant (i.e. washing of floors, cleaning the brewing house, cellars and cleaning in place) as well as the chemicals used during the cleaning process

3.2: Total chemical oxygen demand (TCOD) removal results

The results obtained from this research study on TCOD removal in SBR-2 are presented in **Table 2**. From the figure, it can be deduced that the reduction in TCOD concentration in the reactor effluent stream was as a result of microbial activities taking place in the system during treatment. This is supported by Metcalf and Eddy, who confirmed that during the anaerobic phase, polyphosphate accumulating organisms consume readily biodegradable organic substrates (i.e. COD) with the aid of energy made available from stored phosphorus, thus enriching the sludge with the polyphosphate accumulating microbial population. However, from **Table 2**, it could be seen that the TCOD removal varied with different batches, and the system did not show an indication of stability regarding TCOD removal. The TCOD removal was recorded at 55% on average, and this was less than the findings reported from previous studies. Generally, the low TCOD removal was caused by by the variation in terms of TCOD loading rates as presented in **Table 2**, microorganisms are very sensitive to sudden changes in wastewater composition, thus compromising the treatment efficiency.

Moreover, the low TCOD removal was an indication confirming that for the brewery wastewater used in this study, only 55% of the TCOD fraction was readily biodegradable COD. It is important to note that the fact that high removal efficiencies on slowly biodegradable COD can be achieved under long hydraulic retention time (HRT) operation. This justifies the lower TCOD removal efficiency because of lower

HRT. Higher TCOD removals can be achieved at a HRT of 3 to 5 days.

Table 2: TCOD removal results (SRT of 7 days and HRT of 18 hours)

SRT (DAYS)	TCOD (mg/L)		TCOD REMOVAL (%)
	TCOD IN	TCOD OUT	
1	9000	7800	30
2	9500	3800	50
3	8200	11500	10
4	10000	10800	15
5	9500	9000	25
6	6200	7600	20
7	6800	6700	25
8	8800	9000	20
9	9200	5000	44
10	5800	4200	28
11	6800	8200	19
12	5000	7800	15
13	3800	12800	4
14	6800	6400	25
15	9000	8600	24
16	12000	6300	46
17	6600	5800	28
18	8000	7300	26
19	9400	7200	30
20	7000	8600	19

3.3 Effect of sludge retention time on ammoniacal nitrogen

The SRT for nitrogen pollutant removal was determined experimentally by measuring the ammoniacal –N concentration with a variation in SRT. Ammoniacal-N is highly soluble and toxic in water, and it exists as an ammonium ions. The findings of the study on ammoniacal –N removal with SRT variation are presented in **Table 3.** According to the optimum SRT for biological nutrient removal range from 3 to 5 days under mesophilic temperature. As can be seen from the figure below, the SBR showed stability at a SRT of 3 to 5 days, reaching an ammoniacal-N removal efficiency of 80%. This confirmed that the biodegradation of orthophosphates was achieved through solids retention time. The SRT of 5days was considered to be the maximum since longer SRT is associated with the promotion of the glycogen accumulating bacteria, thus compromising the system treatment efficacy.

Table 3 Ammoniacal-N removal profile with SRT variation

SRT (DAYS)	Ammoniacal N Removal Efficiency
1	50
2	85
3	80
4	80
5	75

3.3.1 SBR results on (NO_3-N + NO_2) removal

Brewery wastewater samples were analyzed for nitrates and nitrites. **Table 4.** presents the results of the SBR on nitrites and nitrates removal efficiencies. It can be seen that the brewery wastewater used in this research study contained NO_3-N+NO_2-N ranging from 2.87 to 49.4 mg/L. When analyzing **Table 4**. the SBR treatment efficiency was less than 50 % for reactor influent with a NO_3-N+NO_2-N concentration of less than 4.0 (NO_3-N+NO_2-N) mg/L. The low SBR removal efficiencies could be attributed to the fact during the biodegradation process of ammonia in wastewater, i.e. nitrification process, both NO_3-N and NO_2-N are produced, thus enriching the microbial population with NO_3-N and NO_2-N. However, the up-take of NO_3-N and NO_2-N seemed to be slower during the anaerobic phase which favours denitrification process.

Table 4: Results for the SBR-1 on (NO_3-N + NO)

SRT (DAYS)	NO3-N+NO2-N (mg/L)	NO3-N+NO2-N REMOVAL (%)
1	2.5	42.5
2	2.5	21
3	8.0	50
4	2.5	35
5	4.0	60
6	2.5	48
7	15.0	85
8	3.0	65
9	2.5	48
10	7.0	70
11	2.5	25
12	8.0	80
13	15.0	55
13	45.0	85
14	15.0	80
15	4.0	30

3.4 Effect of pH on biological nutrient removal

According to Metcalf and Eddy (2014), microbial population metabolic activities are inhibited at pH levels of 9.5 and above or below 4.0. Figure 2 below presents the pH profile attained for this research study for both SBR-1 and SBR-2. The pH is a very important parameter which affects microbial metabolic activities. It can be seen that the pH was maintained within the range of 4.9 to 8.4 for both SBR-1 and SBR-2. From the pH values obtained in this study, it is observed that they did not inhibit any microbial activities. For all experimental runs, the pH was adjusted by adding NaOH in cases of low pH levels and HCl in cases of high pH levels from the influent stream.

3.5 Summary of Results for an Aerobic-Anaerobic SBR Treatment Efficacy on Biological Nutrients Removal

Table 5 presents the findings of the study on overall biological nutrients percentage removal obtained in this experimental research study. The results obtained in this study indicated SBR overall nutrients removal efficacies of 69% NH_3-N, 59% TKN, 56% NO_3-N+NO_2-N, 60% TN, 64% TON and 67% TIN. This figure shows strong congruence with previous studies conducted on biological nutrient removal using a SBR seeded with un-acclimated activated sludge.

The significance of SBRs application in biological nutrient removal is confirmed in this study. A patent (No. NG/PT/NC/O/2024/16574) by Egbosiuba et al. (2024), found that the integration of advanced nanomaterials could potentially improve the removal of pollutants in sequencing batch reactors (SBRs) by enhancing adsorption and catalytic degradation processes, thereby optimizing brewery wastewater treatment efficiency.

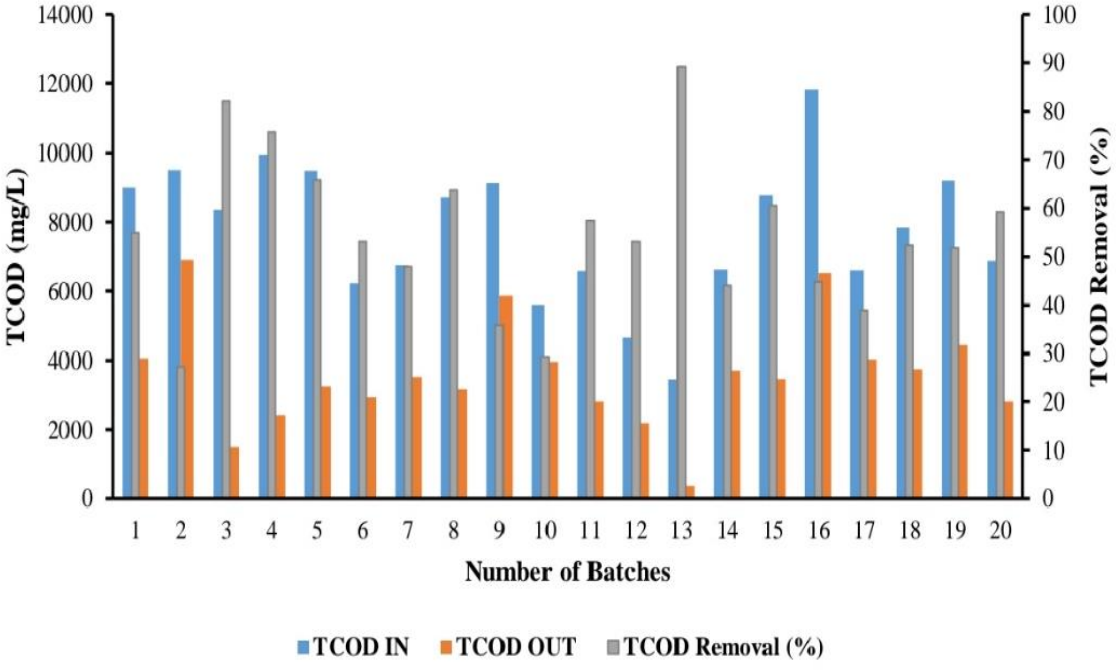

Figure 2: pH profile for both SBR-1 and SBR-2

Table 5: SBR-1 overall treatment efficacy for all biological nutrients investigated

Biological Nutrients	SBR Removal efficacy (%)
NH3-N	69
TKN	59
NO3-N+NO2-N	56
TN	60
TON	64
TIN	67

4. Conclusion

The aim of this research study was to assess the impact of biological nutrient removal (BNR) on wastewater quality. Cyclic aerobic-anaerobic sequencing batch reactor (SBR) technique of BNR was employed, using activated sludge for the removal of nitrogen and orthophosphates pollutants. Industrial wastewater samples generated from a brewery was used. We determined the efficiency of SBR in treating brewery wastewater for biological nutrient removal method.

Results obtained for the characterization of brewery wastewater composition revealed that wastewater generated from the brewery contained high organic, inorganic and biological nutrients pollutants. It was also observed that the composition of brewery wastewater used in this study fluctuated greatly, which was similar to previously done studies on brewery wastewater characterization.

The results for sludge retention time (SRT) and hydraulic retention time (HRT) revealed that higher biological nutrient removal was achieved with increasing SRT, particularly on orthophosphates removal. It was also observed that an increase in HRT resulted in an increase in BNR. The findings of the study on mass balance between SRT and HRT results explicitly showed that biodegradation of biological nutrients were mostly achieved through the SRT more than HRT for both aerobic and anaerobic phases.

The findings of the study on orthophosphates removal efficacy demonstrated high removal efficacies ranging from 33 to 81% and recording 69% on average. It was observed that higher orthophosphates removal efficacies were achieved at a SRT of 5 days and above. Based on these findings, it may be concluded that the SBR demonstrated high orthophosphates removal efficacies at a SRT of 5 days and above, moreover, the SBR was found to be stable at a SRT f 3 days.

The SBR system under cyclic aerobic-anaerobic technique was also investigated for nitrogen pollutant removal by measuring the percentage removal of NH$_3$-N, TKN, NO$_3$-N + NO$_2$-N, TN, TON and TIN. The findings of the study on SBR cyclic anaerobic-aerobic configuration indicated good nitrogen pollutant removal efficacies of 69% NH$_3$-N, 67% TIN, 64% TON, 60% TN, 59% TKN and 56% NO$_3$-N+NO$_2$-N on average. Based on these findings, the SBR cyclic anaerobic-aerobic configuration demonstrated good BNR efficacies from industrial wastewater generated from brewery that is characterized with high organic load. Therefore, the aim of this study, which is to assess the impact of BNR on wastewater quality, has been met. This is because the SBR system demonstrated to be a sound technology to be implemented as a treatment process for industrial wastewater.

Recommendations

The following recommendations are proposed for further studies to be conducted on BNR from industrial wastewater:

- It is recommended that an investigation on BNR using brewery wastewater with a well-balanced C:N:P ratio should be done to improve BNR efficacies.
- In this research, temperature within the reactor was left unadjusted. It is recommended that further studies have to be done on SBR systems for BNR with temperature variation to investigate the effect of temperature on the SBR performance for BNR.

The SBR was inoculated with un-acclimated sludge, since both the sludge and brewery wastewater were taken from the same plant. Further studies are recommended to be conducted using well acclimated sludge under cyclic aerobic-anaerobic configuration. This could improve the biodegradation of biological nutrients during the cyclic operating configuration of the SBR system

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