The impact of high biodegradable COD fraction in poultry processing wastewater to SBR performance

Sam Le Eh Kan1, Muhammad Ridwan Fahmi1, Abdul Haqi Ibrahim1, Che Zulzikrami Azner Abidin1 and Andy Surin Khoo2

1Faculty of Civil Engineering Technology, Universiti Malaysia Perlis, (UniMAP), Perlis, Malaysia.
2Public Work Department Hulu Perak, 33300 Gerik, Perak.

E-mail: samle@kkjerai.edu.my

Abstract. The present study investigates the impact of high biodegradable COD fraction in poultry processing wastewater on the performance of lab-scale SBR. The SBR’s reactor was operated under 3 phases with different airflow rates namely 2.5 L/min, 5.0L/min, and 7.0L/min; and each phase would have a constant 21days of Sludge Retention Time (SRT). The sample of poultry processing wastewater consists of 84.06% of biodegradable components and 15.94% of the non-biodegradable component. It was observed that high readily biodegradable soluble COD (rbsCOD) had caused a rapid bacteria’s metabolism to consume nutrient as fast as possible which consequently tuned the COD removal efficiency from 85.0% to 92.9% and increased the SVI from 51.66 mL/g to 66.96mL/g (2nd phase) and 110.1 mL/g (3rd Phase). The removal efficiency of Ammonia Nitrogen and Total Suspended Solid was observed in the range from 69.3% to 81.2%, and 61.8% to 81.7% respectively. The fluctuation of the biodegradable COD component in poultry processing wastewater was observed to affect the oxygen demand, where the oxygen transfer efficiency dropped from 3.82% to 0.63% as the airflow rate increase from 2.5L/min to 7.0L/min along with the increase of biodegradable COD fraction. Hence, this experiment provides a clear perspective of poultry processing wastewater behavior to SBR performance.

1. Introduction

The Malaysian livestock industry is one of the largest sources of protein for Malaysians where the ex-farm value was estimated at around RM 19.8 Billion in 2016 and more than 50% was contributed from the poultry meat industry [1]. There was an estimated around 1.2 Million Metric Tonne of poultry meat had been processed, whilst the demand was stood at an average of 1.3 Million Metric Tonne from 2009 to 2014 [1]. The wastewater from the poultry processing industry can create havoc on the environment and social impact if the wastewater were mishandled or not properly treated. Some researchers had conducted a study on the effect of chicken blood and its component on wastewater characteristics shown a significant effect on sewerage treatment plan and how the sewerage authorities to impose surcharged to the poultry industry [2].

In line with this situation, poultry industries were looking into a solution to overcome this problem. Therefore, the Sequential Batch Reactor (SBR) offers a better and attractive alternative to the conventional continuous activated sludge process to achieve excellent efficiency in the removal of various contaminants due to its practicable and economic. The dynamics and flexibility of SBR ensure there is adequate potential for future expansion and operational configurations with a minimal cost [3-5]. Many researchers conducted various studies regarding the SBR method in dealing with poultry
processing wastewater by introducing additional filter material, the attached growth technique, the addition of the Anaerobic phase, Electrocoagulation, various Hydraulic Retention Time, etc. [6-9]. The poultry processing wastewater is considered as high strength wastewater contains high organic compounds where the COD/BOD ratio was 4 to 1, while other biological parameters were above the Environment Quality Act’s Standard [2,6,10]. Many researchers had conducted a study on poultry processing wastewater with a wide range of standard parameters indicate that the degree of contaminations was different from one factory to another factory as shown in table 1.

Table 1. Characteristic of poultry industry wastewater.

| Parameter | Unit | Range | Average | Range | Average | Range | Average |
|-----------|------|-------|---------|-------|---------|-------|---------|
| COD       | mg/L | 575 - | 1502 ±  | 3154 - | 5422 ±  | 777 - | 1301 ±  |
|           |      | 2626  | 538     | 7719  | 2282    | 1825  | 741     |
| BOD5      | mg/L | 216 - 788 | 484 ± 160 | 1341 - | 1602 ±  | 573 - | 875 ±  |
|           |      | 1212  | 434     | 1821  | 243     | 1177  | 427     |
| TSS       | mg/L | 53 – 1047 | 200 ± 131 | 377 – 5462 | 3438 ± 2696 | 395 – 783 | 589 ± 274 |
| TN        | mg/L | N.A   | N.A     | 162 – 564 | 361 ± 215 | N.A   | N.A     |
| NH4+ - N  | mg/L | 38 - 210 | 96 ± 50 | N.A | N.A     | N.A   | N.A     |
| pH        |      | 7.87  | 0.39    | 7.3 – 8.6 | 0.42    | 6.90  | 0.42    |

*Author’s current study
Yackob et.al, 2018
Aziz et.al, 2018

The efficiency of SBR operation is depending on the biodegradable process in Mixed Liquors Suspended Solid which is also depending on the oxygen transfer from the aeration system. Therefore, the occurrence of oxygen transfer from the gas phase to the liquid phase in the aeration tank plays an essential role in the aerobic biological treatment, or else the effectiveness of biological degradation will be jeopardized. To serve that purpose, the oxygen transfer which consumes the largest composition of energy in every wastewater treatment plant needs a high efficiency in oxygen transfer to achieve carbon neutrality [12].

There many techniques to investigate the oxygen transfer process in the reactor and it can be range from direct dispersion of air into the water either by strip diffuser, modified airlift, fine bubble column reactor, orifices, etc. [13-15]. Some researchers had shown that the oxygen transfer coefficient is directly proportional to an interfacial surface contact area and oxygen-deficient, but adversely to liquid film thickness in their research in aeration reactor using a modified small Parshall Flume [15]. Some literature indicates that a high concentration of biodegradable COD would affect the design process and the performance of the biological treatment [16]. Due to the high strength and degree of pollution caused by poultry processing wastewater, the present study was conducted to investigate the impact of high biodegradable COD fraction in poultry processing wastewater on the performance of lab-scale SBR.
2. Materials and method

2.1. Sample preparation & reactor setup

Raw wastewater and activated sludge as microbial culture seed from the poultry processing industry (Advance Chicken Processing (M) Sdn. Bhd., Jejawi, Perlis) were collected in batches and stored in the refrigerator in constant temperature. The poultry wastewater was in the high concentration of biologically contaminates such as blood, fat, feather, and other organic materials. A laboratory-scale SBR with a capacity of 13L (GT 3001 R) rectangular Perspex tank; with a working volume of 8 L consists of 4.5 L of raw poultry processing wastewater and 3.5 L of activated sludge were used in this experiment. The reactor was equipped with a 10.5” of strip air diffuser at the bottom of the reactor floor and connected to 3 air pumps (Regent 9500, Regent 7500, Regent-JIT 666A) with combined airflow up to 7L/min.

The operation of SBR consists of 5 phases which started from Fill, React, Settle, Decant, and Idle Stage. In each cycle, 3 L of fresh wastewater was feed into the reactor during Fill Stage. At this moment, initial readings of Dissolve Oxygen (D.O) were taken using DO Meter (YSI 5000) as well as the influent sample for the COD test. The air diffuser of 3.5 L/min was then operated at React Stage for aeration up to 17.5 Hours before its stop for 2 Hours in Settle Stage where a volume of 3 L of supernatant/treated effluent will be discharged in the Decant Stage before it continued to reach Idle Stage for 1.5 Hours each. Feeding of influent and discharge of effluent was performed by using a peristaltic pump (BL 100H, NATONGPUMP). The SBR’s operation was controlled using a 24-hour programmed electrical timer (ES-24HT, Eurosafe). The D.O readings were collected at all stages where the main focus was during React Stage to determine the oxygen transfer coefficient (kL,a) by using the Dynamic Method based on Unsteady State dissolve oxygen concentration material balance and samples for COD Test, BODs, Total Suspended Solid and Ammonia Nitrogen Test will be collected daily.

After 21 days of acclimatization period (Air Flow Rate of 3.5L/min), the SBR was operated on three stages under different diffuser inlet air flow rate (2.5L/min, 5.0L/min & 7.0L/min) which creates different D.O levels to evaluate the effect of airflow rate and the Oxygenation Efficiency (E) on SBR performance. The diffuser inlet airflow rate was varied using a gas flow meter (LZQ-5).

2.2. Chemical Oxygen Demand fraction

The assessment of carbonaceous matter in wastewater is normally measured either by BOD or COD and it is very important for analysis for the activated sludge process [16]. Relatively the COD parameter became a common parameter to use, so many methods of determining COD fraction had been proposed by researchers on domestic wastewater but it is hard to find the actual COD fraction on poultry processing wastewater. Generally, the COD can be quantified to biodegradable and non-biodegradable concentrations in the first stage; while the other stage is to categorize either soluble or particulates. The COD fraction can be presented in figure 1 [17-23].

![Figure 1. COD Fractions in wastewater.](image-url)
The readily biodegradable soluble COD (rbsCOD) and non-biodegradable soluble COD (nbsCOD) in the wastewater (influent and effluent) needs to be filtered with 0.45-micron fiberglass filter [17,18,22]. The sbpCOD can be determined by equation 1 [22].

\[
\text{sbpCOD} = \left( \frac{\text{BOD}_5}{k} \right) - \text{rbsCOD}
\]

Where \( k \) is the BOD decay coefficient (k = 0.35 to 0.70, for raw sewerage). The rbsCOD is determined using the rapid physical-chemical method and the influent rbsCOD can be calculated by equation 2 [24].

\[
\text{rbsCOD} = \text{COD}_{\text{sol}} - \text{nbsCOD}
\]

Where \( \text{COD}_{\text{sol}} \) is the influent truly soluble COD & nbsCOD is effluent non-biodegradable soluble COD. The \( \text{COD}_{\text{sol}} \) is determined at the supernatant product from flocculated influent wastewater by Zn(OH)\(_2\) at a pH of 10.5 and filtered by a 0.45micron filter. While the nbsCOD is determined by using the effluent and using the same method as \( \text{COD}_{\text{sol}} \) [19].

2.3 Performance monitoring and analysis

The evaluation of oxygen transfer thru air diffuser was performed by estimating the Oxygenation Capacity (OC) and Oxygen Transfer Efficiency (OTE). The rate of oxygen transfer by aerator or known as Oxygenation Capacity is defined as the standard rate of oxygen transfer \( \frac{dC}{dt} \) at initial oxygen concentration \( C_i = 0 \) in standard condition [25].

\[
\text{OC (gram, 0²/Hr.L)} = \left( \frac{dC}{dt} \right) = k_L a (C_s - 0) = k_L a \cdot C_s
\]

While Oxygen Transfer Efficiency (OTE) is defined as the fraction of oxygen transferred into the water due to pass one cubic meter of air [13,25,26].

\[
\text{OTE ()} = \frac{\text{OC} \times \text{Volume liquid in tank (Litres)}}{\text{Mass of Aeration intensity (gram/Hr)}} \times 100\%
\]

Where Mass of Aeration Intensity (gram/Hr) = 0.298 (g/L) \( \times \) Air Flow rate (L/min) \( \times \) 60min

Performance of oxygen transfer to SBR operational efficiencies was performed by analyzing soluble Chemical Oxygen Demand (sCOD), Biochemical Oxygen Demand (BOD\(_5\)), Ammonia Nitrogen (NH\(_3\)-N), Total Suspended Solids (TSS), and pH. The microbial culture was monitored as well. Mixed Liquor Suspended Solids (MLSS), Mixed Liquor Volatile Suspended Solids (MLVSS), and Sludge Volume Index (SVI) were monitored throughout the study. The organic contaminates removal efficiency either COD, BOD\(_5\), NH\(_3\)-N, or TSS can be determined by the equation as shown:

\[
\text{COD Removal Efficiency (}} = \frac{\text{Influent COD - Effluent COD}}{\text{Influent COD}} \times 100\%
\]

\[
\text{BOD}_5 \text{ Removal Efficiency (}} = \frac{\text{Influent BOD}_5 - \text{Effluent BOD}_5}{\text{Influent BOD}_5} \times 100\%
\]

\[
\text{NH}_3-N \text{ Removal Efficiency (}} = \frac{\text{Influent NH}_3-N - \text{Effluent NH}_3-N}{\text{Influent NH}_3-N} \times 100\%
\]

\[
\text{TSS Removal Efficiency (}} = \frac{\text{Influent TSS - Effluent TSS}}{\text{Influent TSS}} \times 100\%
\]
\[ SVI, \left( \frac{mL}{g} \right) = \frac{\text{Settled Sludge Volume} \times \text{Sample Volume} \times mL/L}{\text{Suspended Solids Concentration} \times mg/L} \times \frac{1000 \text{ mg}}{\text{gram}} \] (9)

3. Results and discussions

3.1. The COD fraction of poultry processing wastewater

The sample (influent and effluent) results from lab-scale SBR reactors were collected and the COD fraction was determined daily. The average of carbonaceous content in terms of COD fraction in poultry processing wastewater is showed in figure 2.

![Figure 2. COD Fractions in Poultry Processing wastewater.](image1)

![Figure 3. COD Fractions trends in the Experimental Phase.](image2)

The study found that poultry processing wastewater consists of a high value of readily biodegradable COD (rbsCOD) of 56.66% from total COD and the less constitute was non-biodegradable soluble COD (nbsCOD) which stand at 2.59%. It was found that the biodegradable component took almost 84.06% of the organic matter in the wastewater which is important data for SBR design. The experiment also found that the carbonaceous constitute was fluctuated and varies due to the factory's daily production activities. The trends of COD fractions are shown in figure 3.

It was learned that high contain rbsCOD would provide a favorable condition for microorganism growth as it is easy to be metabolized rapidly, while the sbpCOD requires a secondary organism to synthesis before it can be consumed slowly by an upper microorganism [16]. At the same time, some literature had found that the high content of rbsCOD would generate risk to bulking problems [27]. By comparison to domestic wastewater from other researcher studies, it was clear that the poultry processing wastewater was at high rbsCOD as showed in table 2.
Table 2. Comparison between poultry processing wastewater & domestic wastewater based on the previous researcher.

| Carbonaceous Constituent/ Resources of wastewater | aPoultry Processing Wastewater, Jejawi, Perlis | bGibraltar Town Domestic wastewater | cLeszno City Municipal T.Plan | dAverage of 21 w/water T.Plan |
|---------------------------------------------------|-----------------------------------------------|-----------------------------------|-------------------------------|-----------------------------|
| rbsCOD                                            | 57%                                          | 42%                               | 53%                           | 26%                         |
| sbpCOD                                            | 27%                                          | 28%                               | 29%                           | 28%                         |
| nbsCOD                                            | 3%                                           | 6%                                | 8%                            | 6%                          |
| nbpCOD                                            | 13%                                          | 24%                               | 10%                           | 39%                         |

a Author’s current study  
b Rodriguez et.al, 2016  
c Myszograj et.al, 2017  
d Roeleveld & VanLoosdrecht, 2002

3.2. Effect of biodegradable COD fraction on SBR performance
3.2.1. Performance of pollutants removal (sCOD, BOD₅, TSS & NH₃-N). Based on figure 4, the efficiency of pollutant removal increased with the increase of biodegradable COD fraction in the wastewater. The removal efficiencies in all three stages were generally reliable which shown a consistent pattern. The SBR reactor shown the highest removal efficiency during the 2nd and the beginning of the 3rd phase of the experiment as the biodegradable COD fraction had risen to its average high of 1390.05 mg/L or 84.4%.

![Figure 4. The efficiency of pollutant removal during the experimental period.](image)

During this time, the average removal of COD, BOD₅, NH₃-N, and TSS removal efficiencies were 92.6%, 91.6%, 82.0%, and 77.9% respectively. The observation found that the rate of microorganism growth had increased due to high rbsCOD in this period and the MLVSS had increased by 44.9% and 30.5% from 1st Phase to 2nd Phase and 2nd to 3rd Phase respectively. This high loading of biodegradable COD fraction with lower F/M ratio had created a good flocculating condition in the reactor which promotes a flavored condition for a smaller floc-forming microbial’s in their metabolism activities and subsequently, it had led to higher COD removal efficiency [28].
3.2.2. Sludge Volume Index (SVI). The SVI of the operation of the SBR reactor during the experimental period (Day 1 – 63) concerning biodegradable COD Fraction and F/M ratio is shown in figure 5 and figure 6.

The SVI or SV30 is a good indicator of an abundance of poorly settling microorganisms in the sludge which was related to the filamentous microorganism that has a high surface area to volume ratio [14]. From figure 5, the SVI showed an increment along with the increment of biodegradable COD fraction except for the last 2 weeks of the experiment; where the SVI kept on soared high. As the airflow increased from 1st phase to the 2nd and 3rd phase, the SVI had shown a consistent increment where it rose from an average of 51.66 mL/g to 66.96 mL/g (2nd phase) and 110.1 mL/g (3rd Phase) respectively. The high biodegradable COD concentration had caused the microorganism to gain momentum to growth and such event had to disintegrate organic loading and produces more cell as the colonial increased. Consequently, COD removal efficiency was observed slightly lower caused by the F/M ratio rose due to high MLSS concentration along with the high biodegradable COD [29].

![Figure 5. SVI trends during the experiment.](image1)

![Figure 6. SVI concerning F/M ratio.](image2)

3.2.3. Oxygen transfer performance. In the submerged aerated process in the SBR, the oxygen transfers from the air bubbles diffused from energized pump transfer into the surrounded liquid. In the activated sludge process, oxygen is consumed by the microorganism to disintegrate all elements in the wastewater into a new cell as well as other biodegradable matter. The oxygen transfer coefficient (kLa) for 2.5, 5.0, and 7.0 L/min air flow rate were shown in table 3.

It is found that the oxygen transfer coefficient measured was higher than domestic and other industries especially pharmaceutical waste. KLa measured from their experimental result were 0.055 \(^{-1}\) and 0.3975 \(^{-1}\) for airflow of 5 and 10 L/min each by using pharmaceutical waste [30], but some researchers showed a higher value of 33.84 \(^{-1}\) for domestic wastewater [31]. Some researchers set-up a flow rate of 3.33L/min with different aeration time and frequency resulting in a lower oxygenation efficiency range from 0.77% up to 1.50% [32]. It was found that as the airflow increased in the bioreactor, the oxygen transfer coefficient (kLa) continues to descend to its lowest value starting from 1st phase to 3rd phase of the experiment as shown in figure 7. This trend provides a good agreement as the coefficient of determination (r\(^2\)) shown a significant correlation of 0.9495 and it is consistent with many researchers who report the same finding on their research on wastewater test [16,26,34].
Table 3. The result of oxygen transfer performance of measured actual airflow rate.

| Air Flow Rate (L/min) | Oxygen transfer, coefficient, $k_{La}$ (Hr$^{-1}$) | Oxygen Transfer Capacity of the system, OC (g O$_2$/m$^3$.Hr) | Oxygen Transfer Efficiency (%) |
|-----------------------|-----------------------------------------------|---------------------------------------------------------------|-------------------------------|
| 2.5                   | 1.094                                         | 8.541                                                         | 3.82%                         |
| 5.0                   | 0.892                                         | 6.969                                                         | 1.56%                         |
| 7.0                   | 0.502                                         | 3.923                                                         | 0.63%                         |

At the same time, the differential value of oxygen transfer rate, $k_{La}$ also depends on the type of diffuser & reactor configuration leads to the differential gas holdup, bubble up rise velocity, and flow regime [13,33].

Besides that, as the MLSS concentration increased due to high biodegradable COD in the reactor, the oxygen transfer rate was observed to decrease exponentially as shown in figure 8. This finding also showed a good agreement with the researcher that found that the increasing value of SVI would be resulting in the reduction of the oxygen transfer coefficient [14]. The increase of MLSS concentration also causing the lowering of the oxygen transfer efficiency due to the liquor viscosity had increased the bubble size and thickness of the liquid film at the air–liquid boundary zone. Therefore, a higher airflow rate didn’t provide an upmost efficiency required in the reactor concerning the oxygenation process. The airflow regime is depending on the rate of the airflow from the diffuser supplied from the external pump and the diameter of the orifice which were believed to be related closely in the bubble formation process [33].

Therefore, higher air diffused has increased the superficial gas velocity (SGV) a probability to create a heterogeneous regime bubble formation which leads to less oxygenation efficiency, and this finding shown a good finding related to oxygen efficiency that decreased in a power-law relationship. Some researchers showed there is a strong correlation between Oxygenation Efficiency and bubble hydrodynamics [13].

![Figure 7. The Oxygen Transfer Coefficient (kLa) during the experiment phase](image1)

![Figure 8. Biodegradable COD and OTR during the experiment phase](image2)
4. Conclusions
The study presented was clearly shown that the higher degree of biodegradable COD fraction in Poultry Processing Wastewater had affected the performance of the lab-scale SBR. This experiment also reveals that poultry processing wastewater consists of almost 84% of biodegradable COD fraction and it was higher than domestic wastewater in terms of COD fraction. This was due to the contaminates agent such as blood, fat, feather and other organic material from the poultry processing plant had been mixed up with water runoff at the collecting pond. The SBR performances in removing organic contaminants were significantly affected by higher biodegradable COD concentration and it was shown by the trends removing efficiency of the COD, BODs, and NH₃-N as well as Total Suspended Solid removal and SVI value. Besides that, the high biodegradable COD fraction had provided a suitable condition for microorganism growth to boom and causing the lowering of the oxygen transfer efficiency due to the liquor viscosity had increased the bubble size and thickness of the liquid film at the air-liquid boundary zone, although the airflow was increased in each phase. Therefore, this experiment had provided a clear view of high biodegradable COD fraction to lab-scale SBR performances as well as providing a good view for the designer in designing and indicates the SBR plant performance for such contaminates material.

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