Design of Sequencing Batch Reactor (SBR) Treatment Plant for Abattoir Wastewater (A Case of Apa Mmini Stream)

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Authors’ contributions

This work was carried out in collaboration between both authors. Author OD designed the study and wrote the protocol and also managed the analyses of the study. Author NBO wrote the first draft of the manuscript performed the statistical analysis and managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

Aim: The study aimed at designing a wastewater treatment method for removal of (Biological Oxygen Demand) BOD₅ using Sequencing batch reactor (SBR).

Study Design: SBR functions as a fill-and-draw type of activated sludge system involving a single complete-mix reactor where all steps of an activated sludge process take place.

Methodology: The intermittent nature of slaughterhouse wastewaters favours batch treatment methods like sequence batch reactor (SBR). Attempts to remediate the impact of this BOD₅ on the stream, led to the design of a sequence batch reactor which was designed to treat slaughterhouse effluent of 1000 L.

Results: The oxygen requirement for effective removal of BOD₅ to 95% was determined to be 21.10513 kgO₂/d, while L:B of 3:1 was considered for the reactor. Also, air mixing pressure for the design was 0.16835 bar, while settling velocity was $3.44 \times 10^{-4}$ m/s.

Conclusion: To ensure proper treatment of BOD₅ load of the slaughterhouse, a sequencing Batch reactor of 1000 litre carrying capacity was designed. For effective operation of this design, the

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1. INTRODUCTION

Water contamination increased in recent times as the pollution sources increase especially in unindustrialized nations of the world. The cradles of water contamination are numerous oscillating from point sources to diffuse (non-point) sources of pollution. Most reports on the consequences of water contamination tend to affect human life which according to WHO [1] report, is among the principal reasons for death in developing countries. This contamination of shallow water bodies, triggered through the activities of humans, is an increasing occurrence globally [2]. In Nigeria, surface water contamination is being concomitant with shallow runoff, industrial emission, cold-room discharge, domestic waste and slaughterhouse effluent. The slaughterhouse industry is a significant component of the livestock industry providing domestic meat supply and jobs for over 170 million people in Nigeria [3]. In Nigeria, slaughterhouses are situated indiscriminately without facilities for appropriate supervision of the wastewater discharge, which are ultimately discharged into streams, rivers and water bodies that still serve as key sources of household water for many communities [4]. As a result, human lives have been compromised due to the consumption of heavily contaminated water high in fecal coliform, total solids, nitrates and other physicochemical parameters [5,6]. The principal wastes commence from the point of slaughtering, hide removal, paunch management, rendering, trimming, processing and clean-up procedures. Livestock production turns out a chief pollutant of the nation locations and cities, as soon as the slaughter waste is inappropriately processed, and particularly, released into watercourses, and such practices can bring about enteric pathogens and superfluous nutrients into shallow water [7,8]. The majority of the slaughterhouses in Nigeria are situated near streams, natural ponds or rivers, and a typical example is the Elelenwo slaughterhouse that discharges its effluent into Apa Mmini stream. Elelenwo slaughterhouse effluent is released into Apa Mmini stream exclusively without any practice of treatment which impacts negatively on the water quality evaluation of the stream, nutrient enrichment, loss of dissolved oxygen, the proliferation of pathogenic microorganisms and other unsightly conditions [9,10,11]. The river is highly coloured and turbid with visible suspended particles despite the fact that the stream still serves as a source of household water hoard to the community. As a result, there is a need to design a wastewater treatment system for the slaughterhouse in order to protect lives and environment.

2. MATERIALS AND METHODS

2.1 Study Area

The slaughterhouse considered for this study is situated at Elelenwo, located on Latitude 4°51'02.65 N and Longitude 7°43'38.05 E as shown in Fig. 1. The effluent from these slaughterhouse activities is discharged into Apa Mmini stream. The study would be carried out along various points on APA Mmini stream in Elelenwo, Rivers State.

2.2 Study Design

The sampling stations were divided into five parts as designated below.

- a) Upstream (100 m before point of effluent discharge, S1).
- b) Point source (effluent discharge point, S2).
- c) Midstream (100 m off the discharge point, S3).
- d) Downstream 1 (100 m off the midstream, S4).
- e) Downstream 2 (100 m away from downstream 1, S5).

Keywords: Sequencing Batch Reactor (SBR); Biochemical Oxygen Demand (BOD); oxygen requirement; energy requirement.
2.2.1 Biochemical Oxygen Demand (BOD₅) sample analysis method

Air tight 300 m1 capacity BOD bottles were filled to over-flowing with the sample. The initial liquefied oxygen in the trial was determined. Dilution water stood prepared by measuring out 22.5 g/l MgSO₄·7H₂O; 27.8 g/l CaCl₂·2H₂O; 0.25 g/l FeCl₃·6H₂O; Phosphate buffer: 8.5 g KH₂PO₄; 21.75 g of K₂HPO₄; 33.40 g Na₂HPO₄·7H₂O; 1.7 g NaCl, at pH 7.2 and into a measuring flask and the capacity made up to 1.0 L with disinfected water. The subjects of the decanter stood turned by swirling and covered. The dilution water was first saturated with liquefied oxygen by shaking in an incompletely packed magnum before using to dilute the samples. Two BOD decanters were then filled with the diluted samples and another 2 bottles with the dilution water to serve as blank. The decanters stood stoppered carefully to avoid the entrapment of air. One experimental and one blank BOD bottles were utilized for the initial DO determination. The remaining 2 BOD bottles were water-sealed by filling the flared neck of the bottles with purified water from a wash bottle. The cover-cap supplied with the BOD decanters was used to retain the water. The decanters remained incubated at 20°C for 5 days. After this period the final DO was determined using dissolved oxygen meter. The BOD₅ in mg/l of the trials was evaluated using the relationship.

\[
BOD_5 \left(\frac{mg}{l}\right) = \frac{D_1 - D_2}{P}
\]  

Where:

\(D_1\) = Dissolved Oxygen (mg/l) of samples 15 minutes after preparation
\(D_2\) = Dissolved Oxygen (mg/l) of samples 5 days after incubation at 20°C
\(P\) = Decimal Volumetric Fraction of samples used.

2.2.2 Design parameters

Sequencing batch reactor (SBR) is an improved structure of activated slurry scheme (stimulated or adapted microorganisms are reverted to the vessel to act on arriving wastewater) which operates a solitary batch container to process wastewater [12,13]. Equalization, ventilation, and clarification are attained chronologically in the batch container, thus demanding a moderately small area.

The basic assumptions for the tenacity of this SBR design are characterized below:

1. BOD loading = 65%
2. Solid Sediments (SS) = 35%
3. Diameter of sediments = 75µm = 75 x 10⁻⁶ m
4. The cauldron is vertical and rectangular in shape
5. The density of sediment = 1100 g/m³
6. Altitude of the reactor = 2B (where B = Breadth to of reactor)

![Fig. 1. BOD₅ distribution at various sampling points in Apa Mmini stream](chart)
Table 1. Design parameters for sequencing batch unit

<table>
<thead>
<tr>
<th>Component</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height of clear water (Hw)</td>
<td>$H_w = \frac{V_w}{L \times B}$</td>
</tr>
<tr>
<td>Height of sediment (Hs)</td>
<td>$H_s = \frac{V_s}{L \times B}$</td>
</tr>
<tr>
<td>Total height of the reactor (H)</td>
<td>$H = H_w + H_s$</td>
</tr>
<tr>
<td>Total Pressure (PT)</td>
<td>$(\rho_w H_w + \rho_s H_s) g$</td>
</tr>
<tr>
<td>Air Mixing Pressure (Pm)</td>
<td>$P_m = P_T \times 30%$</td>
</tr>
<tr>
<td>Settling Velocity (Vt)</td>
<td>$V_t = \frac{gd}{18\mu_w}$</td>
</tr>
<tr>
<td>Time of Settling (ts)</td>
<td>$t_s = H/V_t$</td>
</tr>
<tr>
<td>Theoretical air Required</td>
<td>$TAR = \frac{\rho_{air} \times 0.23}{kgO_2/d}$</td>
</tr>
<tr>
<td>Oxygen Requirement</td>
<td>$OR = \frac{\rho_{air} \times 0.23}{kgO_2/d}$</td>
</tr>
<tr>
<td>Energy Requirement</td>
<td>$\frac{Actual\ air\ required \times 24 \times h}{(\frac{h}{2})}$</td>
</tr>
</tbody>
</table>

$H_s$ = Height of settled sediments; $H_w$ = Height of clear sediments; $\rho_w$ = Density of water; $\rho_s$ = Density of solid
$g$ = Acceleration due to gravity; $p$ = Pressure
$f$ = Force; $A$ = Area; $P_m$ = Air mixing pressure; $P_T$ = Total pressure exerted by the reactor content
$P_w$ = Pressure exerted by clear water; $P_s$ = Pressure exerted by settled sediment
$D$ = Diameter of the reactor; $H$ = Total height of the reactor; $V_t$ = Settling velocity; $D_s$ = Diameter of sediment particle
$\mu$ = Viscosity of water; $t_s$ = Settling time

The basic parameters for the SBR design are as defined below and each parameter will be calculated as obtainable in Table 2 of this research study with specified units and dimensions.

3. RESULTS AND DISCUSSION

3.1 BOD Distribution and at Various Points of Api Mmini Stream

Plots of BOD distribution profile at Apa Mmini stream at various sampling points is as presented in Fig. 1.

3.2 Sequencing Batch Reactor (SBR) for Slaughter House Wastewater Treatment

The need for selection of SBR is centered on its portability and inexpensive nature. The process works on a fill, react, settle, draw and idle mode. It comprises of a simple reactor where air is gurgled through in an attempt to achieve degradation of BOD$_5$. The hypothetical draft of the SBR is as presented in Fig. 2.

3.3 Sequencing Batch Reactor (SBR) for Elelenwo Slaughterhouse Wastewater Treatment

The need for the design of SBR for slaughterhouse wastewater became necessary when the finite element prediction showed a high pollution rate downstream along with the stream profile. The results show that the effluents require treatment before discharge into the Api Mmini stream. Additionally, air supply in the SBRs could improve its performance efficiency; aerators with higher aeration rates enhance COD removal and nitrification. The mixing was improved by acquiring mixers that could perform continuously and adjustable up to a rate of 0.16835 bar at all phase for effective nitrification and COD removal [14]. With a higher volumetric exchange rate of 50%, was ensured to enable a higher volumetric turnover and allow the use of smaller reactors. With an oxygen requirement of 21.10513 kgO$_2$/d Nitrification would be complete.
Table 2. Computational results of sequencing batch reactor design

<table>
<thead>
<tr>
<th>Component</th>
<th>Formula</th>
<th>Expression</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height of clear water (H&lt;sub&gt;w&lt;/sub&gt;)</td>
<td>( H_w = \frac{V_w}{L \times B} )</td>
<td>0.65 ((0.55 \times 1.65))</td>
<td>0.7163 m</td>
</tr>
<tr>
<td>Height of sediment (H&lt;sub&gt;s&lt;/sub&gt;)</td>
<td>( H_s = \frac{V_s}{L \times B} )</td>
<td>0.35 ((0.55 \times 1.65))</td>
<td>0.3857 m</td>
</tr>
<tr>
<td>Total height of the reactor (H)</td>
<td>( H = H_w + H_s )</td>
<td>0.7176 + 0.3857</td>
<td>1.1 m</td>
</tr>
<tr>
<td>Total Pressure (P&lt;sub&gt;T&lt;/sub&gt;)</td>
<td>( (\rho_w H_w + \rho_s H_s)g )</td>
<td>[ \frac{kg}{m^3} \times 0.7163m + 1000 \frac{kg}{m^3} \times 0.3837m ] \times 9.81 \frac{m}{s^2}</td>
<td>0.010791 bar</td>
</tr>
<tr>
<td>Air Mixing Pressure (P&lt;sub&gt;m&lt;/sub&gt;)</td>
<td>( P_m = P_T \times 30% )</td>
<td>0.1295 \times 1.3</td>
<td>0.16835 bar</td>
</tr>
<tr>
<td>Settling Velocity (V&lt;sub&gt;t&lt;/sub&gt;)</td>
<td>( V_t = \frac{gd_z^2(\rho_s - \rho_w)}{18\mu_w} )</td>
<td>( \frac{9.81m}{s^2} \times \frac{(75 \times 10^{-6}m)^2}{(1100 - 1000) \times 10^{-4}kg/m^3} \times 18 \times 8.90 \times 10^{-4}kg/m.s )</td>
<td>3.4445 \times 10^{-4} m/s</td>
</tr>
<tr>
<td>Time of Settling (t&lt;sub&gt;s&lt;/sub&gt;)</td>
<td>( t_s = \frac{H}{V_t} )</td>
<td>1.1 m</td>
<td>0.037 days</td>
</tr>
<tr>
<td>Theoretical air Required</td>
<td>( TAR = \frac{0.466kg/d}{\rho_{air} \times 0.23} )</td>
<td>0.466 (kg/d)</td>
<td>1.6884 (kgO_2/d)</td>
</tr>
<tr>
<td>Oxygen Requirement</td>
<td>( OR = \frac{1.2kg/m^3 \times 0.23}{\rho_{air} \times 0.23} )</td>
<td>1.6884 (kgO_2/d)</td>
<td>21.10513 (kgO_2/d)</td>
</tr>
<tr>
<td>Energy Requirement</td>
<td>( \frac{Actual \ air \ required}{Aerator \ Oxygen \ Transfer \ Rate \ (kgO_2/kwh)} \times 24 \frac{h}{d} )</td>
<td>0.85 (\frac{kgO_2}{kwh} \times 24 \frac{h}{d})</td>
<td>1.035 (Kw)</td>
</tr>
</tbody>
</table>
as a result of adequate oxygen supply from 1.6884 kgO₂/d aerator used in the study. The oxygen supply from the aerator available in the local market remained fixed and could be increased. Therefore, it is recommended that nitrification be evaluated for various aeration rates for aerators available in the market to obtain the optimum aeration rate. Computational results of the SBR design is as shown in Table 2.

4. CONCLUSION

To ensure proper treatment of abattoir wastewater from slaughterhouses, a sequencing Batch reactor of 1000litre carrying capacity was designed. For effective operation of this design, the pressure wielded by the mixing air was 0.16835 bar which was far greater than the pressure wielded by the reactor content and the nozzle. Settling velocity of 0.0003445 m/s for 0.887 hrs was requisite for the cauldron to be stable and a theoretical air requirement of 1.6884 m³/d was calculated. Hence the power dissipated by the intensifying air effervesces to ensure efficient mixing of oxygen in the cauldron was calculated as 26530003.91 Kilowatts. With these design parameters, the high BOD₅ load downstream of the watercourse can be handled to drop below as FMEnv recommended limit of 50 mg/l.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES


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