

Management of Liquid Solid Waste

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Abstract Human activities produced huge amount of solid waste. Thus one of the main concerns in the land filled site management is the production of leachate. If managing will not properly so many problem are to be faced in which linkage of leachate is one the important matter. The treatment of Leachate is complex issue due to high suspended solids; colour and COD are amongst the main form of pollutants in leachate. Application of physical or biological process alone is normally not effective to remove these constituents, especially for leachate with lower BOD/COD ratio. The paper presents the results of treatability studies on high strength landfill leachate. During the studies physico-chemical methods, biological treatment and an ozonation were tested. Optimization of treatment using each treatment method was performed. the treatment system produced the high quality effluent, suitable for discharge to the surface water.

Keywords: landfill leachate, biological treatment, coagulation-flocculation, ozonation

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1. Introduction

One of the most important aspects related to siting, planning, design, operation and long-term management of Municipal Solid Waste (MSW) landfill is the management of leachate. Leachate from MSW landfill sites are often characterized as heavily polluted wastewater. Leachate is a complex organic liquid formed primarily by the percolation of precipitation water through open landfill or through the cap of the completed site [1]. Leachate may contain large amount of organic contaminants which can be measured as chemical oxygen demand (COD) and biological oxygen demand (BOD), ammonia, halogenated hydrocarbons, suspended solid, significant concentration of heavy metals and inorganic salts [2,3]. If it was not treated and safely disposed, landfill leachate could be a potential source of surface and groundwater contamination, as it may percolate through soils and subsoils, causing pollution to receiving waters [4].

The specific composition of leachate influences its relative treatability and depends to a large extent on the contamination to be removed [5]. In general, the treatment of landfill leachate often involves a combination of various techniques. Several processes derived from water and wastewater treatment have been applied for the treatment of leachate. These include aerobic and anaerobic biological treatments, photo-oxidation and membrane processes, chemical oxidation and precipitation, activated carbon and adsorption and coagulation-flocculation [6]. Biological processes are quite effective for younger leachates (containing mainly volatile fatty acids), but less efficient for the treatment of stabilized leachate [7].

However, leachate with low organic content is best treated with physical/chemical process [9]. Chemical precipitation using lime indicated that between 70 and 90% removal of color, turbidity, suspended matter and dispersed oil could be achieved [10]. Therefore, a combination of physical-chemical and biological methods is often required for the efficient treatment of leachate [11].

Landfill leachate is usually characterized by a high content of organic matter (expressed as COD, BOD₅ and TOC), high concentration of ammonia and metals as well as high alkalinity. Leachate quality can fluctuate over both short and long term and is related to a number of physical, chemical and biological processes in the landfill as well as weather conditions [12]. Therefore a leachate treatment system must be flexible enough to produce the same quality effluent, despite the variation in the strength of the leachate. In order to meet this criterion, leachate treatment plants utilize a combination of physical, chemical and biological treatment, which is often followed by advanced oxidation process (AOP) or chlorination [13,14]. In this paper the results of the treatability studies on a high strength leachate are presented. The aim of the treatability studies was to determine the most efficient and cost effective technology for leachate treatment that would produce an effluent acceptable for discharge to the surface water. During the studies, physico-chemical methods, biological treatment and ozonation were tested. The performance of the whole treatment system was also evaluated.

2. Material and Methods

Leachate was collected weekly from a leachate collection system at the landfill and analyzed for general

chemistry parameters, ammonia nitrogen, total phosphorus, phenols, calcium, iron, magnesium and manganese. The landfill consists from an old part – partially capped and a new active part. Therefore collected samples contained a

mixture of the leachate from both parts of the landfill. The average values of these parameters are presented in [Table 1](#).

Table 1. Leachate Parameter

S.No	Parameter	Average Value(*)
1	pH	6.88
2	Alkalinity	3850
3	Total Suspended Solids	102
4	Volatile Suspended Solids	69
5	BOD ₅	4920
6	COD	7880
7	TOC	2360
8	TKN	590
9	Ammonia-N	538
10	Nitrate	0.42
11	Nitrite	< 0.1
12	Total Phosphorus	2.2
13	Phenols	1.2
14	Calcium	530
15	iron	63
16	Magnesium	178
17	Manganese	8.4
18	Potassium	720
19	Sodium	1310
20	Chloride	1390
21	Sulphate	90

(*) – average of 20 samples collected weekly

Table 2. Results of Physico- Chemical Treatment of Leachate pH Adjustment and Aeration

Sample/Treatment	Parameter							
	NH ₃ -N		COD		TOC		Fe(diss)	
	Conc [mg L ⁻¹]	Rem [%]	Conc [mg L ⁻¹]	Rem [%]	Conc [mg L ⁻¹]	Rem [%]	Conc [mg L ⁻¹]	Rem [%]
Raw Leachate (RL)	480	–	7900	–	2420	–	9.98	–
RL Aerated (*)	394	18	5360	32.2	1700	29.8	3.5	64.9
RL + NaOH (pH=9.1)	476	–	7400	6.3	2410	–	7.8	21.8
RL + NaOH, Aerated (*)	420	12.5	5190	34.5	1690	30.2	0.42	95.8
RL + Ca(OH) ₂ (pH=9.3)	486	–	7310	7.5	2420	–	5.4	45.9
RL + Ca(OH) ₂ ,Aerated (*)	408	15	5065	35.9	1630	32.6	0.3	96.9

Note: (*) Air to water ratio 50:1

Table 3. Results of phosphoric acid treatment with aeration (air/water ratio 50:1)

Sample/Treatment	Parameter							
	NH ₃ -N		COD		TOC		Fe(diss)	
	Conc [mg L ⁻¹]	Rem. [%]	Conc [mg L ⁻¹]	Rem. [%]	Conc [mg L ⁻¹]	Rem. [%]	Conc [mg L ⁻¹]	Rem. [%]
Raw Leachate (RL)	490	–	7900	–	2480	–	10.2	–
RL Aerated	408	16.7	5510	30.2	1760	29.0	3.2	68.6
RL + 10 mg L ⁻¹ H ₃ PO ₄	386	21.2	5350	32.2	1780	28.2	3.5	65.7
RL + 20 mg L ⁻¹ H ₃ PO ₄	360	26.5	5400	31.6	1810	27.0	3.6	64.7
RL + 50 mg L ⁻¹ H ₃ PO ₄	290	40.8	5480	30.6	1800	27.4	3.5	65.7
RL + 75 mg L ⁻¹ H ₃ PO ₄	282	42.4	5310	32.8	1820	26.6	3.8	62.7
RL + 100 mg L ⁻¹ H ₃ PO ₄	270	44.9	5360	32.1	1740	29.8	3.8	62.7

2.1. Physico-Chemical Treatment

All samples of leachate were aerated using laboratory aerators supplying 1-5 L of air per minute. Some aerated samples were also treated with sodium hydroxide, lime or phosphoric acid. During initial tests the impact of an air to water ratio on ammonia nitrogen and COD removal was investigated. It has been found that air to water ratio 50:1

resulted in an optimum reduction of both parameters. For higher air to water ratios no significant differences were observed. Changes in the leachate chemistry after sodium hydroxide, lime or phosphoric acid treatment were also determined ([Table 2](#) and [Table 3](#)). Tests with the leachate treated with sodium hydroxide (pH = 9.1), lime (pH = 9.3) or phosphoric acid (50 mg L⁻¹) were conducted at an air to water ratio 50 : 1. Control samples (without chemicals addition) were aerated in the same conditions as the

treated samples. Treated and aerated samples were analyzed for COD, TOC, ammonia and suspended solids. Four tests were conducted for each treatment option and the results were then averaged.

2.2. Respirometric Tests

Respirometric tests were conducted using a Comput-OX, 12 channel respirometer (N-CON, Systems Company, Larchmon, N.Y.) equipped with a water bath with a precision temperature control. The system was monitored

and controlled by a computer with CTOX program. In each respirometric run six reactors contained raw leachate and six others contained treated leachate. All reactors were fed with 2 mL of return activated sludge (RAS) taken from a wastewater treatment plant that was capable of degrading a variety of industrial wastes as well as providing nitrification. Respirometric tests were supported by chemical analyses of tested samples for the concentration of ammonia, COD, TOC, TSS and VSS. For raw and treated leachate three respirometric tests were conducted and the results were averaged.

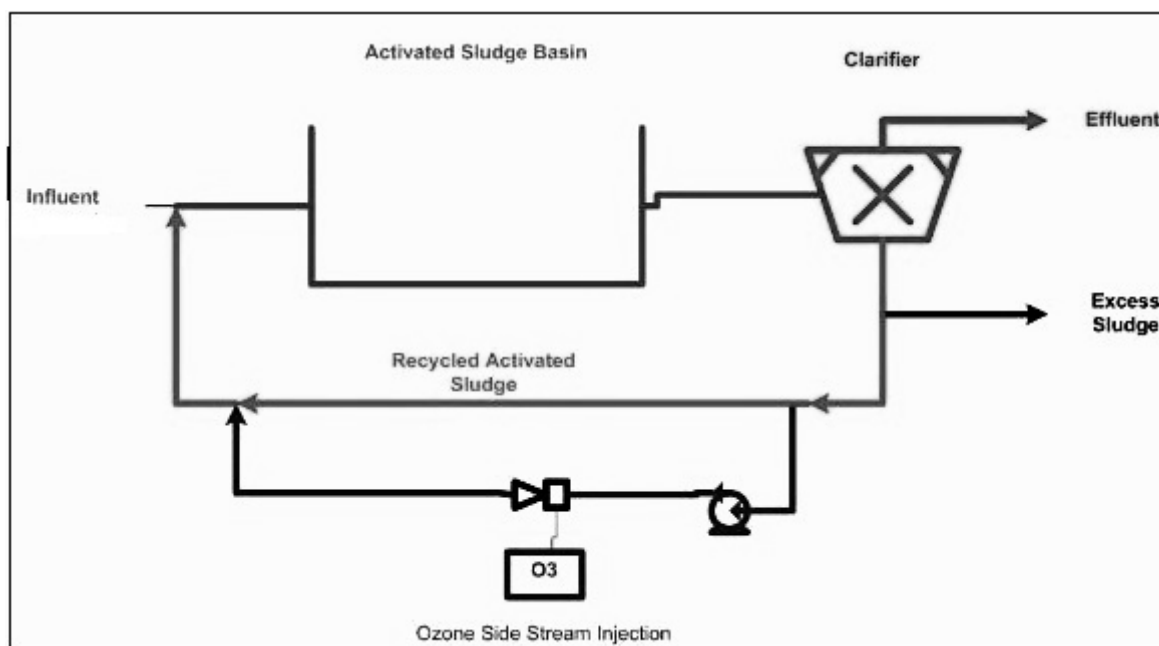


Figure 1. Experimental arrangement of leachate

Table 4. Results of Bench Scale Activated Sludge Studies

Treatment Time (days) elapsed	HRT (hrs)	Parameter (mg L ⁻¹)										
		Influent				Effluent						
		pH	NH ₃ -N	COD	DOC	pH	NH ₃ -N		COD		DOC	
						Conc	Remov (%)	Conc	Remov (%)	Conc.	Remov (%)	
4	100	7.1	395	4800	NA	8.7	95	76	1656	65	NA	
5	100	7.2	380	4800	NA	8.8	82	78	1238	74	NA	
10	110	7.4	390	4960	NA	8.6	73	81	1165	77	NA	
10	110	7.3	406	4990	2200	8.9	73	82	1102	78	154	93
10	120	7.3	368	5600	2360	8.9	47	87	828	85	162	93
10	120	7.3	388	5350	2240	8.9	36	91	909	83	123	95
10	125	7.2	385	4700	2170	8.8	9.5	98	550	88	134	94
10	125	7.2	410	4580	1980	9	1.6	>99	403	91	128	95
10	125	7.2	390	4800	2090	8.9	0.4	>99	398	92	119	94
10	125	7.2	398	4680	2120	8.9	0.8	>99	270	94	85	96

2.3. Bench Scale Activated Sludge Studies

The bench scale treatment system (Figure 1) consisted of the following utilities: a leachate tank (1), a peristaltic pump (2), an aeration tank with air diffusers (3), a primary clarifier (4) a denitrification tank equipped with a magnetic mixer (5) an aerobic tank with air diffusers (6) a secondary clarifier (7), an ozonizer (8) an effluent tank (9) and a sludge storage tank (10). The system operated in continuous mode. Initially, the aeration tank was filled with a mixture (5:1) of treated leachate and RAS from the treatment plant and aerated for 4 days to acclimatize the sludge. The treated leachate was then pumped into the aeration tank at a rate 2.5 ml/min to maintain hydraulic

retention time (HRT) of 100 hrs. Samples of the influent, the mixture from the aeration tank and the effluent were analyzed for pH, ammonia, nitrate, COD and TOC. The results are presented in Table 4. After 20 days the flow rate was reduced to increase HRT to 120 hrs and the denitrification unit was included into the treatment train. Initially the HRT of the denitrification tank was 12 hours which was subsequently increased to 20 hours. The recirculation rate in the denitrification unit was maintained at 5 times of the influent flow. Analyses of the influent and the effluent from the anoxic – aerobic system are presented in Table 4.

2.4. Ozonation Studies

Ozonation of the effluent from the biological system was conducted using a laboratory ozonator, generating 10 mg of ozone per min. 1L samples of the effluent were purged with ozone for 20 minutes. Treated samples, after

1, 2, 5, 7, 10, 15 and 20 minutes of ozonation were analyzed for COD, TOC and color. Five ozonation tests were conducted. The averaged results of 6 independent tests are presented in Table 5.

Table 5. Ozonation of the Effluent from Biological Treatment

Sample/ Treatment	Ozonation Time /Parameter (mg L ⁻¹)														
	0 min			5 min			10 min			15 min			20 min		
Raw Effluent	860	104	210	640	93	80	560	86	65	480	72	50	380	70	45
After Coagulation/Flocculation	538	98	150	490	86	80	450	72	60	400	68	45	300	58	40
Filtrate	466	89	122	422	73	70	380	70	55	230	54	30	120	42	20

3. Results and Discussion

3.1. Leachate Characteristics

The investigated leachate, as presented in Table 1, has a very high concentration of organic substances (COD = 7880 mg L⁻¹; TOC = 2360 mg L⁻¹). Most of them is biodegradable (BOD = 4920 mg L⁻¹). The main inorganic constituents of the leachate are: bicarbonates (alkalinity = 3850 mg CaCO₃ L⁻¹) and chlorides (1390 mg L⁻¹) of calcium (up to 530 mg L⁻¹), sodium (1310 mg L⁻¹) and potassium (up to 720 mg L⁻¹). Elevated concentrations of ammonia nitrogen (590 mg L⁻¹) and iron (63 mg L⁻¹) were also found. A high concentration of inorganic salts as well as organic substances in the leachate indicate complicated equilibria existing between cations and anions. Thus we can expect that the majority of calcium, magnesium and iron exists in the form of complexes with various ligands and not as a free cations. This had to be taken under consideration when design an effective treatment system. In order to meet stringent criteria for the effluent (BOD₅ = 10 mg L⁻¹; COD = 50 mg L⁻¹; NH₃-N = 1.0 mg L⁻¹; iron = 1.0 mg L⁻¹) very efficient treatment technology was required.

3.2. Laboratory Studies on Physico-Chemical Treatment

The aim of these laboratory studies on physico-chemical treatment of the leachate was to determine the ability to remove inorganic salts, organic substances and ammonia nitrogen using chemical precipitation and aeration. Initial aeration tests determined that an optimum air to leachate ratio is approximately 50:1 that is why this ratio was maintained during all subsequent aeration tests. Titration tests revealed a very high buffering capacity of the leachate, particularly above pH = 9.0. Therefore, pH adjustment tests were conducted only to this value which is much lower than required for efficient ammonia stripping (pH ~ 11). Results of these tests, as presented in Table 2 indicate that aeration of the leachate can substantially reduce the concentration of iron (64.9 %), organics (COD: 32.2 %; TOC: 29.8 %) and ammonia nitrogen (18 %). Alkalinization of the leachate considerably enhanced the removal of iron (95.8-96.9 %) and organics (COD: 34.5-35.9 %; TOC: 30.2-32.6 %). The unexpected higher concentrations of ammonia in the alkalinized leachate, as compared to that without alkalinization is likely related to hydrolysis of organic substances, at higher pH, which resulted in the production of ammonia. A decrease

(10 %) of Total Kjeldahl Nitrogen in the leachate after aeration of alkalinized samples confirmed this hypothesis.

Two sets of tests were conducted to determine the removal of ammonia nitrogen and magnesium from the leachate in the form of magnesium ammonium phosphate (MgNH₄PO₄). In one set of tests phosphoric acid was added to the aerated leachate. In the other tests aerated leachate was treated with phosphoric acid during mechanical mixing. Treated samples were analyzed for COD, TOC, iron and ammonia nitrogen.

Results of phosphoric acid treatment, as shown in Table 3, indicate that addition of phosphoric acid results in the additional removal of ammonia nitrogen (up to 44 % of the initial concentration). The method of phosphoric acid addition (before or after aeration) did not affect the removal of ammonia nitrogen or organics. The optimum dose of phosphoric acid was found to be about 50 mg L⁻¹. Higher doses of acid only marginally increased ammonia nitrogen removal but decreased iron removal. This phenomenon is likely related to fact that phosphate addition increases buffering capacity of the leachate and may enhance formation of soluble iron-polyphosphate complexes. Thus, pH of the aerated leachate treated with phosphoric acid is lower as compared to the raw leachate. At the same time the oxidation of iron (II) to iron (III) would be less efficient, since polyphosphates would stabilize iron (II). There was also a concern that higher concentration of phosphates in the pretreated leachate may exceed the biological demand and eventually might increase the concentration of phosphorus in the effluent above the discharge limit (0.3 mg L⁻¹). This would consequently necessitate additional treatment. The results of the physico-chemical treatment studies demonstrate that pretreating of the leachate through aeration and phosphoric acid treatment results is efficient. It would allow substantially remove of ammonia (up to 40 %) and organics (up to 30 % as COD and TOC). Aeration of the leachate without phosphoric acid or at pH ~ 9.0 was found less efficient in ammonia removal since elevated pH enhances hydrolysis of organic matter and generation of ammonia.

3.3. Biological Studies

The purpose of conducting biological studies was to determine the biokinetics of leachate treatment and the factors affecting organic and ammonia nitrogen removal. Biological studies consisted of respirometric and bench scale investigations. In order to determine the effect of pretreatment (aeration with phosphoric acid and sedimentation) parallel tests for raw and pretreated leachate were conducted. In order to simulate the

conditions at the site, respirometric tests were performed in a water bath at 10°C. The results of respirometric tests demonstrated a high biological activity (high oxygen uptake) of the biomass in the leachate. Substantial removal of COD (70 %) and ammonia nitrogen (65 %) was observed during exponential growth. Total suspended solids (TSS = 196 mg L⁻¹) were substantially higher in reactors fed with raw leachate than those fed with pretreated leachate (TSS = 168 mg L⁻¹), while volatile suspended solids (VSS = 136 mg L⁻¹) were significantly higher in reactors with pretreated leachate as compared to those with raw leachate (VSS = 115 mg L⁻¹). This phenomenon is related to the precipitation of inorganic solids, particularly calcium and iron compounds during biological treatment. Precipitation of solids in pretreated samples was less extensive since substantial amounts were removed during pretreatment. Higher VSS for pretreated leachate suggests that pretreatment removes some inhibitors of biological growth.

Biokinetic parameters were calculated using the IAWQ Activated Sludge Model No.1 [15,16]. Non-linear regression analyses of the respirometric data were performed using the computer program MathCad (version 5.0 plus). These analyses indicated that the kinetics of the investigated biological system comply with the Haldane model for inhibitory wastes. Biokinetic constants, particularly maximum specific growth rate (μ_{max}) and inhibition constant (K_i), were substantially higher for the treated leachate ($\mu_{max} = 0.138 \text{ h}^{-1}$; $K_i = 1048 \text{ mgCOD L}^{-1}$) as compared to the raw leachate ($\mu_{max} = 0.128 \text{ h}^{-1}$; $K_i = 679 \text{ h}^{-1}$). This indicates that pretreatment reduces the concentration of inhibitory substances in the leachate. Since pretreatment also removes a substantial organic load from the leachate it would allow one to reduce the size of the biological treatment system.

Bench scale activated sludge studies were conducted using the system presented in Figure 1. The system was fed with a raw leachate. The conditions in the system were monitored using a pH meter (influent, anoxic tank and aerobic tank) Redox probe (anoxic tank and aerobic tank) and DO meter (anoxic tank and aerobic tank). Samples of the raw and treated leachate were collected regularly and analyzed for COD, TOC, ammonia nitrogen, nitrites, nitrates, iron, color and turbidity. Samples of mixed liquor from the anoxic and aerobic tanks were collected twice a day and examined under a microscope. Initially, pretreated leachate (after aeration with 50 mg L⁻¹ of phosphoric acid and separation of solids) was fed directly to the aeration tank. After 20 days the denitrification unit was included

and the leachate was pumped into the anoxic tank, which had ORP ~ -100 mV. The retention time and recirculation of RAS from the secondary clarifier into the aeration tank as well as recirculation of a mixed liquor from the aeration tank into the denitrification tank were adjusted during the studies to achieve the best removal of COD, ammonia and nitrates. The final parameters of the treatment system were:

Influent flow rate: 2.2 mL min⁻¹

Denitrification tank : HRT = 20 hours; MLVSS = 3800 - 4200 mg L⁻¹

Recirculation of mixed liquor: 10 :1

Aerobic tank: HRT = 100 hours; MLVSS = 4000 - 4600 mg L⁻¹

Sludge age: 11 days

RAS wasted: ~ 150 mL per day

During 30 days of operation at the above conditions, the system achieved a very high removal of ammonia nitrogen (average ~99.6 %) and organics (92% COD and 94 % DOC) as it is presented in Table 4. Microscopic examination of the biomass revealed rich and diversified microbiological life. The pH of the mixed liquor in anoxic and aerobic tank was also very stable and no pH adjustment was necessary. Despite very good efficiency of the biological system, the quality of the effluent was found unsatisfactory for discharge into the surface water, due to COD ~ 200 mg L⁻¹; color > 250 St Units and turbidity > 200 NTU. Therefore ozonation studies on biological effluent were conducted.

3.4. Ozonation Studies

The aim of the ozonation studies was to determine the ozone dose required removing the color from the leachate and improving settling of suspended solids. It was also expected that ozonation would reduce the COD load. Ozonation was conducted using a laboratory ozone generator, which was supplied with dried air. The effluent from biological system was treated with various doses of ozone and samples were analyzed for COD, DOC, color and turbidity. In addition, samples of ozonated effluent were treated with alum and polymer to study the effect of ozone treatment on the settling of suspended solids. As shown in Table 5, ozonation substantially improved the quality of the biological effluent, particularly when this treatment was followed by coagulation/flocculation. The optimum required dose of ozone was found to be 50 ± 60 mg O₃ L⁻¹. Higher doses of ozone only insignificantly decreased COD concentration, but did not affect color and turbidity.

Table 6. Total Performance of the Treatment System

Parameter (mg L ⁻¹)	Sample/Treatment										
	Raw	Pretreated		Biological		Ozonation		Coagulation		Final Effluent	
		Conc.	Remov (%)	Conc.	Remov (%)	Conc.	Remov (%)	Conc.	Remov (%)	Conc.	Remov (%)
BOD ₅	1720	1480	14	50	96.6	NA	NA	20	60	20	98.8
COD	5400	3570	34	280	92.2	190	10.5	160	15.8	160	97
DOC	1300	920	29.2	80	91.3	56	—	50	10.7	50	96.1
NH ₃ -N	510	320	37.3	0.5	99.8	NA	NA	NA	NA	0.5	99.8
NO ₃ -N	<0.1	—	—	0.9	—	18.1	—	—	—	—	—
NO ₂ -N	<0.1	—	—	24.2	—	<0.01	>99.9	—	—	—	—
Fe-total	60	2.8	95.3	—	—	—	—	—	—	2.8	95.3
Fe-diss	9.5	0.3	96.8	—	—	—	—	—	—	0.3	96.8
Colour (St Units)	560	320	15.8	210	34.3	38	81.9	30	21	20	96.4
Turbid (NTU)	>200	>200	—	>200	—	90	>55	10	88.8	10	>95

In order to determine the overall performance of the treatment system, the same samples of the leachate were treated with all the investigated methods for 30 days. The applied treatment methods were optimized according to the results of the previous tests. Samples of the treated stream were collected regularly and analyzed for BOD, COD, DOC, ammonia, nitrates, nitrites, iron, color and turbidity. The analytical data presented in Table 6 confirmed the results of studies on each treatment method and indicated that the treatment technology would produce a high quality effluent which can be discharged to the surface water.

4. Conclusions

Successful treatment of high strength leachate can be achieved by multi stage treatment using physico-chemical and biological methods followed by ozonation. A pretreatment of the leachate using aeration and phosphoric acid addition substantially improved a removal of carbon and nitrogen in biological system. An optimization of each treatment method allows for the design of the treatment system which would produce a high quality effluent.

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