Environmental Studies of Domestic Wastewater Treatment Using Integrated Anaerobic/Aerobic System

*Talaat A. Hegazy, M. A. Abdel-Magied, A. Al-Asmar, and M. S. Ibrahim

Mansoura University, Damietta Branch, Faculty of Science, Environmental Sciences Department, EGYPT
*talaat_hegazy@mans.edu.eg

Abstract: Conventional aerobic technologies based on activated sludge processes are dominantly applied for the treatment of domestic wastewater due to the high efficiency achieved, the possibility for nutrient removal and the high operational flexibility. Anaerobic pre-treatment of domestic wastewater can serve a viable and cost-effective alternative due to its relatively low construction and operational cost, operational simplicity, low production of excess sludge, production of energy in form of biogas and applicability in small and large scales. A viable alternative is the sequential anaerobic–aerobic systems. The performance of the integrated anaerobic/aerobic wastewater treatment system (AAWTS) for domestic wastewater treatment has been investigated. The domestic wastewater and activated sludge were collected from Ras El-Bar wastewater treatment plant. The overall removal efficiency of the suggested system, is in the order TSS < TN < BOD < Cl^- = TDS < COD < NH_3.The deficiency of the applied AAWTS may be due to the limiting effect of salts on the biological treatment of saline influents.

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1. Introduction:

In developing countries where access to safe drinking water is not guaranteed for a majority of the population, it is important to maintain the quality of surface water sources for drinking purposes, industrial development or agricultural expansion. It is obvious that integrated management programs for the available water resources are required. Meanwhile, the responsible authorities should urgently consider a strategy for the proper management and development of non conventional water resources (Tawfik *et al*, 2004 and 2006). Consequently, wastewater like domestic sewage, apart from being sanitized, can become an important source of re-usable water, fertilizer, soil conditioner and energy. Currently, built-up and usually expensive and sophisticated systems for wastewater treatment usually fail, especially in developing countries: no manpower, no finances for operation, maintenance of equipment, etc. Thus, need to develop reliable technologies that treat domestic wastewater is a must. The degree of treatment required varies according to the specific reuse application and associated water quality requirements (Tandukar et al, 2005 and 2007).

Anaerobic digestion presents a high potential in most developing countries for domestic wastewater treatment, and thus is a suitable and economical solution (Foresti, 2001 and Halalsheh, 2002). The anaerobic process can serve as a viable alternative, compared to conventional aerobic processes. The fact that the process can be carried out in decentralized mode means also that this application can lead to significant savings in investment costs of sewerage systems (Gavala and Lyberatos, 2001 and Lettinga, 2004).

The efficiency of an anaerobic digester depends on the dynamics and kinetics of the microbe populations within the reactor and on the narrow limits that thermodynamics places on the ensuing reactions. Acetate is a major product of the fermentation of intermediate organic molecules. About 70% of methanogenesis is through the acetate route (De Smedt et al, 2001 and Fuchs et al, 2003). Very few known species of the methanogenes make use of the acetate route of methane production, but almost all are able to use the alternate H_2/CO_2 route which has the fundamental importance in keeping the H_2 pressure of a system low (El-Mitwalli et al, 2002). Recently, however, more efficient anaerobic systems have been developed, and they are being successfully applied for treatment of low-strength wastewaters such as domestic wastewater, particularly under tropical conditions where artificial heating can be avoided, to cut down on the costs (Foresti, 2001, Carr et al, 2004, Ernst et al, 2006 and Asano, 2007).

Ras El-bar is a major city and resort on the Mediterranean Coast, in Damietta Governorate. The city covers about 200 km north of Cairo and is distinguished by its unique position since it is the point where the Nile River meets the Mediterranean Sea. In addition to that it enjoys a good moderate weather, crystal clear water and numerous tourist places. The climate of Ras El–bar is Mediterranean, and contains a high percentage of iodine. There are approximately 15,000 to 25,000 inhabitants in Ras El Bar. However, during summer season (July-August), it becomes a well known local resort and receives between 200,000 and 250,000 visitors during that period. Thus, organic load increases which contain a high level of salts and this cause an elevation of wastewater salinity. Sodium chloride (NaCl) and other salts may reach wastewater by several means. Seawater has been used as an alternative water source for toilet flushing in some coastal cities, resulting in a high salt content in the sewage.

Also, in coastal areas, infiltration of saline water into sewers is associated with a subsurface water rise and contributes a high concentration of chloride to wastewater. In addition, certain industrial wastewater contains high inorganic salts because of specific technologies, such as cheese, pickling, canning and dye manufacturing. The activated sludge process is usually used to treat wastewater for its low cost, so it is thought that the shock salt loading may influence the process when saline wastewater enters wastewater treatment systems.

The aim of this work is to study the efficiency of domestic wastewater treatment of Ras El–Bar by applying integrated anaerobic/aerobic system as an alternative of the conventional aerobic activated sludge process. To achieve that, the physico-chemical characteristics of domestic wastewater were investigated before and after applications of anaerobic/aerobic treatment system.

2. Material and Methods

All chemicals used were of analytical reagent grade quality. The experimental method involved the collection of composite samples in clean plastic containers of 5 liter capacity at three different units of the treatment plant, namely, a) Influent to the treatment plant, b) Effluent of an aeration tank and c) Final effluent for seven months (monthly sample) for assessment of Ras El–Bar treatment plant performance. The samples were analyzed using the Standard Methods (Adams, 1990; APHA, 2005; and EPA, 2000). The primary parameters included Temperature(T), pH, total dissolved solids (TDS), settlable solids (SS), electrical conductivity(EC), alkalinity, ammonia(NH_3), dissolved oxygen (DO), 5-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), chlorides and sulfide; while secondary parameters are mixed liquor suspended solids (MLSS), sludge volume index (SVI). The pH was estimated using pH meter (3305, Jenway, UK).

Experimental set-up and design

Figure (1) shows a schematic diagram of anaerobic/aerobic wastewater treatment system (AAWTS) which was designed and fabricated by the project team. This module consists of a reactor with capacity of 300 liter volumes, water jacket, stirrer blade, electric heater and stirrer, wastewater filling hole, control valves, variable speed pump and settling tank with 250 liter volumes, and fixed speed return pump. The anaerobic reactor was provided with 5 holes for measuring instruments such as temperature and pH. A separate aeration section with a dimension of 21x 54x90cm and a precipitation section with a volume of 45L were used. Aeration was performed with an air pump and diffusers. The domestic wastewater and activated sludge were provided from Ras El-Bar Sewage Wastewater Treatment Plant. All experiments were conducted in batch-wise at room temperature (25C°±5 C°). After 180 L domestic wastewater and 36 L activated sludge (6 g/L MLSS) were added into the reactor (pH 7.2), stirring started to acclimate activated sludge. During the acclimation period, 180 L supernatant was withdrawn and 180 L fresh domestic wastewater was refilled in the reactor every 24 hours for one month. After acclimation, 180L supernatant was withdrawn and 180 L fresh domestic wastewater was refilled in the reactor. The wastewater samples were harvested for complete analysis. The characteristics of sludge were determined after it was squeezed by distilled water.

3. Results and Discussion:

Special consideration has been given in the current study to the organic content, characterized by BOD_5, COD and the COD/ BOD_5 ratio as shown in Tables (1 and 2). Based on the performance study conducted for different primary and secondary parameters for a period of seven months, Colmenarejo et al. (2006) determined the general efficiency indicator to compare overall performances of the different plants in terms of average TSS, COD, BOD_5 and ammonia removal efficiencies. Similarly, the efficiency of plants is generally measured in terms of removal of organic matter (CPHEEO, 1993). The pH directly affects the performance of a secondary treatment process (Metcalf and Eddy, 2003) because the existence of the most biological life is dependent upon a narrow and critical range of pH. Since, the solids removal is an important measure for the success of a primary treatment unit (McGhee, 1991) and the dissolved solids content of the wastewater is of concern as it affects the reuse of wastewater for agricultural purposes, by decreasing the hydraulic conductivity of irrigated land if the total dissolved solids content in the water exceeds 480 mg/l (Bouwer, 1978). Also, BOD removal is indicative of the efficiency of biological treatment processes (Sincero and Sincero, 1996).

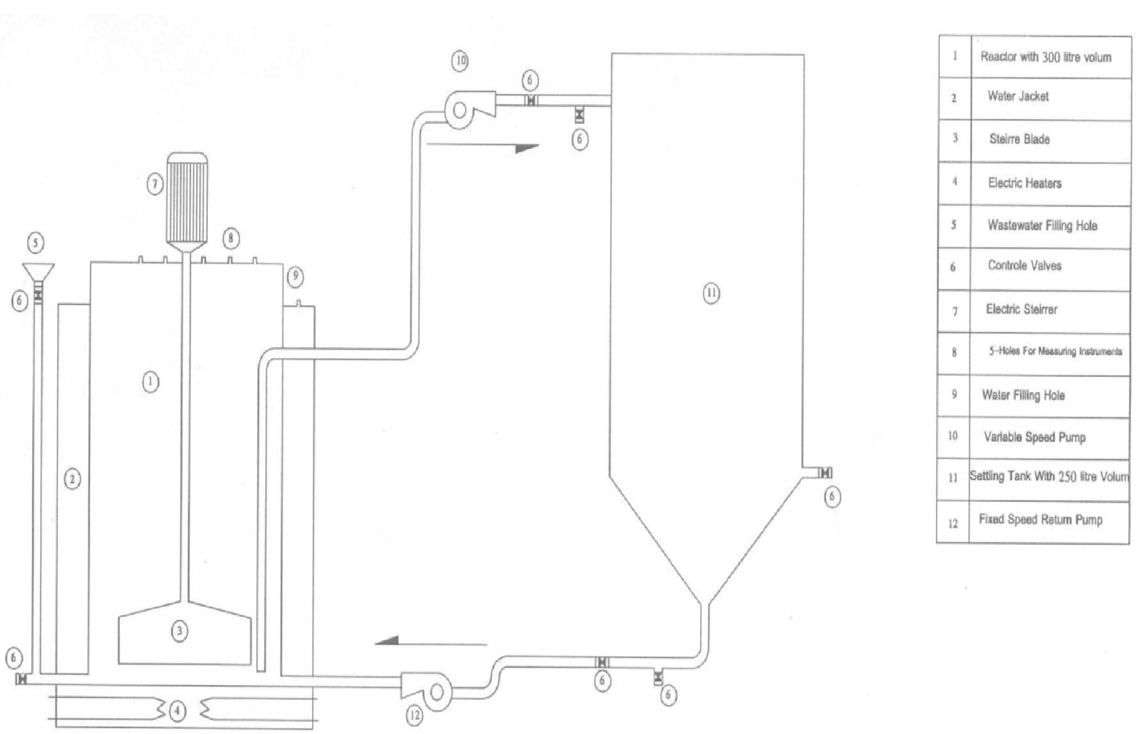

Figure (1): Schematic Diagram of Anaerobic Wastewater Treatment System (AAWTS).

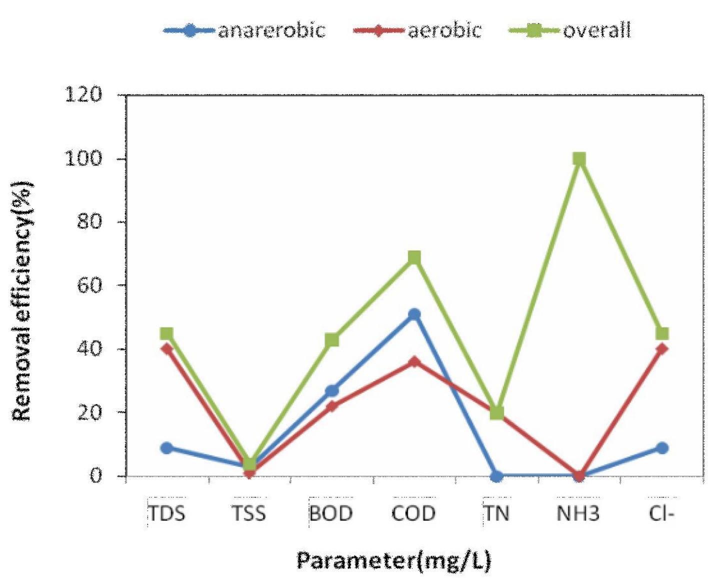

Figure (2): Removal efficiency (%) of the suggested anaerobic/aerobic treatment system (AAWTS).

Influent wastewater characteristics to the inlet of the Ras EL-Bar treatment plant

As shown in Table (1), the wastewater varied in their characteristics, where the pH ranged from 6.6 to 7.72. The concentration of total dissolved solids, settlable solids, BOD_5 and COD were 3325-7504 mg/L, 116-263 mg/L, 126-225 mg/L, 303-542 mg/L, respectively, while the average chlorides and sulfide were 3015 mg/L and 8.8 mg/L, respectively (Table 1). Out of seven months of performance study, the highest value of total dissolved solids (7504 mg/L), settlable solids (263 mg/L), BOD_5 (225 mg/L) and COD (542 mg/L) is attributed to heavy organic and inorganic loading with less liquid content (Kumar, et al., 2010). In the treatment plant, the DO was "nil" at the inlet, stimulated by oxidation of sewage ammonia to nitrates, septic condition, heavy organic loadings.

Table (1): Average wastewater characteristics at the inlet and primary effluent of Ras EL-Bar treatment plant for seven months

Parameter	Raw wastewater (Influent)	Primary effluent	Removal efficiency (%)	Law 48 (1982)
Temperature (C°)	23.7	23.7	-	35
pH	7	7.1	-	6 - 9
Electrical Conductivity (µS/cm)	7678	6157	20	-
TDS(mg/L)	4532	3864	15	-
Settleable solids(mg/L)	212	104	51	50
DO(mg/L)	0	0	-	≤ 4
BOD(mg/L)	185	117	37	60
COD(mg/L)	446	223	50	80
S^{-2} (mg/L)	8.8	2.9	67	1
NH_4(mg/L)	18.5	1.1	94	0
Alkalinity(mg/L)	347	311	10	-
Cl^-(mg/L)	3015	2291	24	-

Effluent wastewater characteristics of the aeration tank

The aeration tank in the treatment plant is considered a most important step in the activated sludge process, and the priority was intended to increase the dissolved oxygen level of sewage so that the efficient aerobic digestion facilitates decomposition of organic matter. This has to be ensured because of low dissolved oxygen content (nil) in the influent. In Ras EL-Bar Treatment Plant, the DO showed a slight increase and ranged from 1.1to 2.3 mg/L in the aeration tank, indicating an inefficient and unsatisfactory working. The pH varied from 6.7 to 7.9 (Tables 2 and 4). Efficiency of the aeration tank was calculated by considering percentage reduction of BOD_5. The average influent value of BOD_5 in the aeration tank was 185 mg/L while the average effluent value from this tank is 120 mg/L. The percentage removal of BOD_5 in the treatment plant is 35.2 % against the expected value of 70-85%, illustrating that BOD_5 reduction is little less than the expected. This slight decrease is attributed to the recycling of old sludge that contained fewer microorganisms, besides insufficiency of MLSS for the aerobic digestion of the organic matter. The DO during the aeration was absorbed by the microorganisms due to less availability of fresh organic matter. As shown in Tables (2 and 4), the MLSS concentration in the aeration tank ranged between 555-3752 mg/L against the expected concentration of 1500-3000 mg/L, confirming suitability of secondary clarifier in terms of microbial content. A SVI value of 46-69 mL/gm indicates bad settling of suspended solids that can be achieved for proper MLSS concentration. The SVI of Ras EL-Bar Treatment Plant was quite low compared to the expected value (60-90 mL/gm).

Table (2): Effluent characteristics of the aeration tank of Ras EL-Bar treatment plant.

Parameter	Aeration tank
Temperature (C°)	23.7
pH	7.3
Sludge Volume(ml/L)	104
MLSS(mg/L)	1723
Sludge Volume Index(mg/L)	53
DO(mg/L)	1.1 - 2.3
BOD(mg/L)	120

Wastewater characteristics of the suggested anaerobic/aerobic wastewater treatment system (AAWTS)

During the working period, samples were taken from: the tank (raw wastewater), which feeds the anaerobic reactor, the effluent of the anaerobic reactor (the influent to the aerobic reactor), the effluent of the aerobic reactor and from the aeration tank (Tables 3 and 4). The removal efficiency of BOD5, COD, TDS and chlorides after anaerobic treatment was 27 %, 51 %, 9%, and 9%, respectively, confirming inefficiency of the anaerobic treatment and its unsuitability to be discharged. However, after aerobic treatment, the removal efficiency of BOD5, COD, TDS, TN and chlorides were 22 %, 36 %, 40%, 20% and 40 %, respectively (Tables 3 and 4).

The overall efficiency of Ras EL-Bar Treatment Plant was calculated by considering the TDS, TSS, COD, TN, NH_3, chlorides and BOD_5 of the influent (raw wastewater) and the final effluent from the suggested anaerobic/aerobic treatment system. Tables (3 and 4) indicated that the reduction in COD is 69 % while the percentage reduction of total dissolved solids was 45 % much below the expected removal of 70-80% indicating poor efficiency in terms of total dissolved solids removal. However, the removal of total suspended solids and BOD_5 was found to be unsatisfactory. The reduction in total suspended solids is 4% against the expected value of 85-90 %, while the reduction in BOD_5 is 43 % against the expected value of 85-90 %. Kassab et al. (2010) stated that the range of TSS removal efficiencies by UASB-AS and UASB –SBR reactors were 85 – 92 % and 84 - 98 %, respectively. On the other hand, the anaerobic SBR or aerobic SBR system cannot remove the TSS content of the wastewater. According to that, our results were agreed with this finding. Suspended solids in wastewater are known to affect anaerobic digestion adversely (Gijzen, 2001; Bodik et al., 2003). They decrease sludge activity due to adsorption and entrapment, limit substrate transfer, lead to the formation of scum layers, inhibit granulation, and enhance sludge production, causing the frequent need to de-sludge reactors (Angelidaki and Sanders, 2004; Kumar et al, 2010).There is usually no correlation between BOD_5 and COD in wastewater with slowly biodegradable organic suspended solids and in complex waste effluents containing refractory substances (Eckenfelder, 1989; Coskuner and Ozdemir, 2006). Hence, treated effluents may exert virtually no BOD and yet exhibit a substantial COD. Since, the COD represents virtually all organic matter, either partially degradable or non-biodegradable and BOD_5 the total oxygen demand, it is necessary to develop a relationship between BOD and COD. Accordingly, the average influent and effluent COD/BOD_5 ratios for the suggested anaerobic/aerobic treatment system were calculated, and it is observed that, the COD/ BOD_5 ratio frequently varied for effluents compared to untreated wastes (Eckenfelder, 1989; Coskuner and Ozdemir, 2006).

The influent wastewater exhibited a ratio of 4 and this value is not comparable to those presented by Metcalf and Eddy (2003). As shown in Tables (3 and 5), the typical COD/BOD_5 ratio of domestic wastewaters is usually in the range 1.25 to 2.5. However, for treated effluents of this study, it was 2.24. This indicates a relatively higher proportion of the non-biodegradable content in treated effluent than raw wastewater. As a consequence, the efficiency of BOD_5 removal is lower than that of COD removal. However, the physical removal of COD by sedimentation and filtration in the sludge bed without anaerobic degradation may be the reason for obtaining higher value of maximum COD removal. Thus, the obtained results using the integrated system of this study was relatively low compared to Kassab et al., (2010), who indicated that the removal efficiency of COD from wastewater treatment using upflow anaerobic sludge blanket (UASB) with activated sludge (AS) or sequencing batch reactor (SBR) system generally in the range of 79 to 85 % They attribute that to the integration UASB with SBR which especially enhance the removal efficiency of organic content of effluent. The removal efficiency of TN after anaerobic treatment was found to be zero. Overall removal efficiencies of TN and ammonia were 20 and 100 %, respectively (Tables 3 and 5). A similar result were reported by Lema and Omil (2001), who found that the ammonia was removed under moderate to low temperature of sewage treatment using UASB reactor. Moreover, the anaerobic reactor removed only the particulate nutrients by sedimentation and filtration and, therefore, it had relatively low removal of nutrients. Luostarinen et al., (2006) obtained a similar result, and they found that percentage of nitrogen removal in the range of 71-77 % under anaerobic and at low temperature conditions. Moreover, Tables (3 and 5) show that the average concentration of chlorides was 3746 mg/L of raw wastewater with anaerobic and aerobic removal efficiencies of 9 and 40%, respectively, and the overall removal efficiency was 45%. However, the high salt content of these wastewaters makes biological treatment with a conventional microorganism difficult. Thus, the biological removal of organic compounds from hypersaline wastewaters requires the use of halophilic organisms that are well adapted to hypersaline media. In order to overcome the inhibitory effect of the salt a specific flora, capable of decomposing organic compounds in high concentrations of salts (>30%), was adapted to saline wastewater by gradual increases in organic and salt concentrations.

The high salinity of industrial waste-waters is one of the causes of the difficulty in treating these wastewaters by conventional systems. As shown in

Tables (1, 3 and 5) the high salt concentrations disrupt metabolic functions and cause plasmolysis and/or loss of activity of microbial flora; hence the biological treatment of saline wastewaters with conventional microorganism results in low chemical oxygen demand (COD) removal efficiency. The effects of salt on the performance of biological processes in the treatment of wastewaters have been studied previously. Wang et al., (2005) have studied the effect of salt concentration on biological treatment of synthetic saline wastewater by feed batch operation. They found that increasing salt concentration reduced the COD removal rate and efficiency. Accordingly, it was necessary to dilute the influent wastewater with fresh or irrigation water to decrease the salinity and enhance the dissolved oxygen. AAWT system can use the anaerobic growth and support medium for biomass, which was retained in a high concentration, thus prolonging the sludge retention time (SRT) of the system, and provided a suitable environment for the growth and activity of slow-growing microorganisms. The limiting effect of salt on the biological treatment of saline effluents may also be overcome if conventional activated sludge is replaced by microorganisms that are well adapted to hypersaline media (Eckenfelder, 1989; Wang et al., 2005).

Table (3): Descriptive statics of the wastewater characteristics from the suggested anaerobic/aerobic treatment system (AAWTS).

	Parameter	pH	T (C°)	EC (µS/cm)	Alkalinity (mg/L)	TSS (mg/L)	TDS (mg/L)	DO (mg/L)	BOD (mg/L)	COD (mg/L)	TN (mg/L)	NH_3 (mg/L)	Cl^- (mg/L)
	No Samples	10	10	10	10	10	10	10	10	10	10	10	10
Raw Wastewater	Mean	7.33	23.5	9910	700	930	6342	0	220	892	44	16	3746
	Max.	7.8	24	9930	710	987	6438	0	253	920	49	19	3905
	Min.	7.1	23	9896	694	890	6117	0	200	850	40	11	3611
	Range	0.7	1	34	16	94	321	0	53	74	9	8	294
Anaerobic Treatment	Mean	7.6	-	9037	756	903	5771	0	160	440	44	17	3409
	Max.	8	-	9098	763	921	5823	0	173	476	56	19	3578
	Min.	7.38	-	9012	734	892	5713	0	145	427	38	15	3397
	Range	0.62	-	86	29	29	110	0	28	49	18	4	261
Aerobic Treatment	Mean	7.5	-	5422	690	893	3463	4.5	125	280	35	0	2046
	Max.	7.8	-	5571	702	900	3563	4.7	127	294	37	0	2157
	Min.	7.3	-	5489	681	886	3459	4.3	119	273	31	0	2035
	Range	0.5	-	82	21	4	104	0.2	6	21	6	0	122

Table (4): Sludge characteristics from the aeration tank of the suggested anaerobic/aerobic treatment system (AAWTS).

	MLSS(mg/L)	SVI (ml/L)
No Samples	5	5
Mean	680	59
Max.	687	61
Min.	673	54
Range	14	7

Table (5): Removal efficiency (%) of the suggested anaerobic/aerobic treatment system (AAWTS).

Parameter	Removal efficiency of Anaerobic treatment (%)	Removal efficiency of Aerobic treatment (%)	Overall removal efficiency (%)
pH	-	-	-
EC(µS/cm)	-	-	-
TDS(mg/L)	9	40	45
TSS (mg/L)	3	1	4
BOD(mg/L)	27	22	43
COD(mg/L)	51	36	69
TN(mg/L)	0	20	20
NH_3(mg/L)	8.8	0	100
Cl^-(mg/L)	9	40	45

4. Conclusion:

The overall removal efficiency of the suggested anaerobic/aerobic wastewater treatment system (AAWTS), is in the order TSS < TN < BOD < Cl^- = TDS < COD < NH_3.The results obtained in this study revealed that, the domestic wastewater of Ras El-Bar Treatment Plant was very saline. These conditions adversely affect the total biological efficiency of the activated sludge during the different stages of biological treatment. This decline of efficiencies may due to the plasmolysis phenomenon of non-halophilic microorganisms and thus responsible microorganisms for biological degradation of organic matter were inhibited. Accordingly, it was necessary to dilute the influent wastewater with fresh or irrigation water to decrease the salinity and enhance the dissolved oxygen. AAWT system can use the anaerobic growth and support medium for biomass, which was retained in a high concentration, thus prolonging the sludge retention time (SRT) of the system, and provided a suitable environment for the growth and activity of slow-growing microorganisms. The limiting effect of salt on the biological treatment of saline effluents may also be overcome if conventional activated sludge is replaced by microorganisms that are well adapted to hypersaline media.

Corresponding author
Talaat A. Hegazy
Mansoura University, Damietta Branch, Faculty of Science, Environmental Sciences Department, EGYPT
talaat_hegazy@mans.edu.eg

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