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Assessment of Effluent Quality at Glen Valley Wastewater Treatment Plant

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Abstract: The effluent treatment process at Glen Valley Wastewater Treatment Plant was assessed weekly in terms of efficiency over 29 weeks. During this period there were significant removals of COD, BOD_5, TSS, NH_3-N and TKN. Average reduction of COD, BOD_5, TSS, NH_3-N and TKN were, 97.7, 99, 98.2, 95.5 and 93.6%, respectively. All these levels of reduction in the final effluent met the target discharge guidelines in Botswana and the treatment plant design discharge guidelines. There was a significant removal of ortho-phosphate (81.4%) in the final effluent, however, the weekly average of 6.82 mg L^{-1} was higher than the expected discharge of effluent to the environment guideline of <1 mg L^{-1}. There was an increase in NO_3- level in the treated effluent (82.2%) over the influent but the final effluent load of 2.7 mg L^{-1} was below the expected discharge level of 10 mg L^{-1}.

Key words: COD, BOD_5, TSS, NH_3-N, TKN, Botswana

INTRODUCTION

The Gaborone Glen Valley Wastewater Treatment Plant is the first of its kind in Botswana based on the activated sludge process of wastewater treatment. It has a capacity of receiving, 40,000 m^3 of sewage daily. It serves Gaborone and it's environ with a population of a bout 400,000 people. It is also the final receptacle for industrial effluent from the few manufacturing industries in Gaborone and its surrounding enclave. The activated sludge process combines both the anaerobic and aerobic processes of wastewater treatment hence effective degradation process of anaerobic waste treatment and significant reduction in sludge output as compared to just the conventional aerobic process[1,2]. The inclusion of the anaerobic treatment process makes it retain the sludge from the aerobic part inside the reactor in order to increase the treatment efficiency. The anaerobic portions are effective for the degradation of fatty acids. The anaerobic reactor is also known to be effective in treating waste water from food, brewery and agricultural industries. The activated sludge process is also used in the treatment of wastewater from chemical industries[3-5]. The process also results in high Chemical Oxygen Demand (COD) load removal[6].

The activated sludge technology derives the activated sludge connotation from a term coined by Arden and Lockett in 1914 as a result of marked efficiency in the treatment process observed when liquor from the secondary settling tank was reintroduced into the aeration tank[7]. At Glen Valley treatment plant, incoming effluent received at the plant is mixed with vacuum tanker discharges from the city, sieving of coarse and foreign materials such as polythene bags, condoms and in extreme cases, very bizarre objects such as aborted foetuses are removed at the coarse and fine screens. The effluent is then pumped along the partial flume where it is aerated and escaping coarse objects and grits from the coarse and the fine screens are removed. The effluent now assumed to be coming from the inlet well is divided into the two primary settling tanks. Settled sludge known as primary sludge is occasionally removed (every 6 h) automatically into thickening tanks where water is removed from it and then to the primary digesters. The primary settling tank effluent enters the aeration tank (axic zone) which is the main treatment centre of the conventional treatment process. There is continuous stirring of the sewage by mechanical aerators whose functioning is regulated by the amount of dissolved oxygen in the sewage. At low dissolved oxygen level, the aerators are triggered on to function to aerate the tank. Here complex organic compounds are oxidised by microorganisms into simple volatile organic acids, ammonia and sulphate compounds. These are then oxidised to nitrates, sulphates, phosphates etc. By facilitating these catabolic processes, the microbes in turn replicate and increase in number. Because COD load of sewage is basically the organic load composition, once

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there is efficient breakdown of organic compounds at the aeration zone, the COD load reduces hence the axic zone is the zone of COD removal. At the anoxic zone, denitrifying bacteria and sulphur forming bacteria during respiration reduce nitrates to nitrites and then elemental nitrogen as well as sulphur by chemically stripping the oxygen of the nitrates and nitrites, sulphate and phosphates. Thus the anoxic zone is termed the denitrification zone. It is also the zone where phosphate reduction occurs naturally during the treatment process. Alternation of axic and anoxic compartments is very efficient in phosphate removal in waste water treatment.

At the secondary settling tank, supernatant clear water continuously flows and is channeled by pipelines into the stabilisation ponds. There is continuous recirculation of settled sludge into the aeration tank to augment the microbe population in the process known as reactivation, a principle upon which the treatment process works. Sludge is occasionally wasted by removal of dead microbes and complex organic substances that the conventional aerobic process can not stabilise into the sludge thickening tanks to facilitate water removal and then to the digesters for anaerobic breakdown of the complex organic substances. Within a period of three weeks marked changes occur in the sludge composition as acid forming bacteria and methane forming bacteria under good Physico-chemical conditions are able to reduce the sludge volume drastically producing methane gas, carbon dioxide and water. At temperature range of 35-38°C, pH range of 6.8 to 7.2, sludge can be reduced to about a tenth of its original volume. The objective of this study was to assess the treatment efficiency of the activated sludge process and conformity of its final effluent to existing Botswana Department of Wastewater and Sanitation effluent and existing treatment plant design discharge guidelines to the environment.

MATERIALS AND METHODS

Sampling: Composite samples were collected based on guidelines of ISO 17025 1999[8]. Incoming effluent was monitored every 24 h in m^3 at the inlet well and the final discharge point at the secondary Settling tank. This was then converted to LS^{-1}. From each sampling point, a 3000 mL was taken every 2 for 24 h (12 samples taken within 24 h). The two hourly samples collected were stored in 5000 mL polypropylene containers at 2°C and used for the analyses.

Analytical procedures: The variables that were analysed were COD, BOD_5, Total Kjedahl Nitrogen (TKN), ammonia nitrogen (NH_3-N), orthophosphate (PO_4^{3-}), nitrates (NO_3^-) and Total Suspended Solids (TSS). COD, BOD_5, TKN, NH_3-N, PO_4^{3-}, NO_3^- and TSS were determined using standard methods for the examination of water and wastewater[9].

RESULTS AND DISCUSSION

During the study period, an average of 33000 m^3 of sewage was received daily which was below the Treatment Plant design full capacity intake of 40000 m^3. An average of 2093 mg L^{-1} COD was received during the study period and 48 mg L^{-1} discharged after treatment. This resulted in a significant reduction of 97.7% (Table 1). The COD load of 48 mg L^{-1} was lower than the expected discharge level of 75 mg L^{-1}. This implied a very high level of COD load removal during the period and an effluent less polluted with organic pollutants and therefore less hazardous effect on the receiving environment. Organic measured as COD are the major sources of pollution which exerts an oxygen demand on the receiving water. A high COD value has the potential to deplete all the dissolved oxygen in the receiving water hence exerting a deleterious effect on the well being of an a aquatic system. In wastewater treatment, COD is a measure of the stabilisation of the organic compound content of the wastewater and is therefore the most important yard stick in treatment process performance. For discharge of treated effluent into the natural environment, the Botswana Department of Wastewater and Sanitation proposed discharge limit guideline is 100 mg L^{-1} COD. The 48 mg L^{-1} discharged over the study period therefore was within the acceptable discharge limit in Botswana.

BOD_5 load removal was 99% during the study period. An average of 957 mg L^{-1} load was received during the study period whilst an average load of 9.3 mg L^{-1} was discharged in the final effluent. Compared to the expected discharge limit and the Botswana Department of Wastewater and Sanitation proposed discharge level of 30 mg L^{-1} was within the acceptable limit within the study period. The intake BOD_5 level of 957 mg L^{-1} for a small city like Gaborone was quite high indeed. This could be attributed to the breweries and paints and chemical industries in the city. BOD_5 is the most important variable in water pollution control since it indicates the actual level of biodegradable pollutants in the water[8]. Therefore an effluent low in BOD_5 is commendable.

TSS is a very important variable in wastewater discharge control. Apart from being source of aesthetic nuisance along river banks, TSS causes havoc in irrigation systems where in form of algae can block pipes, sprinklers, emitters and narrow water channels. TSS can also adsorb heavy metals unto their surfaces and thereby

Table 1: Efficiency of the activated sewage treatment plant, Gaborone, Botswana

Variable mg L^{-1}	Receiving	Discharging	Expected discharge value	Significance	CV	LSD	% Reduction
COD	2093a	48b	<75	****	66.7	459	97.7
BOD	957a	9.3b	<30	**	130.4	637	99.0
TSS	1405a	25.2b	<30	****	56.0	216	98.2
PO_4	36.74a	6.82b	<1	*	243.2	28.5	81.4
NO_3	0.40a	2.71a	<5	NS	275.7	3.23	82.2↑
NH_3-N	30.51a	1.37b	<10	****	43.0	5.59	95.5
TKN	32.71a	2.08b	<12	****	37.2	5.29	93.6

*, **, ****, NS Significant at p=0.05, 0.01, 0.0001, or Non-significant, respectively. Means separated using the Least Significant Difference at p= 0.05; means within rows followed by the same letter are not significantly different, ↑NO_3 concentration increased

facilitating formation of heavy metal complexes[10]. By this, an effluent high in TSS can become an easy vehicle for the introduction of heavy metals to the environment. During the study period, 1405 mg L^{-1} of effluent rich in TSS was received weekly into the treatment plant. With 98.2% level of TSS load removal efficiency, an effluent of 25.2 mg L^{-1} TSS was discharged. This was lower than the envisaged 30 mg L^{-1}. The treatment plant discharges its effluent into the Notwane river. High TSS can cause reduction in sunlight intensity in water bodies and reduce primary productivity especially on green algae. This can disturb the aquatic food chain. Less light can also affect temperature in the aquatic environment impacting negatively on primary and secondary productivity of aquatic life and temperature stratification of the system. TSS can also be a source of organic decay that can release nauseating odours.

Ortho phosphate removal efficiency during the study period was 81.4%. The Intake concentration was 36.74 mg L^{-1} whilst 6.82 mg L^{-1} was discharged. Phosphorus is the only plant nutrient that can trigger plant growth when introduced into an aquatic environment[11]. Nitrogen and phosphorus interact to produce large standing crops of algae[12]. When added singly, phosphorus caused increase in standing crops of algae, whereas nitrogen alone did not elicit a response[12]. This showed that phosphorus controls the growth of phytoplankton hence its limitation reduces the problem of eutrophication. A concentration of 0.01 mg L^{-1} phosphorus can result in eutrophication. In the present study, the level of phosphate in the final effluent was 6.82 mg L^{-1}. This high phosphate in the Gaborone final effluent has promoted the growth of algae in the polishing ponds and Notwane river where the effluent is discharged. Alternation of axic and anoxic compartments encourages removal of oxygen molecule from phosphates. However, the inability of the Gaborone wastewater treatment plant to remove phosphate to below 1.0 mg L^{-1} could be due to the high phosphate concentration in the influent (Table 1). Botswana is a semi-arid country where the per capita portable water use is low. This results in high concentration of phosphate in municipal effluent discharged from homes. Phosphate is a building block for soap and soap powders and also a major source of nutrient in human diet. Since green leaves and plants form a major component of the dietary intake of the residents of Gaborone, the high phosphate effluent at the plant intake may persist.

Nitrate is the end product of the aerobic stabilisation of organic nitrogen and may enter the environment via agricultural run offs or in treated effluents from wastewater treatment plants. In freshwater, nitrate concentration does not pose a problem since photosynthetic actions by green plants constantly convert it to organic nitrogen in plant cells. Nitrates may be found in high concentrations in ground water as a result of unsanitary conditions. Nitrates alone, do not trigger eutrophication in aquatic or water bodies except in combination with phosphates[12]. However, a water source high in nitrate concentration possess health risk to infants under six months of age. Nitrate level of about 100 mg L^{-1} can cause methaenoglobinaemia if that water is used in preparing food. The Intake concentration of nitrate at the treatment plant was 0.40 mg L^{-1}, while 2.71 mg L^{-1} was discharged. The proposed discharged limit to the environment is 10 mg L^{-1}. With the significant increase (82.2%) in nitrate level during the treatment process, the final effluent nitrate level was within acceptable limit (Table 1). The significant increase in nitrate concentration during the treatment process was because more organic matter was broken down and oxidised to nitrates. Even though the final effluent discharged nitrate concentration was within acceptable limits, 2.7 mg L^{-1} nitrate is high enough to cause eutrophication when phosphates are available at a concentration of 0.1 mg L^{-1}.

Nitrogen received in the form of ammonia was 30.51 mg L^{-1} weekly (Table 1). There was a 95.5% significant reduction in NH_3-N (1.37 mg L^{-1}) in the final effluent (Table 1). The discharge limit for NH_3-N is 10 mg L^{-1}. NH_3-N is an indicator of the level of decomposition in the effluent. The high intake value of 30.51 mg L^{-1} indicated that incoming effluent was undergoing decomposition.

Total Kjedahl Nitrogen (TKN) consists of nitrogen from organic and inorganic sources. The difference between the TKN and NH_3-N gives the nitrogen content from organic sources and hence the level of organic decomposition pending. During the study period, the organic matter stabilisation efficiency was 93.6% (Table 1). This was a significant reduction of TKN at the intake from 32.71 to 2.08 mg L^{-1} (Table 1). The plant discharge limit is 12 mg L^{-1}. With the high level of organic matter stabilisation shown, it indicated that BOD_5, COD and TSS were reduced to the minimum thus most of the problems associated with polluted effluent discharged to the environment were reduced significantly. In conclusion, the efficiency of the activated sludge treatment process in Gaborone, Botswana was highly efficient in removing COD, BOD_5, TSS, NH_3-N, TKN and NO_3^- except of orthophosphates to meet the discharge guidelines or standards.

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