Biological Treatment of Landfill Leachate using Sequential Batch Reactor

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Abstract

The treatment of different synthetic leachate solutions was studied under anaerobic conditions in a Sequential Batch Reactors, SBR. The first set of synthetic leachate solutions contained different initial concentrations of COD and ammonia only. The second set contained different initial concentrations of COD, ammonia, and phosphate. The range of initial concentrations of COD were (3,500 - 16,000 mg/l), of ammonia (150 - 700 mg/l), and of phosphate (90 - 400 mg/l). The ratio of COD/N/P was kept constant at 100/4.2/2.5, which was to be found the optimal ratio for efficient removal performance. The absolute percentage of the difference between initial concentrations for each batch treated at the two treatment periods did not exceed 5%. The anaerobic batch treatment was performed on two different synthetic leachates at two different periods of 6 and 24 hours periods. The first synthetic leachate contained COD and ammonia only. The removal efficiencies of COD at 24-hour treatment were higher than those of 6-hour for all tested leachates and with similar removal performances for both periods of treatment. The removal efficiencies of ammonia at 6-hour treatment were generally higher than those at 24-hour for all tested leachates. The second treated synthetic leachate by batch experiments contained COD, ammonia, and phosphate. The removal efficiency of phosphate increased with the increase of initial concentration at the two periods of treatment.

The removal efficiencies of 24-hour treatment were lower than those of 6-hour firstly and then almost equal. That would designate that at high phosphate concentrations, the time of treatment would not affect the removal efficiency of phosphate. Finally, it would be recommended that different types of treatment and operation cycles to be examined in order to establish the most efficient configuration of leachate treatment in SBR.

Keywords: Sequential Batch Reactor; Landfill Leachate; Wastewater Treatment; Pollution Control; Solid Waste; Biological Process

Introduction

Leach'ate is a liquid that has percolated through or out of some substance; a liquid that has been polluted or made toxic by percolating through rubbish; a solution obtained by leaching. Also, Environmental Protection Agency, EPA, provides a more specific definition where the leachate is any liquid including any suspended components in the liquid that has percolated through or drained from hazardous waste. In this context hazardous waste can be very broadly defined and could for example include a salt store, or contaminated soils. In this study the focus will be on the leachate derived from solid waste and in general from Municipal (Domestic and Commercial) Solid wastes often called sanitary wastes [1].

The composition of landfill leachates varies depending on the nature of the deposited wastes, soil characteristics, rainfall patterns and the age of the landfill. Usually, in young landfill leachates the dissolved organic matter is mostly made up of volatile fatty acids (i.e. a high BOD/COD ratio) that decrease with increasing landfill age as a result of the anaerobic decomposition that takes place in the landfill site. As the volatile fatty acid leachate content decreases, the COD/BOD ratio will be used in the leachate's strength. The implementation of the most appropriate technique for the treatment of leachates depends upon the specific characteristics of the particular waste stream;

biological processes are quite effective, when applied to relatively "young" or "freshly" produced leachates, but they are less efficient for the treatment of "older" leachates, while physical–chemical methods are not favored for the treatment of "young" leachates [2].

Material and Methods

Sequential Batch Reactors

The most cost effective method of full strength landfill leachate treatment is normally by Extended Aeration in a Sequencing Batch Reactor (SBR). Very high rates of ammoniacal nitrogen removal can be achieved in a single tank, and then the process is robust and simple to operate. Chemicals are used merely for trace nutrient augmentation and, where necessary, for pH adjustment. Extended aeration, with or without subsequent polishing stages, is suitable for most municipal waste leachates. It is not suitable where inhibitory substances are present at sufficient concentrations to prevent biological activity, or on its own when hazardous substances are present which would pass through the process unaltered. There are five basic phases in the treatment cycle of an SBR (Figure 1). They are; fill, react, settle, decant, and idle. The total time of the five steps is called the operating cycle, or just cycle time.

Figure 1: Bench-scale sequential batch reactor. Aerobic Digester W11, (1995) [3].

The time of each phase is controlled by a programmable logic controller that allows the system to be controlled from remote locations. In the fill phase, the raw wastewater enters the tank, mixed with the settled biomass from the previous cycle. There are different options of fill phase. They can be summarized as follow: Static Fill: no energy input to the system; allows accumulation of substrate; Mixed Fill: mixing without forced aeration, minimal aerobic activity; typically allows either anoxic or anaerobic reactions; Aerated Fill: mixing with forced aeration; typically allows aerobic reactions; often allows simultaneous anoxic and aerobic reactions [4].

Normal domestic waste leachate contains many nutrients to much higher strengths than domestic sewage. These are harmful to receiving watercourses. Leachate also contains many other substances which, depending upon the types of waste disposed of into the landfill, may be toxic to life, or may simply alter the ecology of the stream or watercourse, if not removed by treatment. For domestic landfill leachate ammoniacal nitrogen (NH_4-N) is normally the most difficult constituent to remove. Landfills, which have received significant quantities of hazardous materials, may produce leachates which contain these substances. But for the majority of landfills these are not normally present in the leachate even when co-disposal of these substances occurs [5,6].

Leachate Preparation

In this study, anaerobic treatability of municipal landfill leachate will be evaluated using a lab-scale Anaerobic Sequential Batch Reactors (ASBR's) at different temperatures representing seasonal changes. Loading rates, hydraulic retention times, How can you have load-

ing rates and hydraulic retention times in a SBR. I thought that these are for continuous systems and influent concentrations will also be investigated in terms of removal efficiency and biogas production. This includes the study of nitrification, denitrification and phosphorus removal according to a number of variables that may affect the performance of ASBRs. These variables include amongst others: Cycle time, Nutrient loading, Food-to-microorganisms ratio (F/M), Aeration and filling patterns, Sludge age and Ratio of COD to nutrient concentration. Once the effect of these variables on the performance of the system is considered, simulation and modeling of the anaerobic treatability of municipal landfill leachate in ASBRs can be performed.

The treatment of different synthetic leachate solutions was studied under anaerobic conditions. The first set of synthetic leachate solutions contained different initial concentrations of COD and ammonia only. The second set contained different initial concentrations of COD, ammonia, and phosphate. The range of initial concentrations of COD were (3,500 - 16,000 mg/l), of ammonia (150 - 700 mg/l), and of phosphate (90 - 400 mg/l). The ratio of COD/N/P was kept constant at 100/4.2/2.5, which was found the optimal ratio for efficient removal performance.

The absolute percent of difference between initial concentrations for each batch treated at the two treatment periods did not exceed 5%. Therefore, the removal efficiencies of each batch could be compared for the two periods of treatment. It should be also noticed that phosphate concentrations for last three batches exceeded the desired maximum value (400 mg/l). That would be related to two factors. Firstly, at high phosphate concentrations, dilution of samples was needed to fit the analytical range of the Hach metre. With higher dilution ratio, the measured values would be less accurate and that would result in higher measurements than the actual values. Secondly, the high COD concentrations, which relate to high phosphate concentrations, would be achieved by elevated quantities of starch. Even that starch was a weak source of phosphate; such high amounts would increase the phosphate level [5,6].

COD removal efficiencies of 6-hour and 24-hour treatment periods

The anaerobic treatment was carried out using a shaker for two different periods of treatment. The first period was six hours, which was higher than recommended period for operating cycle of SBRs treating municipal wastewaters [1] to ensure that efficient treatment would be reached. The second period of treatment was 24 hours, which would allow the investigation of the effect of long periods of treatment on the performance of activated sludge regarding the treatment of leachate.

You need a table to specify what are batch 1, 2, 3 etc in the figure.

The comparison between the removal efficiencies of COD of 6-hour and 24-hour treatment at different initial concentrations was illustrated in figure 2 I thought figure 1 is the cycle sof the SBR. For 6-hour treatment, the removal efficiency of COD was almost constant for initial concentrations ranged from 3,800 to 14,000 mg/l. It was around 58% with maximum value of 60% at COD concentration of 12,860 mg/l. For concentrations higher than 14,000 mg/l, the COD removal efficiency decreased with the increase of initial concentration until it reached the minimum value of 48% at COD concentration of 16,000 mg/l You need to explain this! This is happening due to the growth inhibition due to high substrate concentration according to biological reactions. The overall performance of COD removal for 6-hour treatment was not that efficient since the removal efficiency was relatively low, which would result in COD effluent concentrations higher than accepted values. This is due to shorter processing time before reaching the exponential growth rate stage.

For 24-hour treatment, the removal efficiency of COD was higher than that of 6-hour for all tested batches. That was expected since, with more time, the microorganisms would consume more COD especially when operating at the exponential growth rate where the rate of reaction, specific growth rate, μ_{max} is at its highest value. The removal efficiency was almost constant for first five batches, with a value around 78%. Its maximum value was 80% at initial concentration of 12,400 mg/l. For last three batches, the removal efficiency decreased with the increase of initial COD concentration until it reached its minimum value of 71% at COD concentration of 16,000 mg/l. Even with higher removal efficiencies, the overall COD removal performance of 24-hour treatment still not satisfactory in terms of meeting the required COD discharge levels.
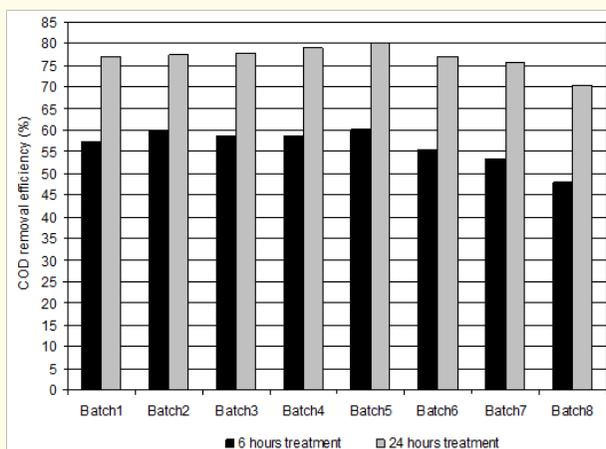
Figure 2: Comparison between COD removal efficiencies of 6 and 24 hr treatment.

Kettunen., *et al*. [7] compared between the effect of anaerobic and sequential anaerobic/aerobic conditions on the treatment of municipal landfill leachate at different temperatures using different types of sludge's. The properties of studied leachates were COD 2300 - 4500 mg/l and ammonia 110 - 160 mg/l.

During the anaerobic batch experiments, three initial COD concentrations were treated using four different sludge's. The conditions of these experiments are in table 1. What did he find? How does this compare with your own results?

Initial COD concentration, (mg/l)	Removal efficiency at 6 hours, %	Removal efficiency at 30 hours, %
2,800	50	74
5,100	51	70
7,050	57	69

Timur and Özturk [8] investigated the treatment of landfill leachate in a lab-scale anaerobic SBR. The COD initial concentration varied from 3,800 to 15,940 mg/l. The period of operating cycle was 24 hours: 10 minutes filling, 22.5 hours reacting anaerobically, 70 minutes settling, and 10 minutes decanting. The COD removal efficiency decreased from around 84% at 3,800 mg/l COD concentration to 64% at 15,940 mg/l COD concentration. Even though the leachate treatment was performed in an SBR but the results were very similar to those obtained by 24-hour treatment in this research and what made Timur and Özturk work very interesting that the range of COD concentrations was very similar to that used in this research.

Ammonia removal efficiencies of 6-hour and 24-hour treatment periods

These are results and should be included in the results section. Figure 3 shows the comparison among the removal efficiencies of ammonia of 6-hour and 24-hour treatment at different initial concentrations. For 6-hour treatment, the removal efficiency of ammonia for first four batches increased with the increase of initial ammonia concentration. The maximum value of ammonia removal efficiency was 62% at initial concentration of 453 mg/l. For concentrations higher than 453 mg/l, the ammonia removal efficiency decreased with the increase of initial concentration until it reached its minimum value of 54% at initial concentration of 787 mg/l. Here again, the overall removal performance of ammonia for 6-hour treatment was not that competent with its relatively low efficiency. That would cause ammonia effluent concentrations higher than accepted values. You need to introduce the nitrates and nitrites issues here since nitrates are

converted to nitrites and then nitrites are removed by conversion to nitrogen. This can be explained in the aerobic/anaerobic conditions for N removal.
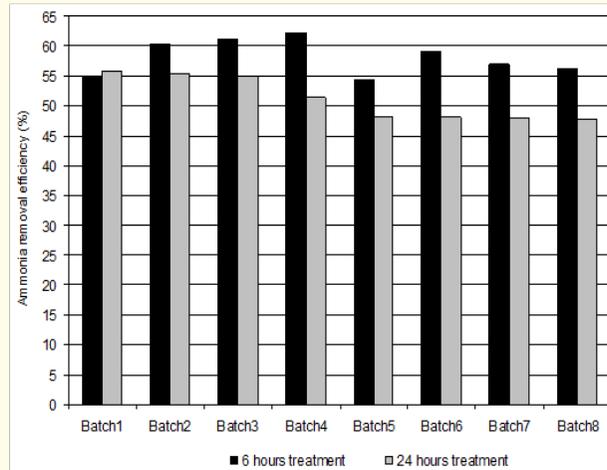

Figure 3: *Comparison between Ammonia removal efficiencies of 6 and 24 hr treatment.*

The ammonia removal performance of 24-hour treatment showed a slightly different from that of 6-hour treatment. The removal efficiency for all treated batches decreased with the increase of initial concentration until it reached its minimum value of 47.9% at initial concentration of 787 mg/l. The removal efficiencies of 24-hour treatment were lower than those of 6-hour for all tested batches, except for first batch where they were almost the same. Since the treatment method used was anaerobic, ammonia removal would not achieve the desired values to comply with approved discharge levels. As it is well known, efficient ammonia removal would be accomplished by the application of combined nitrification/denitrification processes. With anaerobic treatment, only denitrification process would occur and with longer time of treatment, the nitrifying bacteria would lose its ability, especially with the presence of produced-nitrate that could compete with ammonia. Therefore, the 24-hour treatment would cause lower removal efficiency and that was consistent with results discussed above. Therefore, the overall ammonia removal performance for 24-hour treatment was not efficient resulting in effluent concentrations higher than desired values.

Results

Effect of the increase of initial COD, ammonia, and phosphate concentrations on their removal efficiencies

COD removal efficiencies of 6 and 24-hour treatment with the presence of phosphate

The comparison between the removal efficiencies of COD of 6-hour and 24-hour treatments with the presence of phosphate at different initial concentrations was illustrated in figure 4. For 6-hour treatment, the removal efficiency of COD was almost constant for all initial concentrations, except 16,000 mg/l, and it was around 55%. For initial concentration of 16,000 mg/l, the COD removal efficiency reached its minimum value of 45%. The overall performance of COD removal for 6-hour treatment was not efficient, which was similar to that for 6 hours without the presence of phosphate, since the removal efficiency was relatively low and that would outcome in COD effluent concentrations higher than accepted concentrations.

For 24-hour treatment, the removal efficiency of COD was higher than that of 6-hour for all tested batches. With more time, the microorganisms would consume more COD and thus the removal efficiencies of COD at 24-hour would be higher. The COD removal performance of 24-hour treatment was generally similar to that of 6-hour. The removal efficiency was almost constant for first five batches, with a value around 78%. Its maximum value was 81% at COD concentration of 12,830 mg/l. For last three batches, the removal efficiency decreased

with the increase of initial COD concentration, where it reached its minimum value of 66% at COD concentration of 16,000 mg/l. Even with higher removal efficiencies, the overall COD removal performance of 24-hour treatment still not satisfactory in terms of meeting the required COD discharge levels. The 24-hour treatment with the presence of phosphate was similar to that without the presence of phosphate. You need to explain that the phosphate is essential nutrient that is consumed at the same time as COD. It is also consumed in the aerobic process.
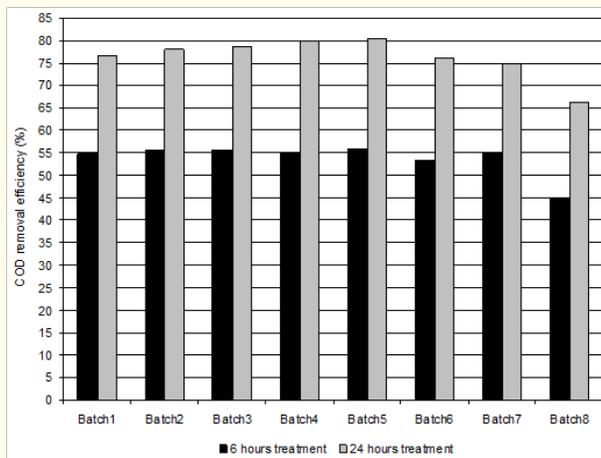

Figure 4: Comparison between COD removal efficiencies of 6 and 24 hours treatment with the presence of phosphate.

Ammonia removal efficiencies of 6-hour and 24-hour treatment with the presence of phosphate

Figure 5 shows the comparison among the removal efficiencies of ammonia of 6-hour and 24-hour treatments with the presence of phosphate at different initial concentrations. For the two periods of treatment, the removal efficiency of ammonia did not show a trend to be outlined. For 6-hour treatment, the efficiency increased with the increase of initial ammonia concentration for first three batches. After that, the efficiency dropped to some extent for the fourth batch but started to increase with the increase of initial ammonia concentration until it reached its maximum value of 50% at initial concentration of 675 mg/l. Finally, at the highest initial ammonia concentration of 697 mg/l, the removal efficiency decreased slightly from its maximum value. However, the ammonia removal performance for 24-hour treatment did not show the same behavior of that of 6-hour. It was for the first batch at the highest value (45%) and then declined to its minimum value of 31% for the second batch. After that, the removal efficiency kept rising and falling with the increase of the initial ammonia concentration.
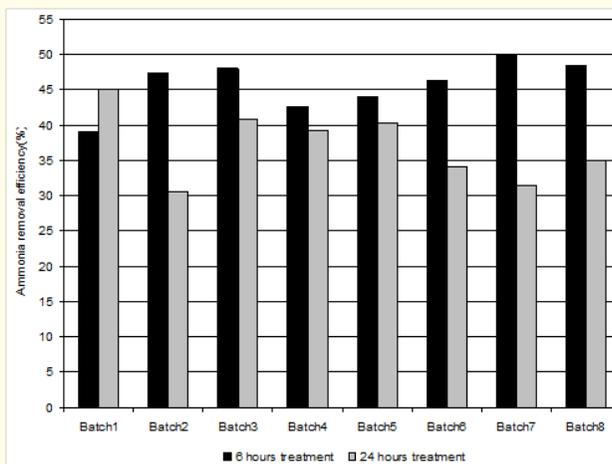

Figure 5: Comparison between Ammonia removal efficiencies of 6 and 24 hours treatment with phosphate.

The removal efficiencies of 24-hour treatment were less than those of 6-hour for all tested batches, except for first batch which was higher than that of 6 hours. Such observation would again support the suggested explanation stated in Section 2.2. What is explained in section 2.2 that supports this? Finally, the overall removal performance of ammonia for both treatment periods was still not satisfactory in terms of meeting the required discharge levels. I think that we need to explain the mechanisms of COD removal, N removal and P removal processes and the conditions associated with it.

Phosphate removal efficiencies of 6-hour and 24-hour treatment

Figure 6 illustrates the comparison among the removal efficiencies of phosphate of 6-hour and 24-hour treatments at different initial concentrations. The removal efficiency of phosphate increased with the increase with initial concentration for the two times of treatment. The removal efficiencies of 24-hour treatment were lower than those of 6-hour for the first four batches. After that, the removal efficiencies were almost equal. That would indicate that at high phosphate concentrations, the time of treatment would not affect the removal performance of phosphate. However, with higher removal efficiencies at high initial concentrations, the overall performance of anaerobic treatment of phosphate still not meeting the required discharge levels of phosphate and further treatment would be required to achieve such requirements. Efficient phosphate removal performance would be accomplished by a sequence of anaerobic/aerobic processes. However, the anaerobic batch treatment of phosphate from synthetic leachate showed high removal efficiencies even at high initial concentrations. The anaerobic condition would cause a release of phosphate and even with the absence of nitrifying bacteria, which would enhance the removal process of phosphate, the PAOs were capable to adapt with the increase of initial concentration.
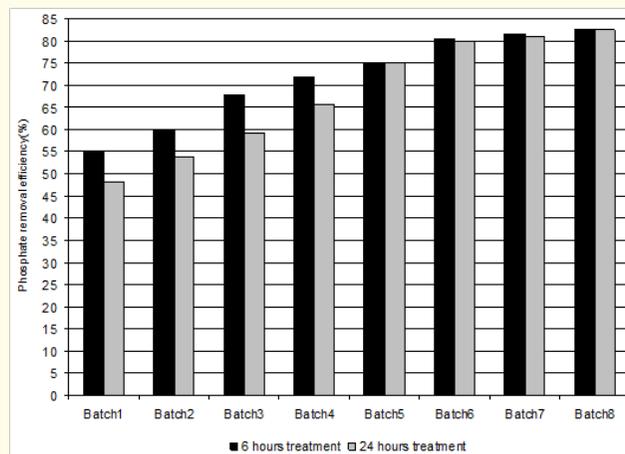

Figure 6: *Comparison between phosphate removal efficiencies of 6 and 24 hours treatment.*

Effect of phosphate presence on the removal performances of COD and ammonia

Effect of phosphate presence on COD removal performance at 6 and 24 hours of treatment

The values of COD removal efficiencies for 6-hour treatment with the use of phosphate were less than those without phosphate, as could be seen in figure 7. The difference between those values, however, was not that high. That would be expected since the consumption of COD was not very dependable on the presence of different nutrients. That would be more justified with the investigation of the effect of phosphate presence on the 24-hour treatment. As shown in figure 8, the COD removal efficiencies were almost equivalent for all batches, except last batch where the removal efficiency with the presence of phosphate was lower than that without phosphate. Such distinction might be due to the high levels of phosphate, which would reduce the activated sludge effectiveness with its competition on the capacity of microorganisms.
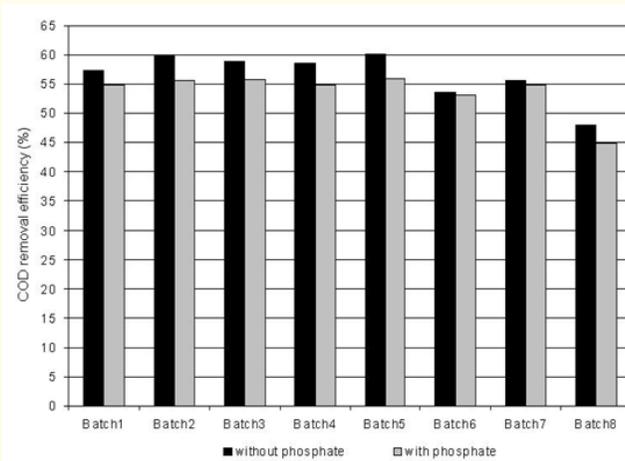
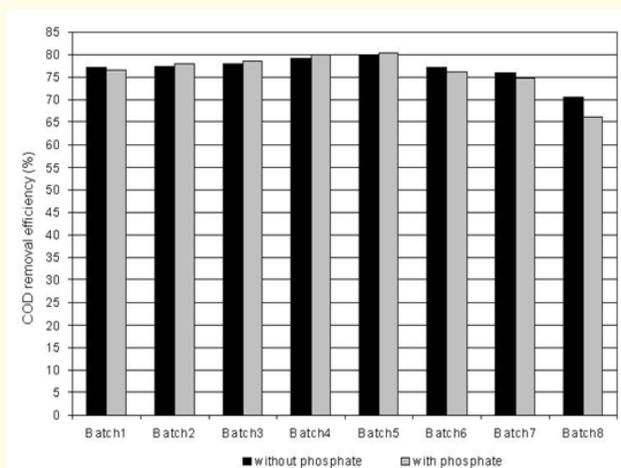*Figure 7:* *Comparison between COD removal efficiencies with and without the presence of phosphate for 6 hours.*

Figure 8: *Comparison between COD removal efficiencies with and without presence of phosphate for 24 hours.*

Effect of phosphate presence on ammonia removal performance at 6 and 24 hours of treatment

The values of ammonia removal efficiencies for 6-hour treatment with the phosphate were lower than without phosphate (Figure 9). The difference between those values could be considered significant high. That would be expected since ammonia removal would be affected by the presence of phosphate. Ammonia removal performance, as mentioned before, would not be efficient under anaerobic conditions. However, phosphate could be removed under such conditions. The presence of phosphate therefore would compete with the ammonia and reduce its removal efficiency. That was also the same tendency with the results of 24-hour treatment, as represented in figure 10. Therefore, it would be recommended that aerobic treatment of leachate should be studied to investigate its effect on ammonia removal with and without the presence of phosphate.
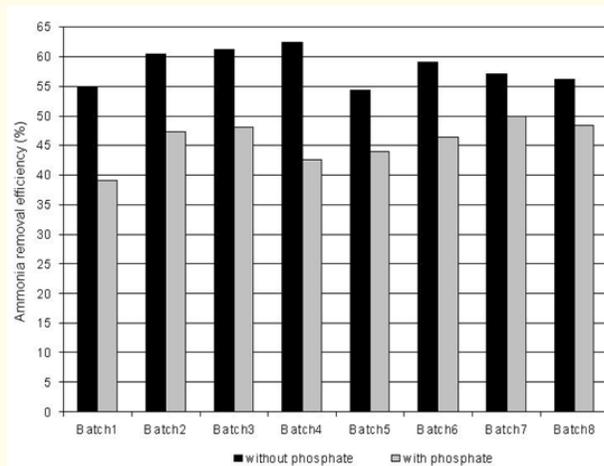
Figure 9: Comparison between Ammonia removal efficiencies with and without phosphate for 6 hrs.
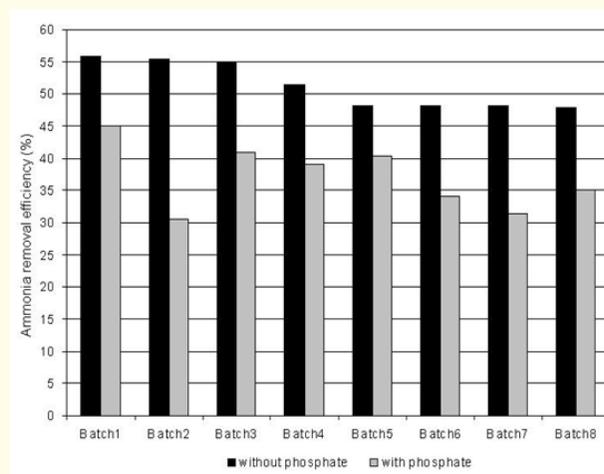

Figure 10: Comparison between Ammonia removal efficiencies with and without phosphate for 24 hours.

Removal Performance

The SBR performances in removing COD, ammonia and phosphate were investigated in this work. Most of the COD removal was accomplished in the anaerobic step and did not improve considerably at the end aerobic step of react phase. The final removal efficiency of COD did not vary that much with the increase of initial concentration. That would suggest that the activated sludge had adjusted with the increase of COD concentration and was competent to such elevation. Ammonia removal efficiency did not improve with the use of anaerobic/aerobic sequence. High ammonia concentration would have an inhibition effect on the activated sludge and would not be overcome with the application of aerobic conditions. The removal efficiency of phosphate improved at the end of the aerobic react step. That would be as a result of the uptake of phosphate by PAOs was supported with the nitrifying bacteria. The increase of initial phosphate concentration caused the difference of removal efficiency between the two react steps to decline. That would indicate that the increase of phosphate concentration caused an inhibition effect on the activated sludge. Therefore, the aerobic process did not generally improve the nutrients biodegradation from synthetic leachates in SBRs.

Variations of COD removal efficiency versus time for different leachate systems were depicted in figure 11. Most of COD removal was accomplished in the first step (anaerobic) of react phase for all treated systems. For example, for first system with initial COD concentration of 5,460 mg/l, the COD removal efficiency was 73% at the end of the anaerobic step. The COD removal efficiency did not improve considerably at the end of react phase for all systems, even that the second react phase was a three-hour aerobic step. That would point out that aerobic process did not boost the treatment process of leachate by SBRs. For the first system, the removal efficiency increased just from 73% to 76% at the end of the react phase. At the end of settle phase, the COD removal efficiency slightly decreased, which could be as a result of the cease of aeration and mixing during the settle phase. Therefore, the concentration of dead zones, which are usually higher than those of mixed zones, would be diffused into the whole solution and decrease the overall COD removal efficiency. For example, the removal efficiency of the first system decreased from 76% to 74% at the end of the settle phase.
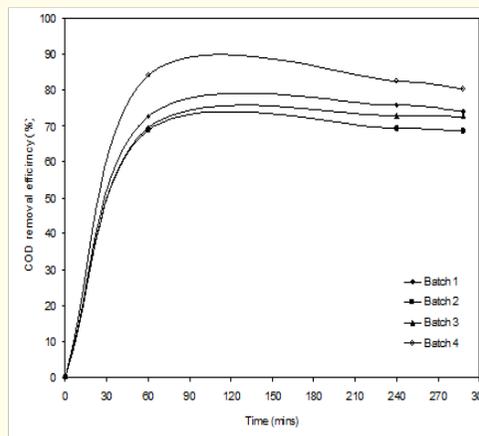

Figure 11: Variation of COD removal efficiency of different leachate systems with time in a bench-scale SBR.

Kargi and Pamukoglu (2003) studied the biological treatment of pre-treated landfill leachate by fed-system operation under aerobic conditions. The initial COD concentration was 7,200 mg/l and the treatment time was up to 30 hours. They studied variation of COD removal percent with time for different COD concentrations prepared by diluting the initial concentration to desired values. The removal efficiencies for different COD concentration at 6 and 30 hours were as following:

Initial COD concentration, (mg/l)	Removal efficiency at 6 hours, %	Removal efficiency at 30 hours, %
2,800	50	74
5,100	51	70
7,050	57	69

They also studied the increase of COD loading rate on the removal efficiency. They reported that the efficiency decreased from 76% to 68% with increase of loading rate from 500 mg COD/h to 4,300 mg COD/h. Such results showed that even with increase of COD concentration, the removal efficiency of 6 hours increased. However, the removal efficiency for 30-hour treatment decreased with the increase of initial COD concentration. Such results would support the stated observations for the treatment of leachate in a bench-scale SBR, which operated however at higher initial concentrations. In addition, the aerobic process for treatment did not present a satisfactory removal performance, which support the conclusions mentioned above for COD removal performance of SBR.

System	Initial COD concentration, (mg/l)	Initial ammonia concentration, (mg/l)	Initial phosphate concentration, (mg/l)
1	5,460	143	52
2	8,600	284	152
3	12,950	509	223
4	15,000	675	271

Table 2: Composition of different synthetic leachate systems treated by a bench-scale Sequential Batch Reactor.

Discussion and Conclusion

The main objective of this study was to investigate the anaerobic treatment of synthetic leachate. Such treatment was examined by two methods: and a bench-scale SBR, or was it just a sequential batch reactor (SBR).

The anaerobic batch treatment was performed on two different synthetic leachates at two different periods of 6 and 24 hours. The first synthetic leachate contained COD and ammonia only. The removal efficiencies of COD at 24-hour treatment were higher than those of 6-hour for all tested leachates and with similar removal performances for both periods of treatment. The removal efficiencies of ammonia at 6-hour treatment were generally higher than those at 24-hour for all tested leachates. The second treated synthetic leachate by batch experiments contained COD, ammonia, and phosphate. The removal efficiency of phosphate increased with the increase of initial concentration at the two periods of treatment. The removal efficiencies of 24-hour treatment were lower than those of 6-hour firstly and then almost equal. That would designate that at high phosphate concentrations, the time of treatment would not affect the removal efficiency of phosphate.

For both periods of treatment, the COD removal efficiencies with and without the presence of phosphate were almost equivalent for all leachates. Such behavior would indicate that the consumption of COD was not dependable on the presence of different nutrients. The removal efficiencies of ammonia in the presence of phosphate were significantly lesser than without the presence of phosphate, for both periods of treatment. That would be as a result the phosphate competition with ammonia, which would reduce the removal efficiency of ammonia.

The removal performances of COD, ammonia and phosphate were investigated in a bench-scale SBR for four systems of leachate. Cycle 2 was chosen since the react phase started with an anaerobic step and thus its performance would be compared with the anaerobic batch experiments. Most of the COD removal was accomplished in the anaerobic step and did not improve considerably at the end aerobic step of react phase. The final removal efficiency of COD did not vary that much with the increase of initial concentration. That would suggest that the activated sludge had adjusted with the increase of COD concentration and was competent to such elevation.

Ammonia removal efficiency did not improve with the use of anaerobic/aerobic sequence. High ammonia concentration would have an inhibition effect on the activated sludge and would not be overcome with the application of aerobic conditions. The removal efficiency of phosphate improved at the end of the aerobic react step. That would be as a result of the uptake of phosphate by PAOs was supported with the nitrifying bacteria. The increase of initial phosphate concentration caused the difference of removal efficiency between the two react steps to decline. That would indicate that the increase of phosphate concentration caused an inhibition effect on the activated sludge. Therefore, the aerobic process did not generally improve the nutrients biodegradation from synthetic leachates in SBRs.

Overall, it had been shown in this study that the anaerobic treatment of leachates was capable generally to reduce the influent concentrations of COD, ammonia, and phosphate. However, the final effluent concentrations were higher than those of accepted values and consequently a post treatment should be performed before discharging to environment. Finally, it would be recommended that different types of treatment and operation cycles to be examined in order to establish the most efficient configuration of leachate treatment in SBR.

Overall, it had been shown in this study that the anaerobic treatment of leachates was capable generally to reduce the influent concentrations of COD, ammonia, and phosphate. However, the final effluent concentrations were higher than those of accepted values and consequently a post treatment should be performed before discharging to environment.

Finally, it would be recommended that different types of treatment and operation to be examined in order to establish the most efficient configuration of leachate treatment in SBR.

The conclusions are excellent and much better than the discussion. In fact a lot of this can go into discussions and the conclusions can be very brief [9-15].

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