Biological Nutrients Removal from Brewery Wastewater using Sequencing Batch Reactor

B.F. Bakare and S.M Khumalo

Abstract— **One of the major challenges faced by South Africa is the issue of environmental pollution more especially surface water pollution. The discharge of industrial wastewater in treatment plants introduces various challenges in the treatment process due to the complex and varying nature of the industrial wastewater. This paper presents an experimental study that was conducted at Mangosuthu University of Technology using a laboratory scale anoxic / cyclic SBR. The overall aim of this study was to investigate and evaluate the performance of a laboratory scale anoxic sequencing batch reactor (SBR) in treating brewery wastewater. The findings of this study are reported based on overall batch averages for the following performance monitoring parameters; Total Kjeldahl Nitrogen (TKN) and Total Nitrogen (TN) removal efficiency of 68 %, with ammonical nitrogen recording the highest removal efficiency of 78 %, operating at an mesophillic temperature range of 21-23 ˚C and a recorded pH range 6-8 respectively. These physicochemical parameters were left unadjusted since they were not inhibiting the biodegradation activity of the microbial population on the treatment of brewery wastewater. The anoxic aeration of the SBR was achieved by feeding oxygen to the reactor in the form of air for a period of 9 hours-per-day at a feed rate of 7.5 L/min. A strong removal significance of $P < 0.05$ was attained in all parameters. The findings of this study presented that the anoxic aeration configuration on a laboratory scale SBR for the treatment of brewery wastewater on biological nitrogen was feasible and in congruent with previously done work.**

Index Terms—**cyclic aeration, sequencing batch reactor, removal efficiencies, microbial population, anoxic**

I. INTRODUCTION

Over the past years our society has shown a speedy population growth rate and industrialization which have resulted in the degradation of various ecosystem on which life relies on.

In the case of surface water quality, such pollution is primarily caused by the improper discharge of inadequate treated industrial and municipal wastewater to surface water (i.e. lakes, rivers, dams, and the ocean) having significant amounts of organic matter, nitrogen and phosphorus which results to the promotion of eutrophication. By definition eutrophication is the toxicity to aquatic organisms and depletion of dissolved oxygen to receiving streams which kills fish if either Nitrogen or Phosphorus lacks, eutrophication does not occur, thus saving the ecosystem.

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The biological Nitrogen and Phosphorus removal from industrial wastewater can be an effective approach for prevention of eutrophication on surface water [1].

According to a research study conducted in China on treating brewery wastewater [2], the brewing industry amongst other industries was found to be the largest consumer of water as well as the largest producers of waste water. The study showed that for each cubic meter of beer produced, the brewing process produce 15 m^3 of effluent. As large volumes of water are being used by the brewing industry in beer production, the amount of wastewater that is being discharged from the industry after production is very high in organic content and thus highly pollutant to the environment [2]. According to a study that was conducted by [3] brewery wastewater is characterised by its high chemical oxygen demand (COD) ranging between 1500-16000mg/L and biological oxygen demand (BOD) values derived from the high carbohydrate and protein content. High nitrate concentrations in drinking water may result in catastrophic health issues to both humans and animals. Nitrate and nitrite contaminated water is also related to several diseases such as methmoglobinemia infants, the compounds can cause DNA mutation, causing gastric cancer [4. The need to invest in cost effective and environmentally friendly technologies for industrial wastewater treatment is required [5]. Therefore the is a great responsibility to manage all the pollution sources such as, municipal, industrial, and agricultural, in order to minimise carbon and nitrogen concentrations to improve the quality of the environment [6].

Nowadays, there are wide varieties of biological wastewater treatment systems which are trusted to be reliable, well designed and tested; however, they seem to be presenting a number of drawbacks in terms of treatment capacity and efficiency. The sequencing batch reactor seems to be the most promising and appropriate activated sludge process which can be utilized in biological nutrient removal [3]. This paper therefore evaluates the performance of a laboratory scale anoxic aeration configuration SBR on the removal of biological nutrients from brewery wastewater generated from a local brewery in Durban South Africa.

II. MATERIALS AND METHODS

Sample Collection and Preparation

Industrial wastewater samples for the study were collected from a local brewery which is the South African Breweries, Durban, South Africa. Brewery wastewater samples were collected at the influent stream to the wastewater treatment plant, the sampling standard method was adopted [4]. Samples were mainly collected for pollutant analysis (characterization), to determine pollutant composition since

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it varies depending on the activities undertaken in the brewing house, and samples were also collected for the investigation of the performance of a SBR for biological nutrients removal. Analysis were conducted immediately upon sample arrival to the laboratory, perhaps kept in a cold room at temperatures less than 4 ˚C for not longer than 48 hours before conducting analysis. A mixed culture of activated sludge was used as seed for both sequencing batch reactors. The activated sludge was allowed to acclimate after inoculation in brewery wastewater for 21 days. Samples collected for the operation of the anoxic sequencing batch reactors was carried out once after 5 days of hydraulic retention time.

Equipment Design

A laboratory scale SBR which use electricity as a source of energy was employed for the investigation as shown in Figure 1, it consists of the following components: Frame – the frame of the reactor is made of metal, all components making-up the reactor are mounted on the frame. Holding Tank – the holding tank of the reactor is about 20 L in volume made of transparent polyethylene, for easy visual observation. The reactor comprised of two reactor vessels with a working volume of 8-13 L made of transparent polyethylene, for easy visual observation. Each reactor vessel consists of three valves, which are used for drawing samples. The SBR consists of a digital thermometer which can read the temperature inside and outside the reactor vessel. The SBR vessel had a radial stirrer made of stainless steel, maintained at 600 revolutions per minute. The stirrer was operated through a drive brake motor system which had a mounted manual switch on the panel as shown in Figure 1. A laboratory scale centrifugal pump was employed to enhance pumping of raw brewery wastewater from the holding tank into the SBR during operation.

Figure: 1 Laboratory Scale SBR.

Experimental Approach

The experimental approach for the investigation was covered within a period of 10 weeks excluding the 4 weeks for characterization, experimental runs were conducted by adopting a hydraulic retention time of 5 days per-run. A detailed operation sequence for the SBR is described in the following section. The fill phase was the first step in operating the SBR, it was conducted beginning with the static fill stage whereby 3 L by volume of inoculated to the reactor bed then toping up brewery wastewater to a working volume of 13 L. Throughout the reacting phase, no volumes were added nor drawn from the reactor vessel. Upon filling the reactor with acclimatized heterotrophic mixed culture activate sludge and brewery wastewater, oxygen in the form of air was supplied at a rate of 7.5 L/min to the reactor vessel for a period of 9 hours per-day using a diaphragm air pump. Settling was done every after 5 days (hydraulic retention time HRT) for all experimental batches. Settling under quiescent conditions was employed, perhaps the reactor bottom conical design allowed gravity-driven sedimentation of the biomass according to particle size. The settling period lasted for 4 hours to avoid sludge bulking. The decant or drawing phase was done was done using a 500 mL sampling bottle, and the sampling period for all batches lasted for 5 minutes at most. The idling sequence was conducted at the end of every batch to enhance the biodegradation efficiency of microbial population and lessen possible sludge problems due to bulking of suspended solids. The operation of the SBR required analysis for both the reactor influent and effluent streams. During the all experimental runs temperature and pH were the two most paramount parameters which were monitored and left unadjusted at mesophillic conditions of 21-23 °C and average pH of 8.1. These conditions favored the activity rate of biomass on the treatment of brewery wastewater through solids retention and biodegradation of high strengths organic pollutants.

Sample Analysis

Samples were analyzed using (Association, 1998) which include the following physicochemical parameters ; pH, conductivity (CD) , Total dissolved Solids (TDS), Ammonium Nitrogen (NH4-N), Biological Oxygen demand (BOD), Chemical Oxygen Demand (COD), Turbidity, Total Solids (TS), Volatile Solids (VS). A value of $P < 0.05$ was considered as statistically significant. Data analysis was initiated with a check of the data for outliers, missing data, and normality through skewness and kurtosis values that could affect relations between variables. A descriptive statistical analysis of the data such as means, standard deviations, ranges, frequencies, percentages and confidence intervals was initially conducted prior to conducting the multivariate analysis. The choice of these statistical parameters was undertaken with the aim of attaining an efficient comparison of the aeration configuration schemes on both SBRs, which is in line with the main objective of this study.

III. RESULTS AND DISCUSSIONS

As shown below, **Table 1** presents brewery wastewater characterization summary of results in terms of range, mean average and standard deviation, for all characterized parameters.

The measured parameters of the brewery wastewater pollutants composition fluctuates greatly. The possible explanation behind the pollutants composition fluctuation is that the strength of pollutants in brewery wastewater depends greatly on the activities taking place inside the brewing house, such as the chemicals that are used during cleaning. The characterization results presented in **Table 1** obtained in this study showed similar characteristics of brewery wastewater composition as to the ones which were presented in literature for previous studies in **Table 1**. Furthermore, the results explicitly indicated high organic pollutants concentration in brewery wastewater, presenting that brewery wastewater has high concentration of organic pollutants.

Table: 1 SAB Brewery Wastewater Effluent Composition.

Parameters	Mean Average	95% CI
TSS(g/L)	0.3 ± 0.2	0.2 - 0.7
pH	5.8 ± 0.6	4.3 - 6.5
EC (us/cm)	23 756 ± 254	2064 -2784
Turbidity (NTU)	235 ± 79	101 – 357
NH_3N (mg/L)	24 ± 6	13 – 32
Total Dissolved Solids (g/L)	1.5 ± 0.1	0.53 -3.81
COD(mg/L)	10 845 ± 1 623	8 960 - 13 104
Total Solids (g/L)	11.3 ± 7.1	5.13 - 25.6
Volatile Solids (g/L)	1.3 ± 0.4	0.72 - 2.02
TKN, (mg/L)	79 ± 6	71 – 93
TN, (mg/L)	82 ± 6.6	74 – 96

Temperature and pH Effect on Nutrients Removal Results

Measurement of the temperature and pH within the reactor was performed to ensure that microbial activity was not impacted as a result of temperature and pH fluctuations. The average temperature was within the range of 19-23 °C for the entire duration of the experimental set-up. This temperature was found to be within the mesophillic temperature appropriate to effective biological treatment that supports microbial activities under aerobic and anaerobic conditions. Thus it could be said that temperatures in which the SBR was operated enhanced microbial activities within the reactor. Furthermore, the pH was kept within 6-8 for most of the experimental batches. During the experimentation period the effluent pH was recorded to be between: 6-8. This was to instigate feasible organic material removal in the SBR. The slight increase is an indication of a high alkalinity production within the two reactors during their operation. This pH level clearly showed it was not inhibiting the efficient operation of these aerobic SBR. This in turn implied that there was good level of biological activity occurring within the reactors' sludge bed in the SBR. It was also noted that the effluent pH met the brewery wastewater disposal standard (pH range of 6.5-8.5) and pH values of 5.0-9.5 according to South African standards [7, 8]

A. Total Kjeldahl Nitrogen (TKN), Total Nitrogen (TN), and Ammonical Nitrogen (NH_3N) Removal Results

The SBR wastewater influent and effluent streams were both analyzed for organic pollutants concentration thus measuring the nutrients removal rate. As shown in **Figure 2,** present's biological nutrients removal efficiencies of TKN, TN and TN which were obtained during the experimental study. The study indicated a great difference between the influent concentration and the effluent concentration, this related to the amount of biological nutrient removal.

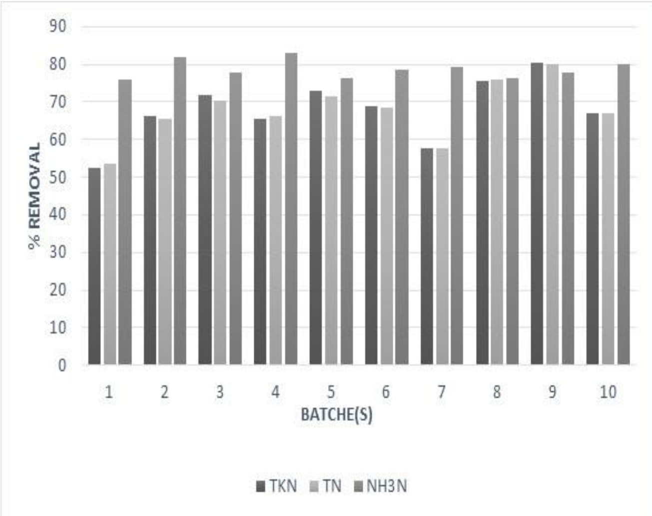

Figure: 2 Percentage Nutrients Removal.

Furthermore, it can be seen that Ammonical nitrogen percentage removal was higher than both the total nitrogen and total Kjeldahl nitrogen removal. Such a nutrients removal trend was observed because TKN and TN cater for all the nitrogen group nutrients pollutants which are present in brewery wastewater, some nutrients might not be biodegradable under anoxic aeration. It can be hypothesized that the high removal efficiency in the form of Ammonical Nitrogen showed a strong ability of the microbial population to carry out nitrification and simultaneous nitrification and denitrification at anoxic aeration configuration. **Figure 3** presents the overall percentage nutrient removals.

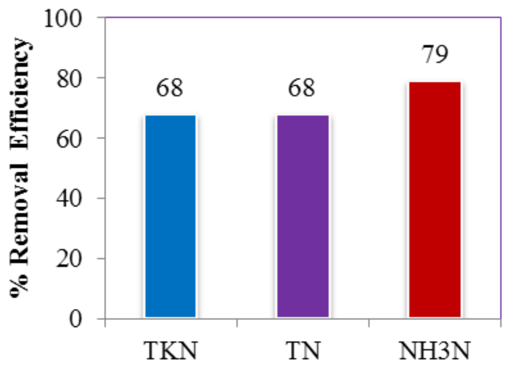

Figure: 3 SBR Overall Nutrients Removal Efficiency.

This study has experimentally proved the theoretical concept on the purpose of anoxic operation scheme on SBRs to optimize its nitrification and denitrification capacity. It was also observed that there was a strong statistically significance in terms of biological nutrients

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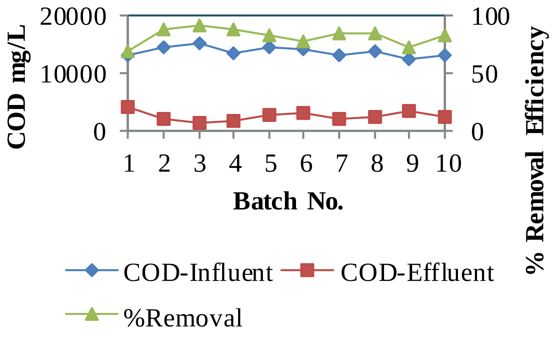
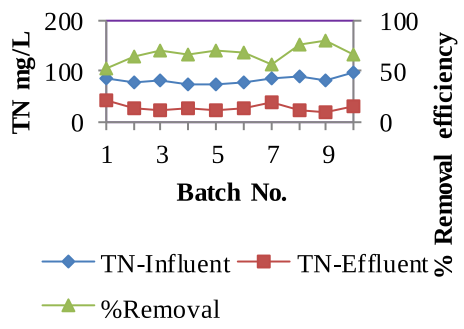
reduction in the SBR as compared to the influent and effluent stream of the reactor, $P < 0.05$.

COD and TN removal results

Chemical Oxygen Demand is indirectly used to determine the amount of organic pollutants found in wastewater. For this research study the removal of biological nutrients was also determine by measuring the COD quantity for both SBR influent and effluent stream as presented in **Figure 4 (a)** and **(b)** below.



(a)



(b)

Figure: 4 (a) and (b) COD removal profile.

As shown above, **Figure 4 (a)** and **(b)** presents the relationship between biological nutrients in the form of TN and COD.

When considering the influent streams for both COD and TN concentrations they indicate high concentrations of more than 14 000 mgCOD /L and more than 90 mgTN/L. Whereas, after treatment the effluent streams indicated lower concentrations of less than 4000 mgCOD/L and less than 30 mgTN/L. The results explicitly indicate that high levels of COD corresponds to high levels organic pollutants in wastewater, moreover the decrease in COD levels gives an indication that indeed biological nutrients was taking place in the SBR during experimental runs. It was observed from the result obtained that there was a statistically significant COD reduction in the SBR as compared to the influent and effluent stream of the reactor, $P < 0.05$.

IV. CONCLUSIONS

The results which were obtained in the study of a laboratory scale sequencing batch reactor for biological nutrients removal operated simultaneously in both aerobic and anaerobic configuration has indicated a good removal efficiency of 68 % TKN and TN removal and 79 % NH3N removal. Based on the experimental perspective, a hypothesis was made that anoxic SBR operated simultaneously in an aerobic-anaerobic configuration can be used as an efficient pre-treatment process for high NH3-N removal from brewery wastewater as compared to TKN and TN biodegradation. These findings as shown in Figure 3 instigated a level of nitrification and simultaneous nitrification and denitrification. Furthermore, another conclusion is made based on the operation of the anoxic SBR in biological nutrients removal that temperature and pH did not inhibited the proficient microbial population activity rate and biodegradation capacity of the removal of high strengths organic pollutants in form of COD and biological nutrients. The temperature of 23 °C and a pH of 8.1 were adapted for the operation of all batch runs.

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