Treatment of Wastewater From a Beverage Factory Using the Activated Sludge Process

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Abstract

The activated sludge process although not popular in developing countries, can be useful in the treatment of high strength wastewater and when land cost is high. In the activated sludge process, secretions by bacteria entraps suspended solids to form dense aggregates which settle under their weight to form sludge, part of which is recirculated. The objective of the study was to characterize the industrial wastewater from a beverage manufacturing plant and to assess the ability of the activated sludge treatment plant to remove key constituents. Influent wastewater from an equalization tank was channeled into a biological reactor, a primary clarifier and a secondary clarifier. The total average hydraulic retention time was 43.6 hours at a flow rate of 1704 m3/d. Influent BOD, COD, Total Nitrogen, Total Phosphorus, Total Suspended Solids, Total Dissolved Solids, iron were 687, 3085, 5.5, 80, 34, 4.2mg/L, respectively. Effluent concentrations of BOD, COD, Total Nitrogen, Total Phosphorus, Total Suspended Solids, Total Dissolved Solids and iron from the second (final) clarifier tank were 2.4, 102.0, 1.0, 0.3, 13.9, 695.9 and 0.1mg/L, respectively, representing a removal efficiency of 99.7, 96.7, 81.3, 99.6, 58.8, 63.8 and 97.0%, respectively. All the parameters mentioned above met regulatory guidelines for discharge into water bodies.

Introduction

The Activated Sludge Wastewater Treatment Systems (ASWTS) has been in use for several decades around the world. The ASWTS requires very high energy input in the form of mechanical aerators for mixing, high capital and operational costs and high production of sludge (Gray, 2010; Mungray and Patel, 2011). Intermittent supply of electricity and poor maintenance culture resulted in the breakdown of many of such treatment systems making them a less popular option for wastewater treatment in developing countries like Ghana. There has however been renewed interest in this technology in recent times due to the introduction of various innovations such as the incorporation of aeration candles and biofilm surfaces which enhances the rate of degradation of substrates (Huang *et al*., 2016).

The activated sludge process (ASP) of the ASWTS utilizes the formation of biological flocs to remove wastewater pollutants. Secretions of extracellular polymeric substances (EPS) by bacteria entraps more bacteria cells and suspended solids to form dense aggregates which settle under their weight to form sludge. The biological flocs which form the sludge contains various kinds of bacteria, protozoans and rotifers and this results in high uptake of organic substrates and microbial growth rates. The active degradation of organic matter by these organisms results in the removal of organic matter and nutrients. Another key feature of the ASP is that the sludge containing active degraders is recirculated in the treatment system for the degradation of fresh wastewater entering the treatment system. Compared to other types of conventional treatment systems ASP can remove faecal bacteria better (Sala-Garrido *et al*., 2011), utilizes shorter residence time in organic matter oxidation, have a higher operational flexibility with respect to organic load and hydraulic variations and a better efficiency in performance in terms of BOD, nitrogen and phosphorus removal (Hanhan *et al*., 2011; Sala-Garrido *et al*., 2011). Additionally, optimum average temperatures of 30oC in developing countries can promote efficient degradation of organic matter in circumstances where high strength wastewater need to be treated in a shorter time. The beverage industry presents such a situation where high concentration of BOD coming in high volumes require shorter retention times and therefore very high degradability capability. The performance of such an ASWTS in Ghana treating high strength wastewater from a beverage industry is not documented in the literature.

High water consumption is one of the major characteristics of the beverage industry and this results in the generation of very high volumes of wastewater (Fillaudeau *et al*., 2006). In beverage industries such as those producing soft drinks, it is estimated that bottle washing alone accounts for 50% of the volume of wastewater generated (Ramirez-Camperos *et al*., 2004; Abdel-Fatah *et al*., 2017). The remaining 50% may come mostly from the cleaning of factory floor and equipment as well as the processing of raw materials for the production of the soft drink. Wastewater from soft drink producing industries usually are characterised by high organic substrate concentration, phosphorus, total suspended and dissolved solids. Soft drink industrial wastewater may have BOD and COD concentrations varying widely depending on the raw materials used but BOD concentrations of 728-1745mg/L and COD concentrations of 620-3470mg/L are typical (Amuda *et al*., 2006). Dissolved carbon may form approximately 10-12% w/v mostly in the form of sugars (Kalyuzhnyi *et al*., 1997; Isla *et al*., 2013; Wickham *et al*., 2018). Characterising the influent wastewater from a soft drink industry over a prolonged period therefore is necessary for ensuring the operational stability of the treatment plant and for assessing its performance. The objective of this research is to investigate the impact of introducing a secondary clarifier to the overall performance of the ASWTP treating wastewater from a soft drink producing factory. Effluent concentrations of key parameters were monitored for two years without a secondary clarifier and this is compared with effluent concentrations monitored over a period of one year when a secondary clarifier had been installed.

Materials and Methods

Description of Setup

The activated sludge treatment plant is located at the premises of a soft drink producing factory in a light industrial area at Accra, Ghana (5°37’44.2” N,0°08’01.6” W and 5°39’07.5” N, 0°05’33.9” W) in the north and (5o37’08.5” W, 0°04’06.8W and 5o37’11.8” N, 0°05’30.9” W) in the south. The treatment plant consists of a grit chamber which receives influent wastewater from the factory and where there is sieving and separation of solid particles from the wastewater. The wastewater then flows into a collection tank, an equalization tank, a biological reactor, a primary clarifying tank and a secondary clarifying tank from which the effluent is discharged and the sludge transferred into a holding tank (Figure 1). The collecting tank is important in controlling the flow rate of wastewater into the equalization tank to avoid spill – over or under feeding of the equalization tank. The equalization tank, measuring 20m x 12m x 5.5m has a residence time of 16.9 hours during which there is thorough mixing of wastewater by mechanical blowers and pH control also occurs, maintaining it at a pH of 8-9 before entering the biological reactor. Biological treatment or degradation of the wastewater occurs in the biological reactor (20m x 15m x 5.5m) in a suspended growth process involving microbial aggregates of bacteria, protozoans, rotifers etc utilizing organic substrates and converting them into microbial biomass and sludge through floc formation. This process is also aided by mechanical aerators maintaining a residence time of 21.1 hours. A primary (9m x 2.5m x 5.5m) and secondary (20m x 2.5m x 5.5m) clarifier having residence times of 1.7 and 3.9 hours respectively aids the settling of biological flocs. The secondary clarifier ensures an improved quality of the effluent allowing for further settling of suspended particles. Sludge from the primary clarifier or the secondary clarifier may be transferred back to the biological reactor or a sludge holding tank (12.5m x 6.2m x 5.5m) depending on the need. The flow rate of the wastewater was maintained at 1704m3/day.

Operation and Monitoring of Treatment Plant

The activated sludge treatment plant was monitored monthly for nine (9) months from January of 2017 to September, 2017 to assess its performance. The characteristics of influent wastewater, biological reactor, primary and secondary clarifiers were monitored monthly. Temperature, pH, conductivity and turbidity were measured in situ using a thermometer, WTW 340 pH meter, a WTW LF 340 conductivity meter and Hach 2100P turbidimeter respectively. Samples were taken from effluent taps for the measurement of total suspended solids, total dissolved solids, Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), alkalinity, phosphate, total phosphorus, Total nitrogen, nitrates, nitrites, ammonia, iron, Total Coliforms and faecal coliforms. All measurements were done between the hours of 8:00-10:00 hours GMT. Determination of concentrations of total suspended solids, total dissolved solids, COD, BOD, alkalinity, phosphate, total phosphorus, Total nitrogen, nitrates, nitrites, ammonia and iron were determined according to Standard Methods (APHA, 2012). Total Coliform and faecal coliform were done using the membrane filtration technique on 0.45µm pore size membranes on nutrient agar and chromocult agar media, incubated at 35-37^{o}C for 24 hours.

Statistical analyses of mean concentrations of key parameters of effluent were used to determine the removal efficiency by expressing the difference in concentration of influent and effluent as a percentage of the influent. Monthly variation in effluent quality over the nine-month period was determined using a one-way analysis of variance of SPSS version 20.0 software as well as a comparison of key paramenters.

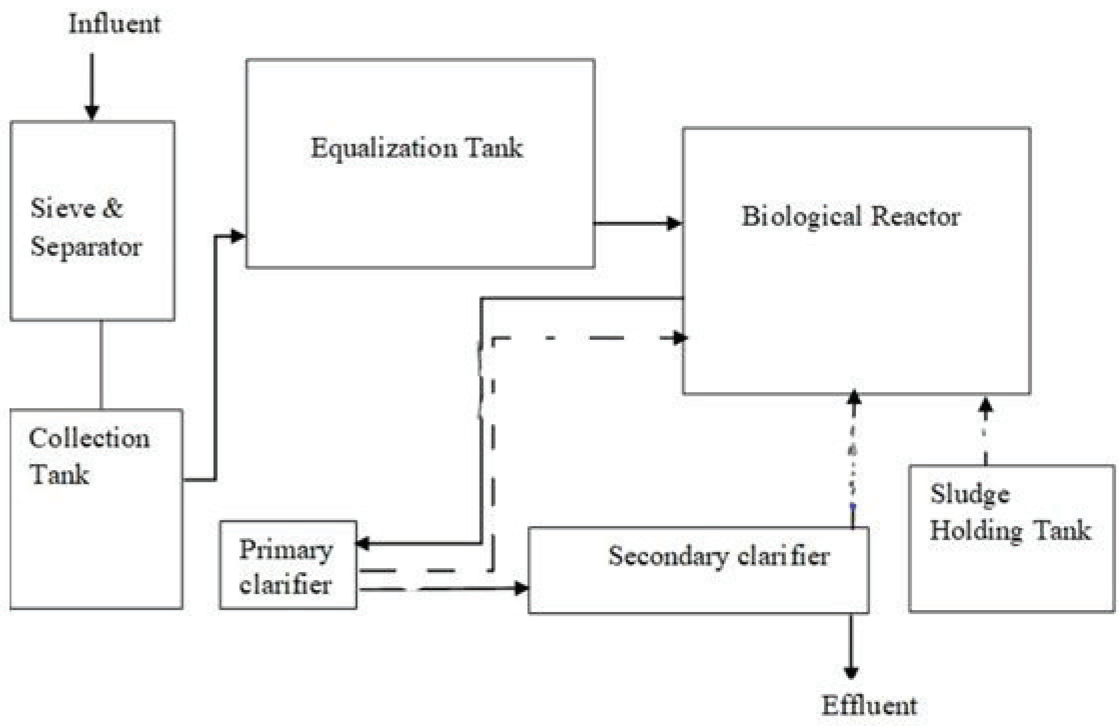

Figure 1. A schematic diagram of the activated sludge treatment plant

Results

Characteristics of the Influent Wastewater

Mean influent wastewater temperature during the period of the study was 31.7±2.2°C, with a pH range of 10.7-13.0 (Table 1). Conductivity of influent wastewater (3091±1195µS/cm) showed the presence of high concentration of ions. TDS, COD, BOD and total phosphorus expectedly had high values of 1922±533, 3085±1572, 688±55 and 80±7mg/L respectively (Table 1). Total coliforms and faecal coliforms were also expectedly low having concentrations of 378±38 and 9±1cfu/100mL respectively (Table 1).

Table 1. Operational conditions in the different components of the treatment plant

Parameters	Mean influent concentration ± sd	Mean concentration in Biological Reactor ± sd	Mean concentration in First Clarifier ± sd	Mean effluent concentration ± sd	Removal efficiency (%)
Temperature	31.7 ± 2.2	28.27 ± 3.16	28.3 ± 3.11	27 ± 1	-
conductivity	3091 ± 1195.2	6023.33 ± 25.17	6090 ± 10	1374 ± 78	-
TDS	1922 ± 533.6	3056.67 ± 20.82	3036 ± 25.17	696 ± 45	63.79
TSS	33.7 ± 6.4	48 ± 1	30 ± 2	14 ± 12	58.79
Turbidity	31.8 ± 3	427.33 ± 92.72	431.67 ± 154.13	15 ± 9	52.48
pH	10.7-13.0	8.3-8.4	8.0-8.1	7.3-8.7	-

Alkalinity	503.3 ± 30.6	1449.67 ± 0.58	1956 ± 5.29	156 ± 31	-
Iron	4.2 ± 0.1	14.33 ± 8.88	2.6 ± 1.81	0.13 ±0.01	96.96
COD	3085 ± 1572.2	810 ± 26.46	217 ± 5.77	102 ± 40	96.69
BOD	686.7 ± 55.1	54.33 ± 4.51	75 ± 0.58	2 ± 1	99.65
Nitrate	2.8 ± 0.4	15.06 ± 0.96	13.55 ± 0.59	0.26 ± 0.05	-
Nitrite	2.7 ± 0.1	0.02 ± 0.0	0.01 ± 0.01		-
Ammonia	0.01 ± 0.0	0.04 ± 0.01	0.01 ± 0.0	0.07 ± 0.02	-
Total Nitrogen	0.7 ± 0.0	14.83 ± 1.12	13.754 ± 0.41	1.03 ±0.19	81.29
Phosphate		66.27 ± 1.76	30.9 ± 29.71		
Total Phosphorous	79.7 ± 6.6	42.30 ± 16.87	41.3 ± 25.58	0.30 ± 0.06	99.62
Total Coliform	378 ±38.4	140 ± 10.26	139.3 ± 27.74	109 ± 6	71.19
Feacal Coliform	9 ± 1		7 ± 3.61	0	100.0

Table 2. Nine-month monitoring of a wider range of parameters in 2017

Parameter	**Monthly replicate samples of effluent in 2017**								
	Jan	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**
Temperature	26.3	26.9	27	28.7	28	27.7	28.8	27.7	25.8
Conductivity	1265	1322	1260	1345	1423	1448	1407	1423	1471
TDS	638	663	632	674	713	726	735	730	752
TSS	23	27	30	22	3	10	2	8	0
Turbidity	20	22	25	25	4	16	7	15	2
pH	8.42	8.71	8.56	8.26	8.99	7.27	8.29	8.13	7.88
Alkalinity	220	196	145	132	143	141	144	148	132
COD	60.04	62.15	79	82.56	137.18	158	79	162.4	97.96
BOD	2.44	4.23	3.048	3.048	1.42	1.78	1.83	2.555	1.12
Nitrate	0.255	0.263	0.257	0.278	0.28	0.28	0.296	0.277	0.131
Ammonia	0.068	0.077	0.075	0.078	0.083	0.08	0.086	0.063	0.014
Total Phosphorous	0.311	0.334	0.305	0.326	0.334	0.318	0.33	0.325	0.155
Total Nitrogen	1.05	1.07	1.03	1.06	1.1	1.13	1.22	1.07	0.55
Iron	0.111	0.132	0.13	0.133	0.136	0.131	0.133	0.127	0.118
Total Coliform CFU/100ml	102	115	114	109	104	109	100	112	115
Faecal Coliform CFU/100ml	0	0	0	0	0	0	0	0	0

Environmental Conditions in Reactors

Temperature in reactors (influent (31.7oC), biological reactor (28.3oC), first clarifier (28.3oC) and second clarifier (27.0oC) were fairly similar ($p > 0.05$, Table 1). Conductivity however almost doubled from 3091μS/cm in influent to 6023 and 6090μS/cm in the biological reactor and first clarifier respectively. It eventually decreased to 1374 μS/cm in the final effluent (Table 1). The TDS (Table 1) showed a similar trend as the conductivity, increasing by a thousand in the biological reactor and the first clarifier and finally reducing to 696mg/L in the final effluent. COD decreased rapidly in the biological reactor from 3085mg/L in the influent to 810mg/L. Further decreasing occurred in the first clarifier (217mg/L) and the second clarifier (102mg/L) as shown in Table 1. Similarly, BOD also decreased significantly in the biological reactor to 54mg/L from its initial influent concentration of 687mg/L.

Total phosphorus decreased by half the initial concentration of 80mg/L to 42mg/L in the biological reactor (Table 1). Little change in total phosphorus concentration occurred in the first clarifying tank (41mg/L). Total nitrogen similarly decreased by half from its initial concentration of 31mg/L to 15mg/L in the biological reactor, finally decreasing to 1mg/L in the final effluent (Table 1).

Final Effluent Quality and Removal Efficiency

Monthly variation in effluent quality over the nine-month period were not significant for the key parameters of TDS, TSS, COD, BOD, total phosphorus, total nitrogen, TC and FC ($p > 0.05$) (Table 2). Removal of TDS and TSS was 64% and 59% but this resulted in a final effluent concentration of 696mg/L and 14mg/L respectively (Table 1). High removal of COD and BOD of 96.7% and 99.7% respectively resulted in final effluent concentrations of 102 and 2.4mg/L. Total nitrogen removal was 96.6% resulting in a final effluent concentration of 1.03mg/L and less than 0.3mg/L for nitrates and nitrites (Table 1). Total phosphorus removal was 99.6% resulting in a final effluent concentration of 0.3mg/L (Table 1). The removal of iron was quite high (96.7%) resulting in a final effluent concentration of iron of 0.13mg/L. A removal of 71 and 100% was observed for total coliform and faecal coliform (Table 1).

Discussion

Characteristics of the Influent Wastewater

Temperature, turbidity, pH, alkalinity, iron, BOD, total phosphorus and total nitrogen concentrations of influent wastewater did not vary significantly during the period of the study. High variations however, were observed in the concentration of conductivity and COD. Changes in ionic and chemical composition of influent wastewater may arise as a result of changes in the quantity and type of raw materials used for the different soft drinks produced by the factory. Quantities of particular soft drink produced by the factory would vary based on demand on the market. TDS, COD, BOD and total phosphorus expectedly had high values of 1922±533, 3085±1572, 688±55 and 80±7mg/L respectively (Table 1) and this is typical of industries producing soft drinks or beverages (Amuda *et al*., 2006). Total coliforms and faecal coliforms were also expectedly low as just enough domestic wastewater was introduced to augment floc formation.

Environmental Conditions, Effluent Quality and Removal Efficiency

At the equalization tank, pH is controlled to ensure that pH in the biological reactor is within a range of 8.0-8.1, optimal for biological degradation of substrate. Increased TDS and TSS concentration of 1922 and 34mg/L respectively in the influent wastewater to 3057 and 48mg/L suggest the rapid breakdown of organic substrate. Indeed, BOD decreased rapidly from 687mg/L in the influent to 54mg/L in the biological reactor while COD also decreased rapidly from 3085 to 810mg/L. Intense bacteria, rotifers and protozoan activity of degradation of organic matter under aerobic conditions occur in the biological reactor resulting in the formation of dense biological flocs which settles as sludge. In the first clarifying tank TDS concentration (3036mg/L) remained fairly similar to that in the biological reactor (3056mg/L) while TSS concentration reduced by 38% (Table 1). Similarly, COD reduced by 78% while BOD concentration remained fairly similar to levels in the biological reactor. This is because processes in the primary clarifying tank are mainly sedimentation of suspended solids and flocs as sludge. Removal of TDS and TSS was 64% and 59%. The 64% removal of TSS recorded was much lower than the 96% reported by Sodhi *et al* (2018) yet it resulted in a final effluent concentration of 696mg/L and 14mg/L respectively which is below the Environmental Protection Agency (EPA) maximum permissible level of 1000mg/L and 50mg/L (EPA, 2017). High removal of COD and BOD of 96.7% and 99.7% respectively resulted in final effluent concentrations of 102 and 2.4mg/L. This is well below the EPA maximum permissible level of 250 and 50mg/L for COD and BOD respectively. COD and BOD removal efficiency of 97% and 95% respectively was reported by Abdel-Fatah *et al* (2017) and this is comparable to what was observed in this study.

Total phosphorus decreased by half the initial concentration of 80mg/L to 42mg/L in the biological reactor (Table 1). Various forms of phosphorus such as organic phosphorus may be oxidized to phosphates during degradation of organic matter while organic nitrogen gets oxidized to nitrites and eventually, nitrates. Total nitrogen decreased by half from its initial concentration of 31mg/L to 15mg/L in the biological reactor, finally decreasing to 1mg/L in the final effluent (Table 1). Oxidation of ammonia and denitrification is reported to be a major mechanism of total nitrogen removal in the biological reactor (Huang *et al*., 2016). Little change in total phosphorus concentration occurred in the first clarifying tank (41mg/L). Nutrient removal was indirectly estimated through the removal of total nitrogen and total phosphorus. Total nitrogen removal was 96.6% resulting in a final effluent concentration of 1.03mg/L and less than 0.3mg/L for nitrates and nitrites (Table 1). Total phosphorus removal was 99.6% resulting in a final effluent concentration of 0.3mg/L (Table 1). The removal of iron was quite high (96.7%) resulting in a final effluent concentration of iron of 0.13mg/L. In a study by Cai *et al* (2018), total phosphorus, total nitrogen and iron removals of 92%, 99% and 95% respectively was reported showing that Activated Sludge Treatment Systems are very efficient in the removal of nutrients. A removal of 71 and 100% was observed for total coliform and faecal coliform (Table 1). The addition of domestic wastewater, mixing it with the industrial wastewater enhances the treatment process, particularly in the biological reactor (Reddy *et al*., 2003).

Conclusions

Influent wastewater coming out of the beverage factory had high TDS, COD, BOD and total phosphorus concentrations of 1922±533, 3085±1572, 688±55 and 80±7mg/L respectively. The Activated Sludge Treatment Systems performed very well, removing 96.7% and 99.7% of COD and BOD respectively. Total nitrogen and total phosphorus removal were 96.6% and 99.6% respectively. The removal of iron, TC and FC were 96.7%, 71 and 100% respectively. The removal of TDS and TSS, although not that high (64% and 59% respectively) resulted in a final effluent quality that is within the maximum permissible discharge levels of EPA Ghana. Final effluent concentrations of COD, BOD, Fe and TC also show levels that were below the maximum permissible discharge levels of EPA Ghana.

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