Evaluation of Biokinetic Parameters and Biological Treatability of Amman Slaughterhouse Wastewater Using Sequencing Batch Reactor (SBR)

Baheera Abu Aamer and Ahmad Jamrah *

ABSTRACT
A bench scale sequencing batch reactor with a total volume of 10L was used to study the treatability of Amman slaughterhouse wastewater and to investigate the effect of both cycle time and phase time on the performance of the sequencing batch reactor (SBR). Results showed that SBR operated with 8 hrs cycle time has achieved the best COD percentage removal of 98.7%. The operational mode resulting in the best treatment outcome was the 40% fill to react ratio which achieved COD removal between 85.3% and 97.3%. The performance of SBR in removing nutrients showed good ON, and P removals of 95% and 81%; respectively. The biokinetic coefficients of Amman slaughterhouse wastewater were determined using four bench scale batch reactors. Values of biokinetic constants obtained were Ks = 229.12mg/L, Y = 0.483 g/g, µmax = 0.618 d-1, and kd = 0.129 d-1; which compare reasonably well with values reported in literature.

Keywords: Industrial Wastewater Treatment, Slaughterhouse Wastewater, SBR.

1. INTRODUCTION
Amman slaughterhouse is one of the main and largest slaughterhouses in Jordan, established in 1972, and serves about 80% of the population in Jordan. The activity of Amman slaughterhouse consumes about 400 cubic meters per day, in which the generated wastewater is discharged directly into the sanitary sewer system (MOGA, 2004). Treatment of this wastewater should meet the Jordanian domestic effluent wastewater standards of 500 mg/l COD, 150 mg/l SS, 45 mg/l NO3, 70 mg/l T-N, and 15 mg/l of total PO4 [21]. Slaughterhouse activities introduce their own forms of polluted wastewater with high organic strength (depending on the degree of blood recovery): 2.3 to 11.4 g/l COD, 0.5 to 1.69 g/l TSS, 0.019 to 0.074 g/l ammonia nitrogen, 0.007 to 0.0283 g/l phosphorus, adequate alkalinity, relatively high temperature and sufficient organic biological nutrients (Gammer and Jacobson, 1970, Rajeshwari, 1999, masse, 1999). Characteristics of the wastewater to be treated constitute an important factor in designing the proper treatment unit. A study of the biodegradability of slaughterhouse wastewater showed very low readily biodegradable COD fraction of 2% (Rodrigo del Pozo, 2003).

In recent years, sequencing batch reactor (SBR) technology has received increasing attention and this is due to the fact that SBR shows capability of achieving removals of COD, suspended solids, nitrogen and phosphorus, in addition to treatment of hazardous wastes (Irvine et al., 1985). Besides, the sequencing batch reactor (SBR) has the potential to be a low cost technology. The SBR process is an aerobic batch technology which consists of distinct stages: fill, react, settle and decant. During the first stage, the reactor is filled with wastewater; which may be static, mixed or aerated depending on treatment objectives (Ketchum, 1997). React, is the time during which the tank receives no flow and completes the desired reactions. The fill and react stages are followed by a settling period, during which the feeding, aeration and/or mixing are stopped. The biomass settles down and the final decanting stage where the final effluent is separated from the medium by a level and/or speed controlled decanting device takes place.

Based on the national level, very few studies are available in the literature about the biological treatment of slaughterhouse wastewater. In addition, information on the design of such processes and biokinetic constants

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under the conditions prevailing in Jordanian industry are not available. This study aims to establish operating criteria to define the capability of SBR system to treat slaughterhouse wastewater.

The objectives of this study are: (1) to evaluate the treatability of slaughterhouse wastewater using sequencing batch reactor technology (SBR), (2) to investigate the effect of cycle time and phase time on the treatment efficiency of slaughterhouse wastewater, and (3) to evaluate the biokinetic constants of slaughterhouse wastewater generated in Jordan. The overall objective is to comply with the Jordanian effluent standards.

2. METHODOLOGY

Composite slaughterhouse wastewater samples were collected from Amman slaughterhouse. Samples were collected from two main effluent lines receiving wastewater from lambs and cows slaughterhouse, and from chicken slaughterhouse. Samples from both streams were mixed in the laboratory in proportion to the corresponding ratios of flow rates of 55%:45% (Saraireh and Jamrah, 2008). Samples were then screened with 0.5 cm opening to remove coarse solids found in the effluent wastewater.

Slaughterhouse wastewater treatment was carried out using a 10L rectangular Plexiglas SBR, with a volume prior to fill of 8L and volume exchange ratio of 25%. Wastewater was fed to the system by gravity through a port placed at the top of the reactor, while effluent was discharged from the reactor through another port placed at its bottom. Mixing was provided during the fill period. Air was supplied to the system through diffuser stone attached to the reactor central point, and connected to air compressor during the fill and react periods depending on treatment objectives. The pH, dissolved oxygen and temperature were measured using Russell model RL 400, and ATC probe electrode. An acclimatization step was carried out before the start of any treatment in order to create a biomass capable of handling wastewater with the characteristic of slaughterhouse wastewater.

Different cycle times were employed to study the effect of cycle time on the performance of the SBR in treating slaughterhouse. Cycle times of 6, 7, 8 and 9 hours were investigated. The phase times were selected so that fill and react phases accounted for 85% of the cycle time, draw and idle phases accounted for 10% and 5% of the cycle time; respectively. In all experiments, the fill to react ratio was 40% to 60%. All the experiments were run one cycle per day with four tracks for each cycle time being investigated. The strategies for the 4 cycle times being investigated are summarized in Table (1).

Results of the first part of the experiments were then used to investigate the effect of fill to react ratio on the treatability of slaughterhouse wastewater using SBR for 8 hours cycle time. Five different operating modes were studied with fill to react ratios of 10%, 20%, 30%, 40%, and 50%. Four tracks were run for each operating mode investigated with one cycle per day. Fill time was separated to both anoxic and aerated periods. Table (2) summarizes the experimental strategies of the five operating modes being investigated.

| Table 1. Strategies for the 4 cycle times being investigated |
|------------------|---------|---------|---------|---------|
| Cycle time       | 6 hours| 7 hours| 8 hours| 9 hours |
| Fill to React    | 40 %   | 40 %   | 40 %   | 40 %   |
| Anoxic fill, hr  | 2.04   | 2.38   | 2.72   | 3.06   |
| React, hr        | 3.06   | 3.57   | 4.08   | 4.59   |
| Settle, hr       | 0.6    | 0.7    | 0.8    | 0.9    |
| Draw and Idle, hr| 0.3    | 0.35   | 0.4    | 0.45   |
| Maximum reactor liquid volume (liter) | 8 | 8 | 8 | 8 |
| Fill/draw volume per cycle (liter)     | 2 | 2 | 2 | 2 |
| Temperature range (°C)                  | 18-23 | 20-25 | 18-23 | 22-25 |
| pH range                  | 7.0-8.0 | 7.0-8.3 | 7.0-8.3 | 7.0-8.0 |
| DO range (mg/L)            | 0.3-4  | 0.3-4  | 0.3-4  | 0.3-4  |

SBR design considerations

| Volumetric exchange ratio (typical range: 20-40%) | 25% |
| Biomass seeding | 30% |
Table 2. Strategies for the five operating modes for 8hrs cycle time being investigated

<table>
<thead>
<tr>
<th>Operating mode for 8 hrs cycle time</th>
<th>10% F.R</th>
<th>20% F.R</th>
<th>30% F.R</th>
<th>40% F.R</th>
<th>50% F.R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anoxic fill, hr</td>
<td>0.34</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Aerated fill, hr</td>
<td>0.34</td>
<td>0.87</td>
<td>1.54</td>
<td>2.22</td>
<td>2.9</td>
</tr>
<tr>
<td>React, hr</td>
<td>6.12</td>
<td>5.44</td>
<td>4.76</td>
<td>4.08</td>
<td>3.4</td>
</tr>
<tr>
<td>Settle, hr</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Draw and Idle, hr</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Maximum reactor liquid volume (liter)</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Fill/Draw volume per cycle (liter)</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Temperature range (°C)</td>
<td>21 - 25</td>
<td>24 - 26</td>
<td>24 - 28</td>
<td>25 - 28</td>
<td>26 - 28</td>
</tr>
<tr>
<td>pH range</td>
<td>7.6 - 8.4</td>
<td>7.6 - 8.3</td>
<td>7.3 - 8.3</td>
<td>7.1 - 8.2</td>
<td>7.1 - 8.2</td>
</tr>
<tr>
<td>DO range (mg/L)</td>
<td>2 - 4</td>
<td>2 - 4</td>
<td>2 - 4</td>
<td>2 - 4</td>
<td>2 - 4</td>
</tr>
</tbody>
</table>

SBR Design Consideration

<table>
<thead>
<tr>
<th>Volumetric exchange ratio (typical range: 20%-40%)</th>
<th>25%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass seeding</td>
<td>20%</td>
</tr>
</tbody>
</table>

Sludge wasting in both parts of the experiment was achieved prior to the end of react time for each cycle. This was carried out to maintain a fixed mixed liquor suspended solids concentration in the reactor within the typical range of 1500-5000mg/l reported by Metcalf and Eddy (2003). Samples were collected from each track during the course of treatment, and were analyzed for TCOD, TS, MLSS, T, DO, PH, and SVI. Samples of selected tracks were also analyzed for BOD, N, and P. All tests were performed in duplicates and conducted according to procedures adopted in the standard methods for the examination of water and wastewater (APHA, 1999).

Four bench scale batch reactors were employed to evaluate the biokinetic constants of the wastewater. Reactors were seeded with sludge collected from the aeration basin of an existing local activated sludge treatment plant after being acclimatized for 2 weeks with volumes of 0.5, 1.0, 1.5, and 2 Liters; respectively. Slaughterhouse wastewater was then fed to each reactor to a total volume of 5 liters in each reactor. Experiments were carried out in room laboratory temperature of 20-25 °C. Mixing was employed to keep contents in suspension. Each reactor was equipped with a 100 mm diameter stone diffuser installed into its central point. The outlet COD, pH, MLSS and MLVSS from the four reactors were measured daily according to slandered methods, until acclimatization point was reached, as outlined by Raj (2005). The pH range throughout the experiments was 7.5- 8.3.

3. RESULTS AND DISCUSSIONS

A set of experiments were conducted using SBR to treat wastewater coming from Amman slaughterhouse. The purpose was to study the effect of cycle time and phase time on the performance of the SBR treating slaughterhouse wastewater. Each experiment consisted of four tracks.

Overall, and during the course of treatment, the pH and alkalinity were increased from an average value of 7.2 and 500 mg/l as CaCO₃ in the influent to 8.2 and 650 mg/l as CaCO₃ in the effluent. The effluent was almost odorless compared to raw slaughterhouse wastewater, with yellowish color instead of the dark red color.

The first part of experiment was conducted to study the effect of cycle time on SBR performance using four different cycle times of 6, 7, 8, and 9 hours with 85% of cycle time fill and react (40% totally not aerated fill and 60% react time) (Irvine et al., 2004). Also, 10% of cycle time was devoted for settling and 5% of cycle time for draw and idle phases. Four tracks were employed for each cycle time. Analyses of tracks results obtained from these experiments showed the capability of the SBR to treat slaughterhouse wastewater in terms of COD removal. Figure (1) shows the influent and effluent COD concentration versus track number for the four cycle times being investigated. The results obtained showed the capability of SBR to satisfy with the Jordanian effluent standards of 500mg/l (Ministry of Water and Irrigation, 1997) using cycle time of 8 hours.
The percentage removal of COD versus track number for the four cycle times are shown in Figure (2). The figure shows that all cycle times were able to achieve good COD percentage removal where COD percentage removal reaches maximum value of 98.7% and a minimum of 83%. Figure (3) shows the maximum, minimum, and average percentage removal of COD versus track no. for each cycle time. The figure shows good performance of SBR in treating slaughterhouse wastewater in terms of COD removal with best results obtained using 8 hours cycle time with maximum, minimum, and average COD percentage removals of 98.6, 92.8, and 96.7; respectively. A reduction in the COD percentage removal was observed when the cycle time used exceeded the 8 hours. This indicates that the 8 hours cycle time result is the best performance of the SBR treatment of slaughterhouse wastewater.

The performance of the SBR treating slaughterhouse wastewater with respect to SS removal shows the same trend compared to COD removal, where the SBR resulted in an effluent with SS concentrations within the range of 10 to 82mg/l. This results in an effluent that complies with the Jordanian effluent standard of 150 mg/l (WAJ, 1997). It should be noted that the obtained effluent concentrations of SS are reasonable, and reflect significant removals, as shown in Figure (4).

Figure 1: Variation of influent and effluent COD concentration versus track number for all operational modes investigated

Figure 2: COD percent removal versus track number for all operational modes investigated
Figure (5) shows the percent removals of SS versus track number for the 4 cycles being investigated. The figure shows that the SS percentage removal reached a maximum value of 99%, and a minimum value of 91%. The 8-hours cycle time resulted in better percentage SS removal compared to the 9-hours cycle time despite the fact that the 9-hour cycle time has longer settling time. This indicates that the settling characteristics of the sludge resulting from the 8-hour cycle time were more favorable.

Figure (6) shows the maximum, minimum, and average percentage removals of SS. The figure shows that the 8- hour cycle time results in comparable percent removals of SS to those obtained with the 7-hour and 9-hour cycle times. This favorable removal of SS can be explained by the anoxic fill which helps in the establishment and growth of biomass with favorable settling characteristics (Jamrah and Al-Bakri, 2004).

Figures (7 and 8) show the relationship between COD removal and organic volumetric loading rate (OLR, amount of COD applied to the reactor per day) and F/M (amount of substrate in the influent per unit mass of cells). Figure (7) shows total COD percent removal versus organic load for all operational modes investigated. The range of OLR obtained throughout experiments was from 0.51 to 0.97. Figure (8) shows total COD percent removal versus F/M for all operational modes investigated. The range of F/M obtained throughout experiments was from 0.12 to 0.21. The figures show that both OLR and F/M were within the ranges reported by Metcalf and Eddy (2003). Figure (7) shows that the COD removal decreases as OLR increases, and that the SBR can achieve stable degree of treatment.
This result can also be seen in figure (8), since COD removal was not affected by the change of F/M.

An inverse relationship was observed between the MLSS and F/M, as shown in Figure (9). The figure shows that a decrease in F/M was observed as MLSS increases. This decreasing relationship indicates the SBR treatment functions within the known biological treatment norms (Jamrah and Al-Bakri, 2004). It should be noted that high SVI results were obtained throughout the experiments but the sludge still possessed enough favourable settling characteristics so that effluent could be drawn easily. This may be attributed to the low F/M.
ratios experienced throughout the experiments (Metcalf and Eddy, 2003). Seviour and Blackall (1998) reported that unfavourable settling characteristics of sludge resulting from treatment of slaughterhouse wastewater can result due to excessive growth of filamentous bacteria; among other reasons.

The SBR showed rapid reduction of substrate concentration as shown in Figure (10). Results presented in the figure are for 2 cycle times. Results presented in the figure are similar to those presented by Jamrah et al. (2008). The figure shows that the effluent concentration of total COD was 240, 280 mg/l, which was only slightly higher than the SCOD of 230, 200 mg/l (for 7 hours cycle time). This is consistent with residual COD levels reported by other researchers for the treatment of meat processing wastewaters (Masse and Masse, 2000; Thayalakumaran et al., 2003 N. Thayalakumaran, R. Bhamidimarri and P.O. Bickers, Biological nutrient removal from meat processing wastewater using a sequencing batch reactor, *Water Sci. Technol.* 47 (2003) (10), pp. 101–108. View Record in Scopus | Cited By in Scopus (7) Thayalakumaran et al., 2003).

In the second stage of experiments, the fill to react ratio was changed in order to study the effect of changing phase time on the performance of the SBR. A cycle time of 8 hrs was chosen for this investigation based on the results obtained from the first stage of experiments. The SBR was operated with 8 hrs cycle time with five different operational modes of 10%, 20%, 30%, 40%, and 50% fill to react ratios, with four tracks for each operational mode.

SBR treating slaughterhouse wastewater showed good performance even with operational mode changing. Figure (11) shows the influent and effluent COD versus track number for all operational modes being investigated. A maximum COD percent removal of 97.3% was achieved, while the minimum COD percent removal was 72%. These results are summarized in Figure (12) which shows the percentage COD removal versus track number.

![Figure 9: Variation of MLSS concentration versus F/M for all operational modes investigated](image)

![Figure 10: COD concentration during the cycle time of 6, and 7 hours with 40% fill to react ratio](image)
Figure (13) shows the maximum, minimum, and average percentage removals for the fifth operational modes. The results showed no significant difference between the 10%, 20%, and 30% operational modes with an average percentage removal of 81.9%, 81.7%, and 81.2%; respectively. The 40% operational mode resulted in the best performance of the SBR with a slight difference from the 50% operational mode. This result agrees with the findings of (Irvine et al., 2004, and Jamrah et al., 2008).

The performance of the SBR with respect to SS removal is shown in Figure (14) with different operational modes. An effluent with 8 mg/l SS represents the highest percentage removal of 99.3%, which is shown in Figure (15), was observed with the 40% operational mode. This indicates that the SBR is capable of removing SS as well as soluble constituents. This result agrees with the fact that the SS removal is affected by the anoxic fill strategy that enhances growth of good settling bacteria. (Jamrah, A. et al., 2008)

Figures (16 and 17) show the relationship between the percentage removal of COD with MLSS and F/M, respectively. The results indicate a stable performance of the SBR even when dealing with high strength wastewater such as slaughterhouse wastewater. In Figure (16), the SBR achieved high percent removal over varying range of MLSS (1976-2580) mg/l. Figure (17)
shows total COD percent removal versus F/M for all investigated operational modes. The range of F/M obtained throughout experiments was from 0.21-0.37. Figure (17) shows no effect of F/M on the COD removal which, which indicates stability of the SBR in treating this kind of waste.

![Figure 13: Maximum, minimum, and average percent removals of COD versus operational modes investigated](image)

![Figure 14: percent removals of suspended solids versus track number for all operational modes investigated](image)

![Figure 15: variation of influent and effluent suspended solids concentrations versus track number for all operational modes investigated](image)
The performance of the SBR in removing nutrients such as N, and P was investigated for selected tracks, and the results are summarized in Table (3). Results show that the 8 hrs cycle time with 40% totally anoxic fill yields the best results of removing nutrients. However, mixing necessarily introduced some oxygen during fill that would promote the aerobic degradation of COD.

TKN remains high in the effluent but most of the ON was converted to ammonium, as reported by Masse D. I, (2000). Typically, biological N removal in SBR is achieved through pre-denitrification, which occurs during the fill phase (or an anoxic phase between the fill and the aerobic react phase). Whereas nitrate-N from previous operational cycle reduced to nitrogen gas by the anoxic heterotrophic denitrifies. Results showed that nitrogen removal is also affected by the length of the anoxic and aeration times, which agrees with the findings of other investigators (Cesar Mota et al., 2005, ANUPAM DEBSARKAR et al., 2006). Also, aeration rate affects N and P removal, as reported by Jianping Liet et al. (2008).

### Table 3. N and P percentage removal for selected tracks

<table>
<thead>
<tr>
<th>Cycle time, hr</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fill to react</td>
<td>40%</td>
</tr>
<tr>
<td>Anoxic fill, hr</td>
<td>2.72</td>
</tr>
<tr>
<td>Aerated fill, hr</td>
<td>0.0</td>
</tr>
<tr>
<td>React, hr</td>
<td>4.08</td>
</tr>
<tr>
<td>Track no.</td>
<td>2</td>
</tr>
<tr>
<td>in</td>
<td>out</td>
</tr>
<tr>
<td>TKN (mg/l)</td>
<td>224</td>
</tr>
<tr>
<td>%TKN removal</td>
<td>50.9</td>
</tr>
<tr>
<td>NH₃ (mg/l)</td>
<td>80</td>
</tr>
<tr>
<td>ON (mg/l)</td>
<td>144</td>
</tr>
<tr>
<td>%ON removal</td>
<td>95</td>
</tr>
<tr>
<td>TP (mg/l)</td>
<td>31</td>
</tr>
<tr>
<td>%P removal</td>
<td>81</td>
</tr>
</tbody>
</table>

Alternating anaerobic and aerobic conditions are required for biological P removal (Wentzel et al., 1988). If influent wastewater does not contain sufficient rbCOD, then there will be a need to use chemical precipitation to enhance P removal. That refers to the fact that both denitrifies and organisms will compete for rbCOD for P release. (Filali-Meknassi et al., 2005).

Evaluation of biokinetics constants of slaughterhouse wastewater was based on a modified form of the Monod equation was. The Monod model was linearized as suggested by Metcalf and Eddy (2003):
The constants presented in the equations indicate the half
velocity constant ($K_s$) in mg/l, the maximum specific
substrate utilization rate ($k$) in g/g.d, the Growth yield
coefficient ($Y$) in g/g, the death rate coefficient ($k_d$) in day-1,
where $\mu_m$: maximum specific bacterial
growth rate, d$^{-1}$.

And for one day test

$$\frac{\Delta X}{X} = Y \frac{\Delta S}{X} - k_d$$

Experimental results were then fitted to the linearized
model as shown in figures (18 and 19). From figure (18),
which represents $\Delta X/X$ versus $\Delta S/X$ on COD, and MLVSS
basis, both growth yield coefficient ($Y$), and death rate
coefficient ($k_d$) can be estimated. The corresponding values
of $Y$ and $k_d$ for slaughterhouse wastewater were 0.483 g/g
and 0.129 d$^{-1}$, respectively.

Biokinetics constants $K_s$ and $k$ can be estimated by
plotting $(1/U)$ versus $(1/S)$ as in figure (19) on COD, and
MLVSS basis, where the inverse of the intercept
represent the biokinetics coefficient $k$, while the slope
will equal to ($K_s/k$). The calculated values of $K_s$ and $k$
were equal to 229.12 mg/l and 1.28 d$^{-1}$, respectively. The
maximum specific bacterial growth rate ($\mu_m$) can be
calculated, a value of 0.618 d$^{-1}$ estimated.

A comparison of the values of biokinetic constants of
slaughterhouse wastewater was carried out between
values obtained in this investigation and those reported in
literature. Table (4) present a summary of these values
and indicates that the biokinetic constant values of this
investigation are very well comparable to those reported
by other researchers.

### 4. CONCLUSIONS

This study investigated the use of SBR for treatment
of slaughterhouse wastewater generated in the city of
Amman. Results showed good performance of SBR in
treating slaughterhouse wastewater, with best results
obtained at cycle time of 8 hrs. Changing the operational
modes affects the performance of SBR. The best results
were observed at operational mode of 40% fill to react
time. SBR achieved maximum percentage reduction of
98.7% COD, and 99% SS all over the experiments and
minimum of 72.1%, and 86.9% COD and SS;
respectively.

SBR showed good results in terms of nutrients
removal from slaughterhouse wastewater. Obtained effluent concentrations were 7, and 6 mg/l ON and P, which represent reductions of 95% and 81%; respectively. Removal of COD and SS were over 96.2 and 97%. Providing an anaerobic fill period followed by an aerobic react allowed biological P removal to take place. The results obtained from batch study fit the Monod model, and the estimated biokinetic constants were, 229.12 mg/L, 0.618 d⁻¹, 0.483 g/g, 0.129 d⁻¹ for $K_S$, $\mu_{max}$, $Y$, and $k_d$; respectively.

**REFERENCES**


التقييم الجنسي والكيميائي لتصنيع المواد والسيرات،

بهايرة أبو أمير واحمد جمراح