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المعالجة الهوائية واللاهوائية للعصارة الناتجة من نفايات في موقع ردم غير مبطن تحت التشغيل: دراسة حالة

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الخلاصة

تم إجراء فحوصات بيئية في هذه الدراسة لتقييم نوعية العصارة الناتجة من الردم غير صحي للنفايات وإمكانية معالجتها باستخدام المفاعلات البيولوجية بالطريقة الهوائية واللاهوائية من أجل تحديد المواد العضوية وتحولها الى مادة النتروجين. وأظهرت النتائج أن هذه العصارة تحتوي على تركيز كبير من المواد العضوية وتم تحديدها من خلال قياس ارتفاع متطلب الأوكسجين الحيوي (BOD) ومتطلب الأوكسجين الكيميائي (COD) ونسبة المواد الصلبة. حيث تراوح التركيز المتوسط لمتطلب الأوكسجين الكيميائي من 795 إلى 1962 ملغم/ لتر وأما المواد الصلبة الذائبة (TDS) فأعلى تركيز كان 23845 ملغم/ لتر. وأظهرت نتائج المعالجة الهوائية واللاهوائية للعصارة في مفاعل على أن كفاءة إزالة المواد العضوية مرتفعة عموماً. حيث تم تحقيق نسبة إزالة حوالي 93% من متطلب الأوكسجين الكيميائي بعد 30 يوما. ولوحظ تحول النتروجين بواسطة عمليات النترجة وعمليات نزع النتروجين والتي تقدمت بمعدلات منخفضة نسبياً وقد انخفض تركيز ثالث أكسيد النيتروجين في المفاعل من 750 ملغ/ لتر إلى ما لايقل عن 300 ملغ/ لتر في عشرين يوماً. وتعتبر جودة العصارة المعالجة بالطريقة الهوائية واللاهوائية بشكل عام ممتازة وذلك لتركيز متطلب الأوكسجين الكيميائي (COD)، والمواد الصلبة، والأمونيا، وجاء التحلل البيولوجي للمواد العضوية موافقاً للمعادلات الحركية من الدرجة الأولى.

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Aerobic /Anoxic treatment of leachate from an active unlined landfill site: A case study

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ABSTRACT

In this study, environmental investigations were conducted on the leachate collected from Al-Sulaibiya landfill site, Kuwait, to evaluate the leachate quality and treatment using aerobic/anoxic biological reactors in order to determine the degradation of organics and transformation of nitrogen. Results obtained show that leachate has high organic strength as expressed by its BOD and COD and high solids content. The COD average concentrations ranged from 795 mg/l to 1962 mg/l and the TDS maximum concentration was 23845 mg/l. The Aerobic/Anoxic (A/A) treatment of leachate in a semi-continuous reactor showed that the organic solids removal is generally high. After 30 days, 93% removal of COD was achieved. Nitrogen transformations by the nitrification and dentrification processes were observed, but the latter process progressed at a lower rate. The NO_3^- concentration in the reactor decreased from a maximum value of 750 mg NO_3-N/L to a minimum of 300 mg NO_3-N /L in 20 days. The effluent quality from the A/A digestion system has generally been excellent for COD, solids, and ammonia concentrations. Biodegradation of organics followed a first-order kinetic pattern.

Keywords: Landfill; leachate treatment; nitrogen transformations; organic solids removal; solid wastes.

INTRODUCTION

Solid wastes generated in Kuwait during the last two decades were disposed off in five landfill sites: Al-Jahra, Al-Sulaybiyah, Mina-Abdullah, and the Seventh Ring Road Site (South and North). These sites consist of old sand quarries that accept different kinds of waste such as construction and demolition waste, confiscated food waste, dead animals, sludge, liquid waste and municipal solid waste. The large quantities of liquid and sludge wastes dumped at landfill sites are a cause of concern as this may be a major factor for the generation of leachate and landfill gas (Al-Yaqout & Hamoda, 2003).

Leachate generation in landfill sites is a major environmental problem that is commonly neglected by municipal authorities in developing countries of the arid region such as Kuwait. The primary causes of leachate production in Kuwait, in spite of the negative water balance, are the improper disposal of liquid and sludge wastes as well as the rising of subsurface water table. The characteristics of leachate in arid climate shows a definite trend with age, type of waste dumped, thickness of waste layer, and hydrogeology of landfill. The leachate from an active landfill is influenced by dumping of liquid waste and is characterized by its high organic strength and heavy metal concentrations (Al-Yaqout & Hamoda, 2003). On the other hand, the leachate generated from closed landfill is characterized by low organic strength and high levels of total dissolved solids (TDS). Results of leachate analysis at closed landfills in Kuwait showed that the organic strength was reduced due to waste decomposition and continuous gas flaring (Al-Yaqout & Hamoda, 2003). Landfill leachate has been generally known as a high-strength wastewater that is difficult to deal with. Leachate from landfills usually has a high content of pollutants, especially recalcitrant organic compounds, such as humic and fulvic acids, xenobiotics, pesticides, and other harmful substances, that result in environmental pollution problems (Vilar *et al.,* 2011). Leachate originating from landfills poses a significant environmental threat to both the groundwater and surface water. In order to minimize the negative impact on the environment, the leachate has to be treated to remove nitrogen, organic compounds, as well as other contaminants.

Most landfill leachates contain high concentration of nitrogen, mainly in the form of ammonium. The ammonium compounds are toxic at high concentrations and have fertilizing effects that may lead to eutrophication of receiving waters. At high concentrations, ammonia itself inhibits the nitrification process. Leachate generated from mature landfills is typically characterized by a high ammonia (NH_3-N) content, low ratio of biochemical oxygen demand (BOD_5) to chemical oxygen demand (COD) (BOD_5/COD), or, in other words, a low biodegradability and high fraction of refractory and large organic molecules (Wang *et al.,* 2003). In many cases, after treatment by a series of oxidation processes, mature landfill leachate still presents a high concentration of recalcitrant compounds and nitrate. When treating this type of leachate, biological methods are ineffective, while physico-chemical and advanced oxidation processes are expensive. By combining several treatment technologies, economic savings and process optimizations can be achieved due to the degradation of the refractory compounds into biodegradable organic matter, and the use of these products as a carbon source for denitrification (Cortez *et al.,* 2011).

Several studies were conducted using aerobic or/and anaerobic treatments of landfill leachate in recent years (Safferman & Bhattacharya, 1990; Cheng *et al.,* 1997; Inanc *et al.,* 2000; Gulsen & Turan, 2004; Yang & Zhou, 2008; Agdag & Sponza, 2008; Trabesli *et al.*, 2009; Guo *et al.,* 2010). High COD content and high COD/BOD ratio of the landfill leachate make anaerobic treatment more advantageous as compared to aerobic process. Fikret & Pamkoglu (2003) studied the aerobic biological treatment of pre-treated landfill leachate by fed-batch operation and reported that nearly 76% COD and 23% NH_4-N removals were obtained with 30 hours of operation with a flow rate of 0.211 h^{-1} and the feed COD content of 7000 mg/L. mgl^{-1} COD. Marttinen *et al.* (2002) obtained up to 92% of COD removals from the treatment of landfill leachate by using upflow anaerobic sludge blanket reactors. Park *et al.* (2001) used anaerobic and sequential anaerobic-aerobic reactors for landfill leachate treatment at different temperatures such as 11 and 24 °C. Nearly 75% COD removals have been achieved by anaerobic treatment at 24 °C with a 10-hour hydraulic retention time (HRT). The overall COD removal in the sequential process was 80–90% with nearly 80% ammonium removal.

Henry & Prasad (2000) investigated the effectiveness of sulfate-reduction pathway in anaerobic treatment of landfill leachate. A series of laboratory-scale anaerobic filters was operated continuously at room temperature (19-25°C) and the experiments were conducted with leachate at COD/SO_4 ratios ranging from 0.8 to 1.54. The study concluded that low strength leachate can be treated aerobically via sulfate reduction. However, treatability via the sulfate reduction pathway was not possible with high strength leachate.

Kabdasli *et al.* (2000) carried out the anaerobic digestion of the leachate in a laboratory-scale mesophilic up-flow anaerobic sludge reactor to study ammonia removal from young landfill leachate by magnesium ammonium phosphate precipitation and air stripping. Ammonia stripping was carried out both by aeration and volatilisation. Optimum pH was adjusted at 12, which gave 72% removal after 2 hours of aeration. The study concluded that magnesium ammonium phosphate precipitation applied to raw and aerobically treated leachate provided ammonia removals over 90 percent where an aerobically treated COD sample was reduced by 40% down to 3000 mg/L. Furthermore, suspended solids removal was almost complete, which also helped to remove organic nitrogen in the suspended form. Trabesli *et al.* (2009) coupled the anoxic and anaerobic treatment of landfill leachate of Jabel Chekir landfill in Tunis, and reported that the overall removal efficiencies achieved by the coupled system were 95% for BOD_5, 94% for COD and 92% for NH_4^+ - N. Govahi *et al.* (2012) investigated the treatment of municipal landfill leachate of Shiraz's city using continuous flow anaerobic reactor and subsequent aerated lagoon, and reported that the COD removal efficiency of 71% and 84% was achieved in the anaerobic reactor and whole system, respectively.

In general, aerobic systems are suitable for the treatment of low strength wastewaters (biodegradable COD concentrations less than 1000 mg/L), while anaerobic systems are suitable for the treatment of high strength wastewaters (biodegradable COD concentrations over 4000 mg/L) (Agdag & Sponza, 2008). The use of anaerobic-aerobic processes can also lead to reduction in operating costs, compared with aerobic treatment alone, while simultaneously resulting in higher organic matter removal efficiency, a smaller amount of aerobic sludge and no pH correction. Anaerobic-aerobic (A/O) systems have received a great deal of attention over the past few decades due to their numerous advantages, not only with regard to municipal wastewater, but also sanitary landfill leachates (Agdag & Sponza, 2008; Yang & Zhou, 2008).

In Kuwait, studies concerning the aerobic/anoxic (A/A) biological treatment of leachate were initiated to provide Kuwait Municipality with a tool to design a new treatment plant. For this purpose, laboratory experiments were conducted in this study using leachate collected from boreholes in an operating site at Al-Sulaybiyah. Although different aerobic and anaerobic biological systems were found effective in treating leachate, the A/A process was tried in this study based on previous work on wastewaters and sludge that showed some advantages of the process as follows: the A/A treatment method is expected to achieve complete denitrification by converting the nitrogen to nitrogen gas, reduce the power needed for aeration and improve the property of treated leachate (Al-Ghusain *et al.*, 2004). The objective of this paper is to identify leachate characteristics at Al-Sulaybiyah landfill and present the results on the treatment of leachate using Aerobic/Anoxic system as an alternative to the anaerobic and aerobic treatment processes.

MATERIALS AND METHODS

Site characterization

In this study, the effectiveness of the Aerobic/Anoxic (A/A) treatment of leachate was investigated on the leachate collected from Al-Sulaybiyah landfill site. The Al-Sulaybiyah landfill site is located in Amghara area about 20-km north of Kuwait City and about 1.5 km from the Gulf shoreline. The landfill site is located on the upstream of wastewater irrigated farms and near the heavily populated Jahra and South Doha residential areas. The site has been used for dumping a variety of solid and liquid wastes for the last 15 years with no provisions for collection of gas and leachate. Since the landfill is unlined, the rising of groundwater table increases the possibility of leachate formation in the landfill sites. Further, the movement of water in the landfill body plays an important role in the leachate formation.

Samples collection and analysis

About 15 leachate samples were collected from the boreholes and then submitted to the laboratory for further chemical/biological testing. The leachate samples were analyzed according to standard methods (APHA, 1998). A brief description of each method and any variations from the original Standard Methods are outlined below:

pH

Continuous pH measurements were made using a pH probe (Mettler Toledo) connected to the pH meter. The pH of the filtered samples was measured using a combined pH electrode connected to a pH meter. Prior to any pH measurement, the probe was calibrated at two pH points (4 and 7). To eliminate any temperature related-errors, a temperature compensation probe was used in conjunction with the pH probe.

Alkalinity

Alkalinity was measured by titrating a known volume of sample (20-ml) with H_2SO_4 to a pH endpoint of 4.8. The normality of the H_2SO_4 was pre-determined with NaOH, which, in turn, was calibrated against a standard solution of potassium hydrogen phthalate.

Solids

The Mixed Liquor Suspended Solids (MLSS) was measured by vacuum-filtration of a known volume of the leachate through a pre-washed, pre-weighed glass fiber (Whattman GF/C). The filter was then dried in an oven at 105 ^{o}C for about an hour, cooled in a desiccator, and weighed on an analytical balance. The MLSS was determined at 550 ^{o}C for 15-20 minutes. Prior to the test, the filters were rinsed with distilled water, dried at 105 ^{o}C for one hour, ignited at 550 ^{o}C and stored in a desiccator until ready to be used. Both ovens used were regularly calibrated to ensure their operational temperature.

Nitrate

Samples were initially centrifuged for 10 minutes at 3500 rpm and filtered through glass fiber filters (Whattman GF/C). Nitrate levels in the filtered samples were then measured using a nitrate ion selective electrode in conjunction with a reference electrode and a temperature compensation electrode. The probes were connected to a millivolt meter. A buffer solution was used as an ion interference suppresser and ionic strength adjustor; this solution consisted of 3.43 g/L Ag_2SO_4 (to remove Cl^-, $Br^{-,}$ I^-, S^{2-}, and CN^-), 2.52 g/L sulfamic acid (to remove NO_2^-), 17.32 g/L $Al_2\ (SO_4)_3\ .18H_2O$ (to complex organic acids), and 1.28 g/L boric acid. The solution pH was then adjusted to 3.0 with 0.1 N NaOH to eliminate HCO_3^- and to maintain constant pH and ionic strength.

The buffer solution (10 mL) was added to 10 mL of the filtered sample for NO_3^- measurement of the samples, a calibration curve was prepared (1- 100 mg/L NO_3^- - N) by diluting a 1000 mg NO_3^- - N/L stock nitrate solution (7.22 g/L KNO_3^-). The calibration plot (millivolt reading versus log concentrations) typically exhibited a slope of 57 ± 3mV per cycle at 25 ^{0}C for NO_3^--concentrations above 3.5 mg NO_3^--N/L. When not in use, the nitrate electrode was immersed in a 100 mg/L solution of KNO_3 and the reference probe was stored in the external filling solution (0.04 M $(NH_4)_2SO_4$).

Ammonium

Prior to the distillation step, the pH of the sample was raised above 9 (borate buffer). The ammonium in the distillate was titrated with a standardized H_2SO_4 solution.

COD

The open reflux method was used for the determination of COD. The samples were refluxed with excess amounts of potassium dichromate (10 mL of 0.125 N $K_2Cr_2O_7$), sulfuric acid, and silver sulfate catalyst for two hours. After digestion, the amount of dichromate remaining was measured by titration with 0.01 M ferrous ammonium sulfate.

Heavy metals

Metal concentrations were determined using "ICP" technique, but some measurements were conducted using Atomic Absorption technique.

Treatability tests

The Aerobic/Anoxic (A/A) digestion experiments were carried out in a fermentor (New Brunswick, Microferm) as shown in Figure 1(a) and (b). The working capacity (volume) of the fermentor was 10 L. The fermentor was operated as a semi-continuous reactor. After an initial aeration period of 24 hours, the A/A operation of the reactor was started by including 8 hour intervals of anoxic digestion and 16 hour intervals of aerobic digestion. It was connected to dual air and N_2 Sources; the flow of either gas was controlled by valves. During the aerobic digestion period, the leachate was stirred at 300 rpm and DO (dissolved oxygen) controller maintained a DO level of 4 mg l^{-1} in the fermentor. The anoxic intervals were introduced by stopping aeration, reducing the mixing speed, and introducing N_2 gas into the fermentor.

The reactor was operated in the A/A mode at room temperature (about 25 $\pm$ 2 ^{o}C) and at a hydraulic retention time (HRT) of 10 days. The HRT was attained by feeding a fixed daily amount of leachate following the withdrawal of the same volume of treated leachate from the reactor. It is to be noted that solids residence time (SRT) would be equal to HRT in the reactor operated in this way. In addition to the continuous monitoring of pH and DO, daily samples from A/A reactor, as well as the feed leachate samples, were analyzed for Total Solids (TS), Volatile Solids (VS), Suspended Solids (SS), Volatile Suspended Solids (VSS), filtrate and total Chemical Oxygen Demand (COD), NH_4^+-N, NO_2^--N, NO_3^--N, and Alkalinity. The filtered samples were collected in a glass bottle to eliminate any interference.

Total solids (TS) is a measure of total dissolved solids (TDS) and total suspended solids (TSS). Volatile solids are those solids in water or other liquids that are lost on ignition of dry solids at 550 °C, and normally represent the amount of organic solids in water. Measurements were made in triplicates and were subjected to statistical analysis.

Treatability tests were carried out to investigate the effect of Aerobic/Anoxic digestion of leachate in a semi-continuous system. The reactor was monitored until a pseudo steady-state was reached due to the relative stability of the digested leachate properties. The average percent removal (R_a%) of a certain chemical parameter was calculated as:

$$R_a\,\% = (C_f - C_e)\,100 / C_f$$

Where

C_f = Concentration of the chemical parameter in the feed of the reactor, and

C_e = Concentration of the chemical parameter in the effluent of the reactor

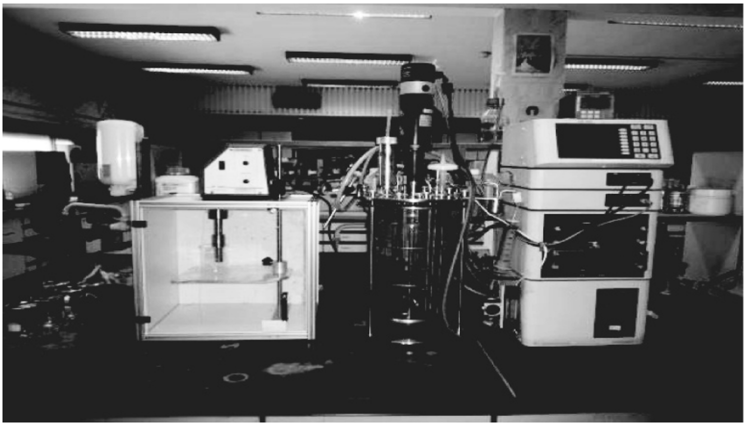

Fig. 1(a). Aerobic/Anoxic test using New Brunswick Fermentor.

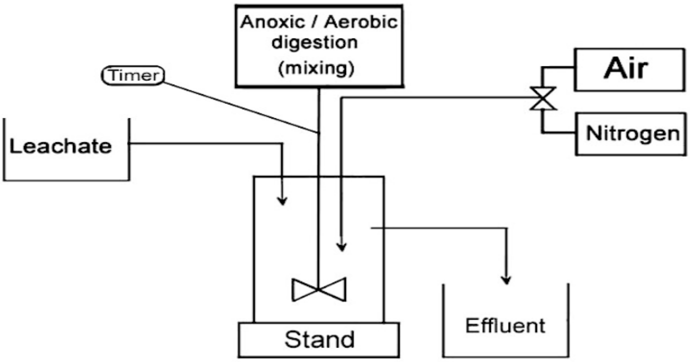

Fig. 1(b). Schematic diagram of the Aerobic/Anoxic treatment.

RESULTS AND DISCUSSION

The geology of Al-Sulaybiyah landfill site is dominated by sand and limestone, which vary in grain size. The depth to the water table from the ground surface varied between 4-m in the northern edge to about 12-m at the southern edge. Al-Muzaini & Muslamani (1994) reported that the groundwater has high concentration of leachate contaminants. Landfill flow direction was similar to the regional groundwater flow direction towards the northeast (Al-Senafy *et al.*, 2003; Al-Yaqout & Hamoda, 2003). The ambient temperature, which ranged between 20° C and 50° C affects the generation of leachate and its characteristics. The annual average rainfall in Kuwait is 110-mm, which is considered not a significant factor in leachate generation. Calculated values of climate water balance based on the precipitation and Pan-evaporation data for the past 15 years were always negative even in the wettest seasons (Al-Yaqout & Townsend, 2001).

Leachate characteristics

The chemical characteristics of leachate samples collected during the 8-month monitoring period are summarized in Table 1. Analysis of samples shows high organic strength of the leachate as expressed by its BOD and COD values. The leachate is also nutrient rich, especially in phosphorus and nitrogen. It contains a wide variety of trace metals and other inorganic contaminants. A major contributor to nitrogen in leachate is the decomposition of complex nitrogenous compounds in the garbage fraction of the solid waste.

The maximum concentration of BOD from the ten boreholes was 312 mg/L recorded at borehole (B). The mean BOD concentration values ranged from 5 to 56 mg/L. In comparison, typical BOD concentrations reported in the literature ranged from 50 to 100

Table 1. Average leachate concentration at Al-Sulaiybiyah landfill

S.N.	Parameter	BH* (A)		BH (B)	
		Mean	S.D.	Mean	S.D.
1	pH**	7.28	0.30	6.72	0.25
2	Alkalinity (as $CaCO_3$)	2574	501.8	2864	1310.6
3	Conductivity** (mS/cm)	11	0.78	48	21.7
4	BOD	20	8.6	56	7.8
5	COD	869	685	1962	965.1
6	TS	32747	25440.9	117260	36420.7
7	TVS	3129	1930.6	10920	3207.6
8	SS	13527	8372.4	33069	10907.6
9	VSS	1257	603.2	4347	1912.1
10	TDS	5713	399.1	23845	10907.6
11	SO4	1939	1395.3	2408	1005.4
12	Cl	4423	496.3	23320	5466.5
13	NO3	959	614.8	778	584.3
14	Zn	0.60	0.50	2.08	1.8
15	Cd	0.13	0.08	0.24	0.14
16	Pb	1.08	0.55	1.74	0.63
17	Ni	0.78	0.56	0.82	0.54
18	Fe	162.72	159.84	388.75	259.7
19	Co	0.58	0.2	0.93	0.5
20	Mg	329.5	107.02	565.42	95.75
21	Ca	972.74	844.03	1475.7	924.82
22	Cu	0.28	0.22	0.92	0.8
23	Al	90.36	11.99	210.75	186.3
24	Na	1897.5	628.6	7564.4	1958.2
25	Hg	8.92	1.29	27.41	12.35

* BH = borehole ; ** All Concentrations are in mg l^{-1} except pH and Conductivity.

S.D. = Standard Deviation.

mg/L for 15 years old landfill (McBean *et al*., 1995). In this study, the concentration values of BOD are relatively low, where leachate is referred to as stabilized and the landfill at its most active level. The maximum COD concentration at borehole (B) was 6144 mg/L. Typical concentrations for older leachate ranged between 500 to 3000 mg/L (McBean *et al*., 1995).

The maximum and minimum concentrations of suspended solids were 104,032 mg/L and 98 mg/L, respectively. It is clear that Al-Sulaibiyah leachate suspended solids concentrations are very high and the total suspended solids for untreated domestic waste in Kuwait ranges between 300 – 500 mg/L (Hamoda *et al.,* 2014). The average TDS concentration was 23,845 mg/L at borehole (B). The variability in concentrations may be attributed to the infiltration events flushing out varying amounts of dissolved constituents. Total alkalinity is a measure of the buffering capacity, which is probably derived from the presence of substantial concentrations of carbonate-bicarbonate, hydroxide and organically derived fatty carboxylic acids (Henry & Heinke, 1989). The overall total alkalinity range of values was between 800-2864 mg/L.

Nitrogen is one of the nutrients in MSW leachate that has a major concern principally because of their importance in biological treatment. Main sources of Nitrogen in MSW leachate is the decomposition of complex nitrogenous compounds in the garbage fraction of the waste. Nitrate concentration data show that values tend to fall in three groups of between 0-100 mg/L, 200-700 mg/L, and at greater than 1000 mg/L. The maximum value recorded was 2220 mg/L at borehole (A).

The data from reactor are presented in Tables 2 and 3. The values reported in the tables are the mean values calculated over the last 10 days of steady-state operation.

Solids removal

The variation of the solids with time during the A/A treatment is shown in Figures 2(a) and 2(b). The extent of removal is generally high, except that suspended solids removal is generally low. Initial observation of the data shows that the solids concentrations have increased until day 6 and then decreased gradually. This is due to the solids build-up after full aeration of the sample. As a result, the percent removal can be calculated after day six of testing. The reduction in solids concentration was measured to be 55.7%, 71.9%, 34.4%, and 60.9% for total solids (TS), total volatile solids (TVS), suspended solids (SS), and volatile suspended solids (VSS), respectively.

Organics removal

The relationship between COD concentrations and operating time is shown in Figure 3. Soluble COD was measured throughout the digestion run. After 30 days, 93% removal of COD was achieved. The supernatant COD in the reactor was stable at an average (steady-state) concentration of 68 mg/L compared with the initial COD of about 952 mg/l. The results of COD and other parameters concentrations are shown in Table 3. In comparison, the results of anaerobic treatability studies in landfill achieved COD removal efficiencies about 40 to 90% (Calli *et al,* 2002; Kabdasli *et al.,* 2000, Timur & Ozturk, 1997). The reduction of COD during the reactor operation over a period of 30 days

Table 2. Concentration of solids during A/A treatment

Period (day)	TS (mg/l)	TVS (mg/l)	SS (mg/l)	VSS (mg/l)
0	12666	1785	2664	317
1	13714	2008	5112	518
2	14180	1976	5214	495
3	15020	1881	5695	528
4	24122	2045	16519	1319
5	26863	3664	17994	2274
6	47274	6156	20359	2289
7	34047	6294	21854	2168
8	29518	4434	20497	1992
9	23925	3971	19422	2139
10	26947	2668	16739	1676
12	30302	2831	20706	1607
14	24384	2476	18781	1507
16	28278	2301	19850	1515
18	26899	1996	17698	1371
20	21499	1785	9996	662
22	19972	2044	9403	876
24	21261	2354	10782	941
26	19766	1523	16096	959
28	20368	1385	14850	1024
30	22724	1273	19019	902

Table 3. Variations of leachate parameters during A/A treatment

Period (day)	Filtrate COD(mg/l)	Nitrate (mg/l)	Nitrate end of Anoxic (mg/l)	Ammonia (mg/l)	pH	Alkalinity mg CO_3/ l	Nitrite (mg/l)
0	952.32	503	0	229.6	7.76	192	13
2	890.88	738.0	950	103.0	8.22	109	10
4	752.64	499.0	986	107.0	8.12	111	30
6	399.36	557.0	545	103.0	8.09	111	17
8	353.28	445.0	495	96.3	8.44	78	14
10	337.92	391.0	477	82.3	8.41	47	16
12	307.2	394.0	482	73.4	8.34	46	19
14	384	413.0	457	60.5	8.44	44	1
16	368.64	356.0	381	72.2	8.17	33	1
18	184.32	319.0	465	63.8	8.25	24	0
20	61.44	300.1	340	73.9	8.17	31	0
22	61.44	353.0	346	72.8	8.16	15	29
24	95.232	438.0	243	69.4	8.13	12	45
26	76.8	440.0	352	51.5	8.02	12	48
28	122.88	400.0	302	47.0	7.91	10	62
30	58.368	382.0	289	28.0	7.87	7	46

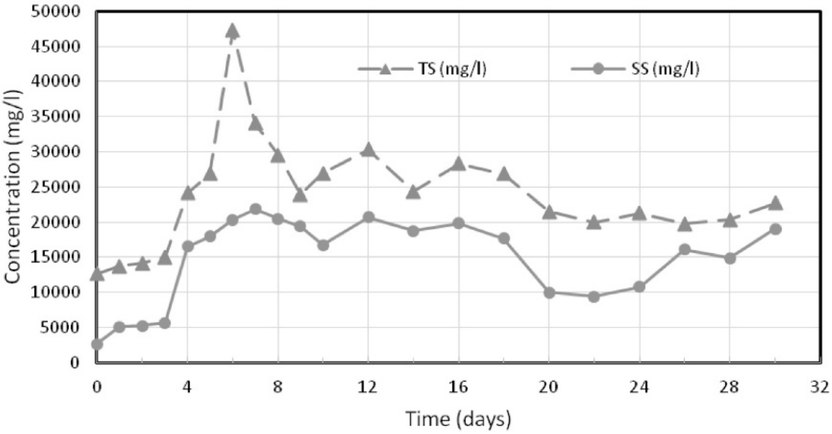

Fig. 2 (a). Variation of total solids (TS) and suspended solids (SS) with time during the A/A test.

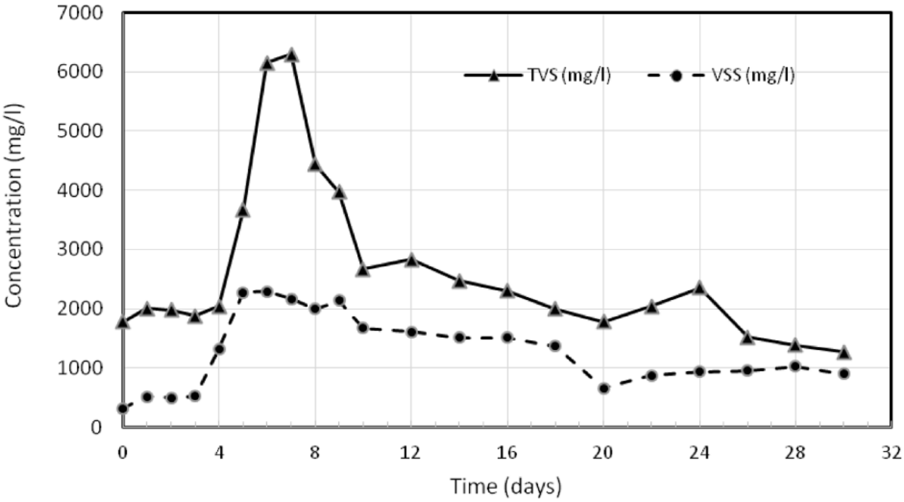

Fig. 2(b). Variation of total volatile solids (TVS) and volatile suspended solids (VSS) with time during A/A test.

followed a pattern of first order kinetic model (Figure 3), decreasing initially at a high rate and leveling-off after about 20 days (2 HRT's), as the system reached a steady-state. This is in agreement with earlier observation reported by Al-Ghussain *et al.,* (2004) for similar systems.

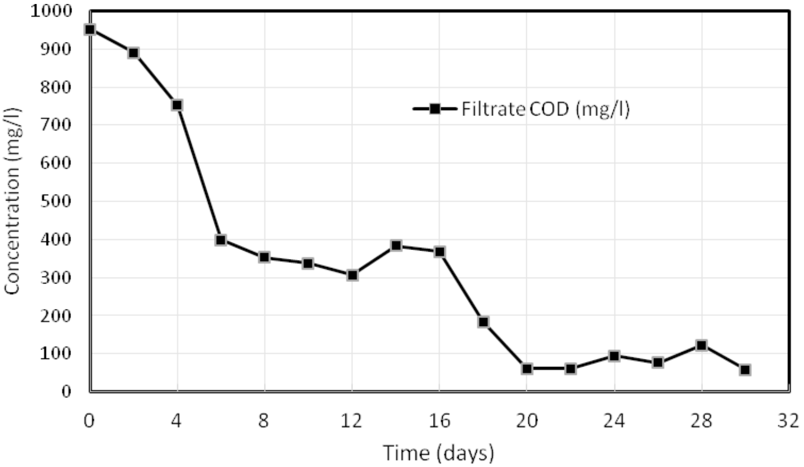

Fig. 3. Variation of COD concentrations with time during the A/A treatment.

Ammonia

As shown in Table 3, the NH_4^+-N concentration in the feed to the reactors was 230 mg NH_4^+-N/L. Figure 4 indicates that during the steady-state conditions, the reactor showed average concentrations of 57 mg NH_4^+ - N/L. This clearly demonstrates the onset of cycles of alternating nitrification and denitrification in the reactor.

NO_2^- and NO_3^-

The data on NO_2^- and NO_3^- are given in Table 3. Figure 4 presents NO_2^- and NO_3^- variations with respect to the operation period. The value of NO_2^- in the reactor increased to a maximum value of 30 mg NO_2 - N/L and after that it is decreased until day 20, then further decreased again until the end of the run.

Table 3 shows that the original level of NO_3-N in the feed was about 503 mg NO_3^- - N/L. However, during the steady-state operation , the NO_3^- - N decreased to 300.1 mg NO_3 - N/L. It should be noted that, the high NO_3^- - N concentration in the reactor is probably due to incomplete denitrification caused by insufficient length of the anoxic cycle in the reactor and/or partial inhibition of the denitrification process. Thus, it is concluded that the anoxic cycles should have been extended to accommodate the available nitrate.

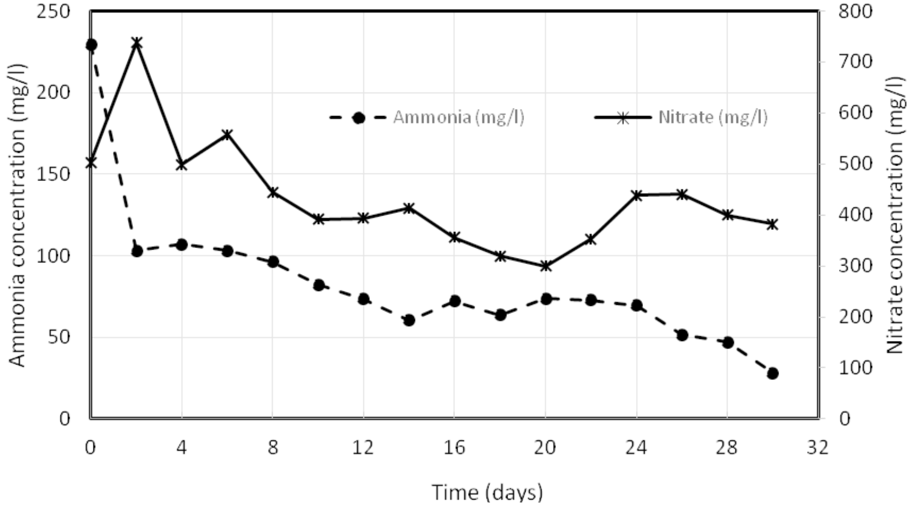

Fig. 4. Variation of ammonia and nitrate concentrations with time during the A/A test.

Alkalinity and pH

The profile of alkalinity and pH for the reactor is shown in Figure 5. The alkalinity observed in the reactor was 13 mg/L as $CaCO_3$ compared to the influent alkalinity, which averaged 192 mg/L (Table 3). This is due to the fact that samples were regularly withdrawn from the reactor at the end of an aerobic cycle when all or most of the alkalinity is consumed during nitrification. The lower alkalinity in the reactor is possibly due to consumption of alkalinity during complete nitrification of ammonia. The pH in the reactor was 7.76 at the beginning, and was restored in the range of 8.1 to 8.4 during the A/A treatment.

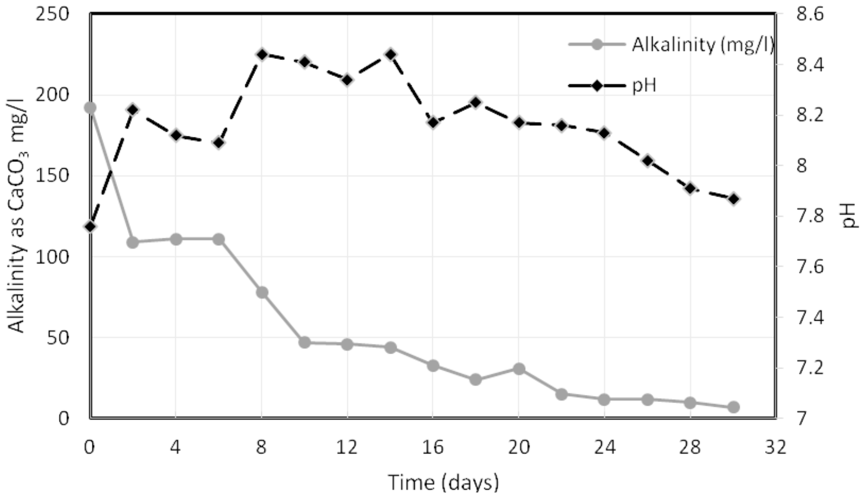

Fig. 5. Variation of alkalinity as $CaCO_3$ versus time during the A/A test.

Leachate samples analyzed from Al-Sulaibiyah landfill can be referred as "stabilized leachate" due to its low BOD values and low ratios of BOD to COD. Leachate of such characteristics indicate that the landfill is biologically at its most active level, where bacteria thrive in the absence of oxygen and convert the soluble organic compounds into methane and carbon dioxide, which are emitted as landfill gas. Al-Sulaibiyah leachate is generated from mature landfill (greater than 10 years) where BOD is less than or equal to 100 mg/L, COD in the range of 1000 mg/L, and BOD/COD ratio is in the range of 0.05 to 0.2. The low ratio of BOD/COD is due to the fact that the landfill contains humic and fulvic acids (Tchobanoglous *et al.,* 1993; McBean *et al.,* 1995). Due to the range of constitutes within leachates, a combination of treatment processes is used, with each playing a specific role in treating the leachate. To determine what treatment system components are needed, the above considerations are taken into account. After summarizing treatment options, McBean *et al.,* (1995) reported that a combination of anaerobic treatment followed by aerobic treatment is considered the most effective approach. The combination of these processes achieves the goals of lower biomass produced and increase of BOD, COD, and SS removal. This study clearly indicates that the A/A process can provide full treatment of the leachate at Al-Sulaibiyah landfill site but further transport of the treated leachate to the central wastewater treatment facility is recommended since final disposal into the Arabian Gulf water is prohibited.

CONCLUSIONS

Data obtained from extensive field and laboratory testing and analysis conducted on the leachate generated at Al-Sulaibiyah "active" landfill in Kuwait, provide a sound basis for the leachate management and future improvements towards site rehabilitation. Al-Sulaibiyah landfill leachate is highly contaminated and contains considerable organic, salt and metal concentrations. Experiments on the A/A treatment, proved that the process can achieve good quality effluent with low COD, solids, ammonia, and NO_3 concentrations. The reduction in solids concentration was measured to be 55.7%, 71.9%, 34.4%, and 60.9% for total solids (TS), total volatile solids (TVS), suspended solids (SS), and volatile suspended solids (VSS), respectively. After 30 days of operation at an HRT of 10 days, an average COD removal of 93% was attained. The supernatant COD in the reactor was stable at an average concentration of 68 mg/L compared with the initial COD of about 952 mg/L. Its NO_3^--N decreased to 300.1 mg NO_3^- - N/L from an initial feed concentration of about 503 mg NO_3^- - N/L due to the anoxic stage, thus shows the merit of the “Aerobic / Anoxic” system over the “Aerobic” system. The results indicated that the biodegradation of solids and organics followed a pattern of first-order kinetic model during the semi-continuous operation of the reactor.

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