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Application Of Nanoparticles With Sequencing Batch Reactor For The Treatment Of Landfill Leachate

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Abstract

Background: Solid waste landfill leachate is one of the most polluted types of wastewater and its treatment is considered as a great challenge. The sequencing batch reactor (SBR) is one of the best technologies used for the treatment of wastewater including leachate. **Objective:** A SBR model was installed (30 days working) for the treatment of raw leachate collected from Elwafa and Elamal sanitary landfill in new Cairo city, Egypt. Two treatment cycles (8 and 12 hours) were applied. A modification in the 12-h treatment cycle was carried out by increasing the aeration the settlement periods. Nanoparticles were used supplemented into the SBR model to enhance the treatment efficiency. **Results:** The results proved the ability of the SBR system without nanoparticles for the treatment of leachate but still leachate has high concentrations of pollutants. After the addition of nanoparticles, the treatment efficiency of SBR system increased significantly. The removal percent of all studied physicochemical parameters were higher than 99% except TP which was 96.67%. **Conclusion:** The treated leachate quality was comparable with the Egyptian standards for the reuse of treated leachate in restricted irrigation. The application of nanoparticles proved as a clean, environment friendly and cheap technology to improve the treatment of leachate using SBR system.

Key words: Leachate, SBR, Nanoparticles.

INTRODUCTION

The increase in population, industrial development, improve in living standards, and increase in human consumption are considered as the main reasons for the production and accumulation of solid wastes which become scattered all over Egypt. As the solid wastes become dangerous to the population and natural resources, the Solid waste landfilling is one of the best solutions to overcome the problem of solid wastes in some countries.

Leachate is a dark brown malodorous liquid leak out from the Solid waste landfill sites. Landfill leachate contains different types of pollutants such as organic materials, dissolved and suspended solids, heavy metals and pathogenic microorganisms (Atmaca, 2009; Lou *et al*. 2009; Kashitarash *et al*. 2012). The untreated leachate can pollute the soil, groundwater and surface water and causes many other environmental issues related to human public health (Gotvajn *et al*. 2009).

There are different biological and physicochemical technologies and methods are used for leachate treatment (Mangkoedihardjo, 2007; Kashitarash*et al*. 2012; Pavithra and Shanthakumar, 2017).

One of the best biological treatment methods is the sequencing batch reactor (SBR) which has some advantageous in comparison with the other biological treatment methods in terms of space utilization, treatment efficiency, and installation and operation costs. The SBR process strategy is characterized by a controlled periodic change of process conditions such as concentration of oxygen, and availability other biological reactants. These environmental conditions are controlled using fill and draw operations at distinct time intervals (Neczaj *et al*. 2005; Perera *et al*. 2014).

Nanoparticles are used for wastewater treatment due to its small size, crystal form, high surface area, structure, high catalytic ability, unique network order and its high reactivity (Zhang, 2003; Zhang *et al*. 2007; Pavithra and Shanthakumar, 2017).

The main aim of the present study is to evaluate the treatment process of landfill leachate using a SBR model supplemented with nanoparticles.

MATERIAL AND METHODS

Samples and sampling:

A 60 liters of raw leachate wastewater were collected from Elwafa and Elamal Solid waste landfill in new Cairo city, Egypt. Leachate samples were collected in plastic containers with 20 liters for each one. Samples were collected and transferred immediately for the experiments according to the standard methods (APHA, 2010). Different samples were collected from the SBR model for analysis (Table 1).

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The SBR model:

Figures (1 and 2) showed the SBR model system. The model composed of two tanks. The first is anaerobic tank (60*30*30) and the second is aeration tank (60*30*30).The system was operated for one month per each treatment cycle at a base of three days. To adjust the mixed liquor suspended solids (MLSS) of the system, seed samples were collected from a wastewater treatment plant at New Cairo city.

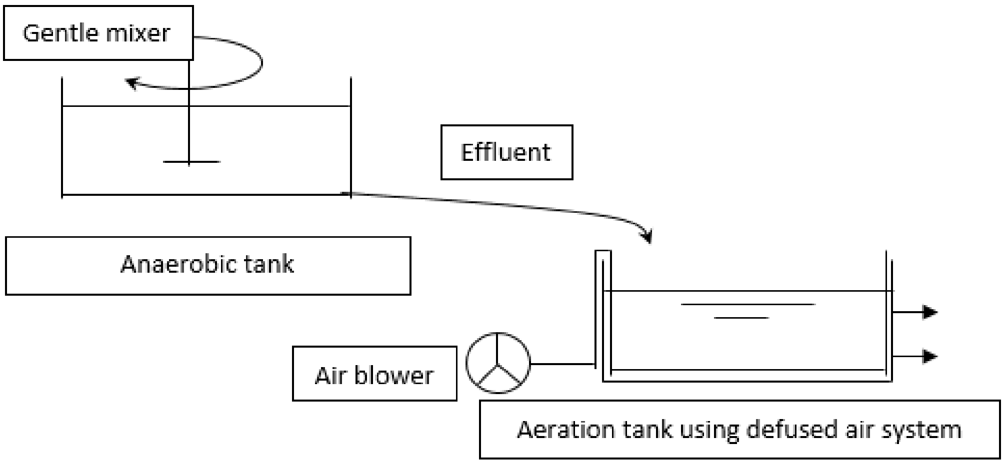
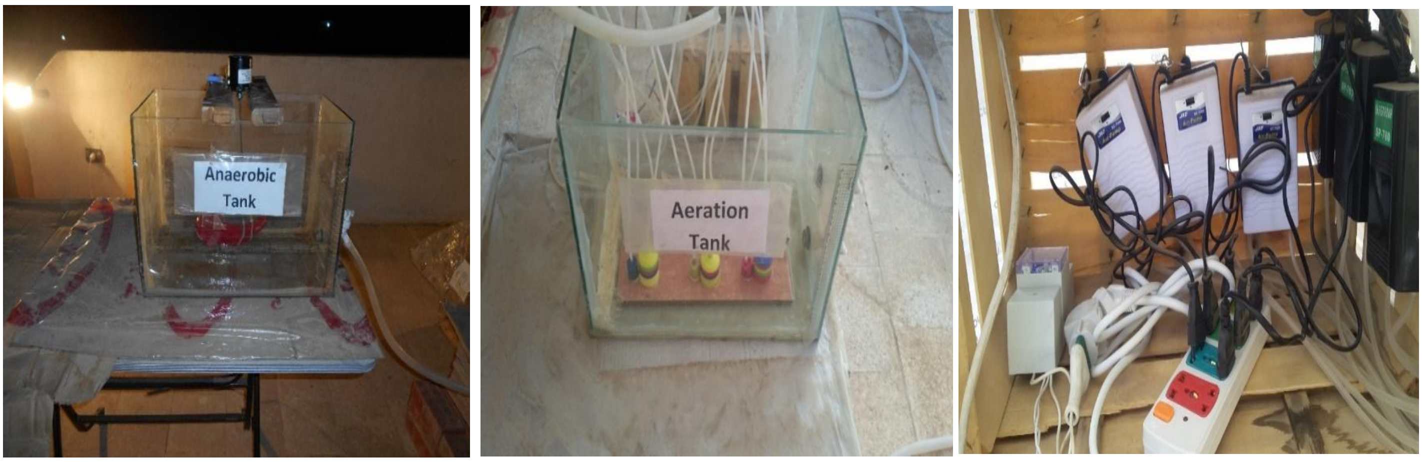


Fig. 1: Schematic diagram of SBR model.



(A) Anaerobic tank (B) Aerobic tank (C) Aerators

Fig. 2: Components of the SBR model.

Leachate treatment method:

The anaerobic tank was filled with the raw leachate with gentle continuous mixing to prevent the sedimentation process. The retention time (h) was one day. After the retention time, the anaerobic effluent transferred into the aerobic tank. Four different aeration cycles were applied and summarized in Table 1.

Table 1: Different aeration cycles.

Aeration cycle	Description	Number of samples for analysis
(1) 8-hours cycle without nanoparticles	Consists of three aeration stages (2 hours each). After each aeration stage, a 30-min anoxic stage was applied. After the third aeration stage, a settling stage (50 min) followed by a decant stage (10 min) were applied.	13
(2) 12-hours cycle without nanoparticles	Consists of four aeration stages. The first aeration cycle was 2.5 hours duration, the next two aeration cycles were 2 hours duration, and the fourth aeration cycle was 3 hours duration. After the first three aeration stage, a 30-min anoxic stage was applied. After the fourth aeration stage, a 50-min settling stage followed by 10-min decant stage were applied.	13
(3) Modified 12-hours cycle without nanoparticles	The same stages as cycle number (2) but the settling stage duration time expanded three times (2, 3 and 4 hours).	3
(4) Modified 12-hours cycle with nanoparticles	The same stages as cycle number (3) with addition of nanoparticles using Jar test with different doses (1, 2, 3, 4, 5 and 6 mg/l).	4 from Jar test and 1 after 4-h settling

The used nanoparticles:

Nanoparticles (INNPT nanomaterial) were produced from Elwatanya company for development, investment and trade, Egypt. The composition of INNPT nanomaterial (weight %) is CaO (35-40%), Al_2O_3 (40-45%), Fe_2O_3 (5-15%) and SiO_2 (2-3%).

Physicochemical analysis:

The raw leachate and SBR model samples were examined according to the standard methods for the examination of water and wastewater (APHA, 2010) for the following parameters; chemical oxygen demand (COD), biological oxygen demand (BOD), pH, total suspended solids (TSS), ammonia-nitrogen (NH_3-N), total Kjeldahl nitrogen (TKN) and total phosphorus (TP).

RESULTS AND DISCUSSION

Characterization of raw leachate:

The results in Table 2 summarizes the physicochemical quality of used raw leachate samples. The samples showed extremely high concentrations of organic pollutants in terms of COD, BOD, NH_3-N, TKN and TP. These high values indicate the old age of the Solid waste landfill site. The measured physicochemical values were considerably higher than the values reported by other studies (Ghafari *et al*. 2009; Aziz *et al*. 2010; Bashir *et al*. 2010; Bhalla *et al*. 2012).In addition, the pH of raw leachate was alkaline (7.9 – 9.0) which indicates the maturity stage of the Solid waste landfill dumping site (Jorstad *et al*. 2004). Some researchers reported the alkaline nature of raw leachate samples (Zhong *et al*. 2009; Palaniandy *et al*. 2010; Bhalla *et al*. 2012; Zainol *et al*. 2012).

Table 2: Characterization of raw leachate samples used in both treatment cycles.

Parameters	Unit	Raw leachate	
		8-hours cycle	12-hours cycle
COD	mg/l	13,000	15,500
BOD	mg/l	5,000	7,000
pH	-	7.9	9.0
TSS	mg/l	8,700	7,900
NH_3-N	mg/l	1,400	1,600
TKN	mg/l	4,100	4,200
TP	mg/l	28.0	30.0

Efficiency of SBR model for leachate treatment:

8-hours aeration cycle without nanoparticles:

Table 3and Figure 3 shows the removal efficiency of the SBR model of 8-h aeration cycle without addition of nanoparticles for the measured physicochemical parameters. It was clear that all values of the physicochemical parameters increased except pH value after the anaerobic stage which may be attributed to the fermentation process occurred due to the anaerobic conditions and formation of acids which decreased pH value. Also, after one day of aeration, the values of physicochemical parameters keep slightly increase due to the short aeration time that is not enough yet to encourage the complete growth and other metabolic activities of aerobic bacteria present in the inoculated domestic wastewater seed. The main reason for using wastewater seed is that leachate is deficient in nitrogen and phosphorous thus by mixing with domestic wastewater, leachate contains more desirable nutrient composition for easier treatment (Perera *et al*. 2014). It was clear that by increasing the aeration period, there was a decrease in the values of physicochemical parameters. At the end of aeration period (30 days), the overall removal percent was 13.85%, 6.0%, 26.44%, 29.27%, 57.86% and 75.0% for COD, BOD, TSS, TKN, NH_3-N and TP, respectively. The obtained results indicate that SBR model was successful in removing the pollutants from the leachate, but still the concentrations of pollutants higher than permissible limits for reuse of treated leachate in irrigation.

Table 3: The removal efficiency of the SBR model of 8-h aeration cycle without addition of nanoparticles.

Parameters	Unit	Raw leachate	Effluent	Removal percent	Limits of law 48(1982)
COD	mg/l	13,000	11200	13.85	100
BOD	mg/l	5,000	4700	6.0	60
pH	-	7.9	9	-	6-9
TSS	mg/l	8,700	6400	26.44	60
NH_3-N	mg/l	1,400	590	57.86	40
TKN	mg/l	4,100	2900	29.27	-
TP	mg/l	28	7	75.0	10

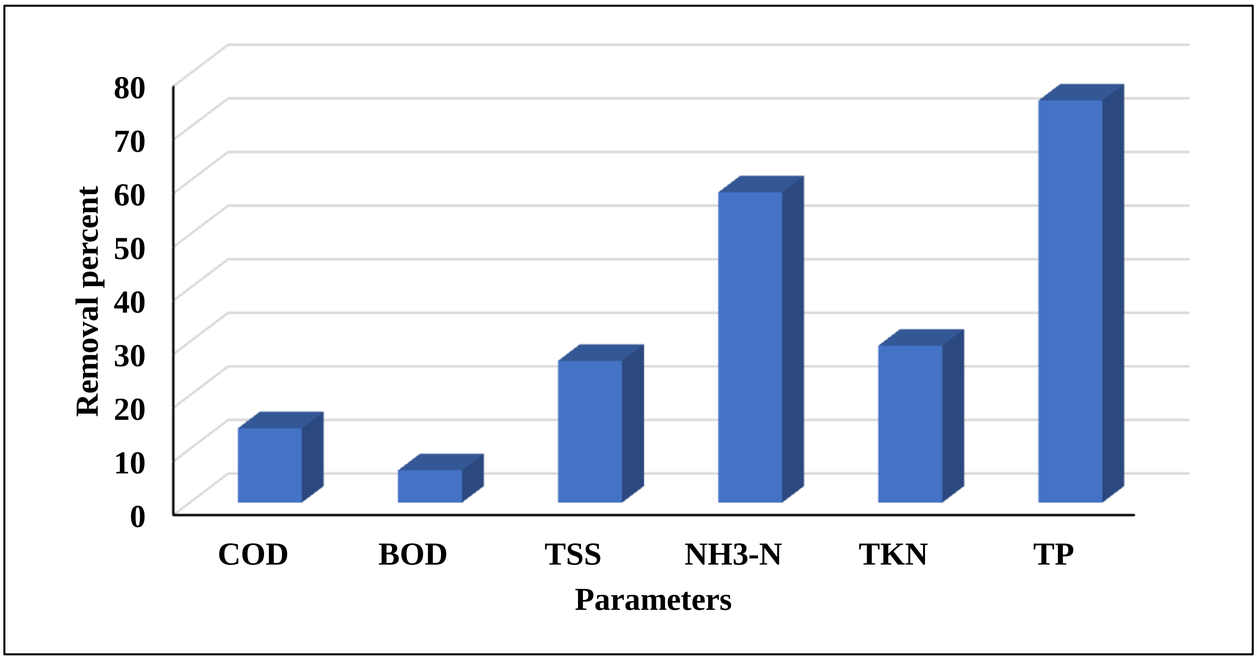


Fig. 3: Removal percentage of SBR model after 8-h aeration cycle without nanoparticles.

12-hours aeration cycle without nanoparticles:

Table 4and Figure 4 show the removal efficiency of the SBR model of 12-h aeration cycle without addition of nanoparticles for the measured physicochemical parameters. The same behavior was observed as the values of physicochemical parameters increased except pH value during the anaerobic stage.

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However, as the aeration periods increased from 8 hours to 12 hours, the removal efficiency of the SBR model enhanced. The overall removal percent was 35.48%, 40.29%, 34.18%, 45.24%, 73.13% and 80.0%, for COD, BOD, TSS, TKN, NH_3-N and TP, respectively. Increasing the aeration time is considered as a solution to improve the treatment process of leachate using SBR system (Aziz *et al*. 2013).

Table 4: The removal efficiency of the SBR model of 12-h aeration cycle without addition of nanoparticles.

Parameters	Unit	Raw leachate	Effluent	Removal percent	Limits of law 48 of year 1982
COD	mg/l	15,500	10000	35.48	100
BOD	mg/l	7,000	4180	40.2	60
pH	-	9.0	9	-----	6-9
TSS	mg/l	7,900	5200	34.18	60
NH_3-N	mg/l	1,600	430	73.13	40
TKN	mg/l	4,200	2300	45.24	-----
TP	mg/l	30	6	80	10

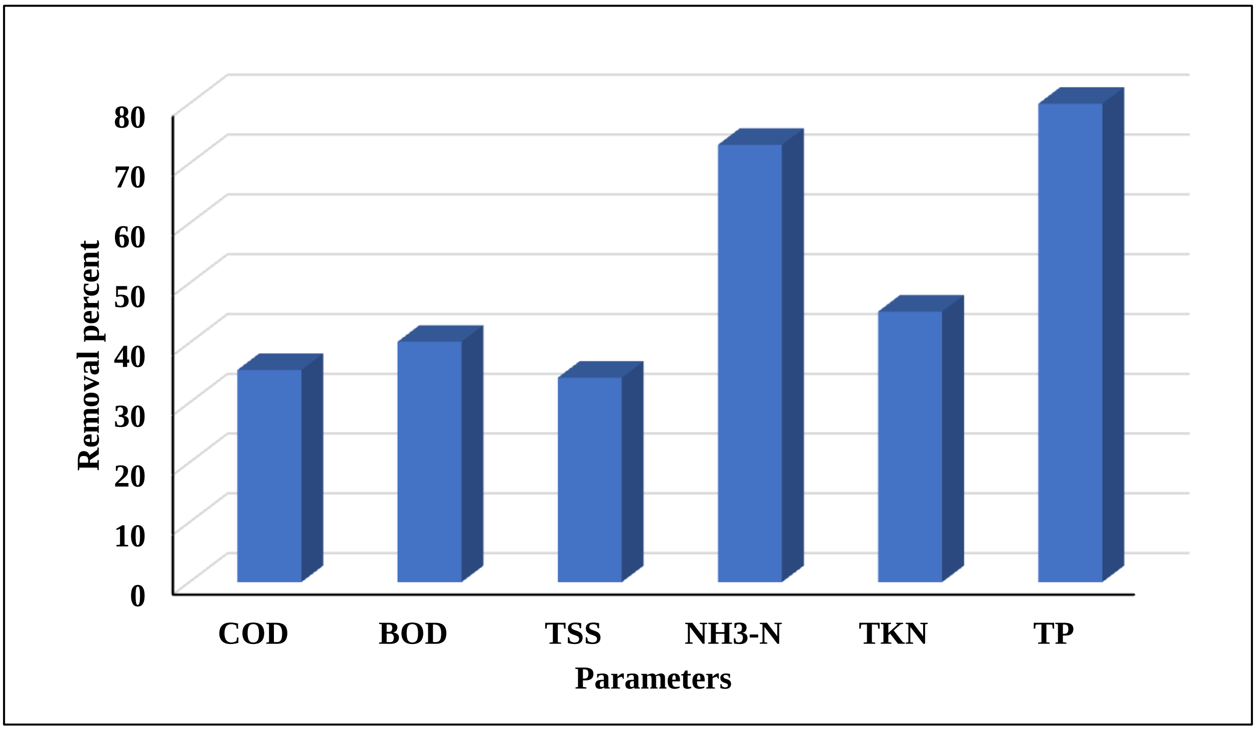

Fig. 4: Removal percentage of SBR model after 12-h aeration cycle without nanoparticles.

Modified 12-hours aeration cycle without nanoparticles:

The settling stage period was modified of the original 12-h aeration cycle (50min) to a three new settling periods (2 h, 3 h and 4 h). It was clear that increasing the settling time has a significant effect on the physicochemical quality of leachate specially in case of TSS (Table 5) and (Figure 5). The effect of settling time on TSS removal is attributed to the gravity effect (Aziz *et al*. 2011). The increasing in the settling time allow more particles to settle thus the value of TSS decrease.

Table 5: The removal efficiency of the SBR model of modified 12-h aeration cycle without addition of nanoparticles.

Parameters	Unit	Raw leachate	Effluent			Removal percent			Limits of law 48 of year 1982
			2 h	3 h	4 h	2 h	3 h	4 h	
COD	mg/l	15,500	9450	8900	8350	39.03	42.58	46.13	100
BOD	mg/l	7,000	3920	3700	3400	44.0	47.14	51.43	60
pH	-	9.0	9	9	9	-----	-----	-----	6-9
TSS	mg/l	7,900	3745	2350	824	52.59	70.25	89.57	60
NH_3-N	mg/l	1,600	300	150	32.5	81.25	90.63	97.97	40
TKN	mg/l	4,200	1600	800	100.5	61.90	80.95	97.61	-----
TP	mg/l	30	4.7	3	1.7	84.33	90.0	94.33	10

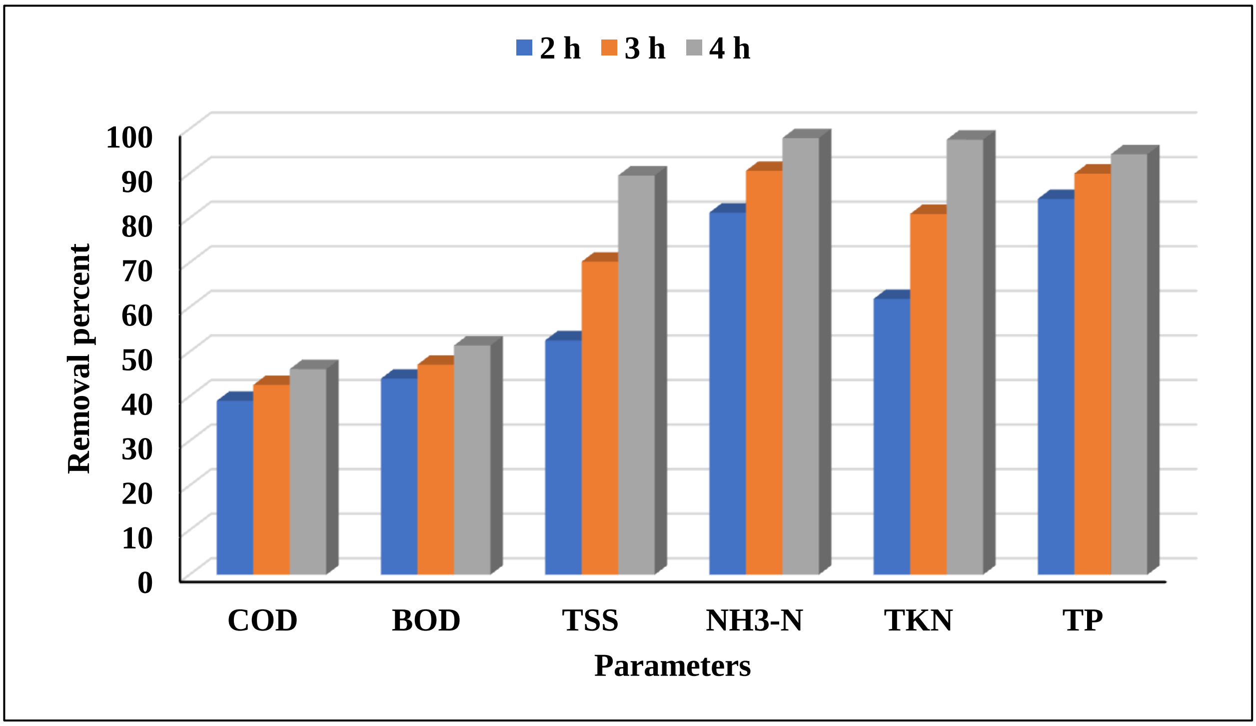

Fig. 5: Removal percentage of SBR model after modified 12-h aeration cycle without nanoparticles.

Efficiency of nanoparticles:

A Jar test was performed on a 12-hour aeration cycle leachate samples after four hours settling time using different six doses of nanomaterial (INNPT). The six doses (1, 2, 3, 4, 5 and 6 mg/l) were used at different retention times (1, 2, 3 and 4 hours) to determine the best nanoparticle dose at the best retention time using turbidity values as index. The turbidity results of the Jar test are summarized in Table (6). Depending on the Jar test results, a INNPT dose of 4 mg/l was selected as the suitable dose to be applied in the SBR model using the modified 12-hour aeration cycle with 4 h settling time. The removal efficiency of the SBR model to treat leachate was enhanced significantly after the addition of 4 mg/l INNPT. All measured physicochemical parameters showed overall removal percent more than 99.0% except in case of TP which was 96.67% as shown in Table 7 and Figure 6.

Table 6: Turbidity results of Jar test using different doses on INNPT at different retention times.

INNPT dose (mg/l)	Turbidity (NTU)			
	Time			
	1 h	2 h	3 h	4 h
1	15	13	8	7
2	17	10	9	8
3	13	12	11	9
4	14	11	5	5
5	15	9	8	6
6	12	11	10	9

Table 7: Removal efficiency of SBR model after modified 12-h aeration cycle with INNPT at modified 12-h aeration cycle.

Parameters	Unit	Raw leachate	Effluent					Removal percent					Limits of law 48 (1982)
			Jar test hours				12h cycle with INNPT+4h settling	Jar test hours				12h cycle with INNPT+4h settling	
			1	2	3	4		1	2	3	4		
COD	mg/l	15,500	540	250	70	40	52	96.5	98.3	99.5	99.7	99.6	100
BOD	mg/l	7,000	400	180	50	30	45	94.2	97.4	99.2	99.5	99.3	60
pH	-	9.0	7	7	7	7	7	-	-	-	-	-	6-9
TSS	mg/l	7,900	250	120	50	48	50	96.8	98.4	99.3	99.3	99.3	60
NH_3-N	mg/l	1,600	25	19	12	7	10	98.4	98.8	99.2	99.5	99.3	40
TKN	mg/l	4,200	60	50	30	20	23	98.5	98.8	99.2	99.5	99.4	-
TP	mg/l	30.0	1.3	1.2	1.0	1.0	1.0	95.6	96.0	96.6	99.6	99.6	10

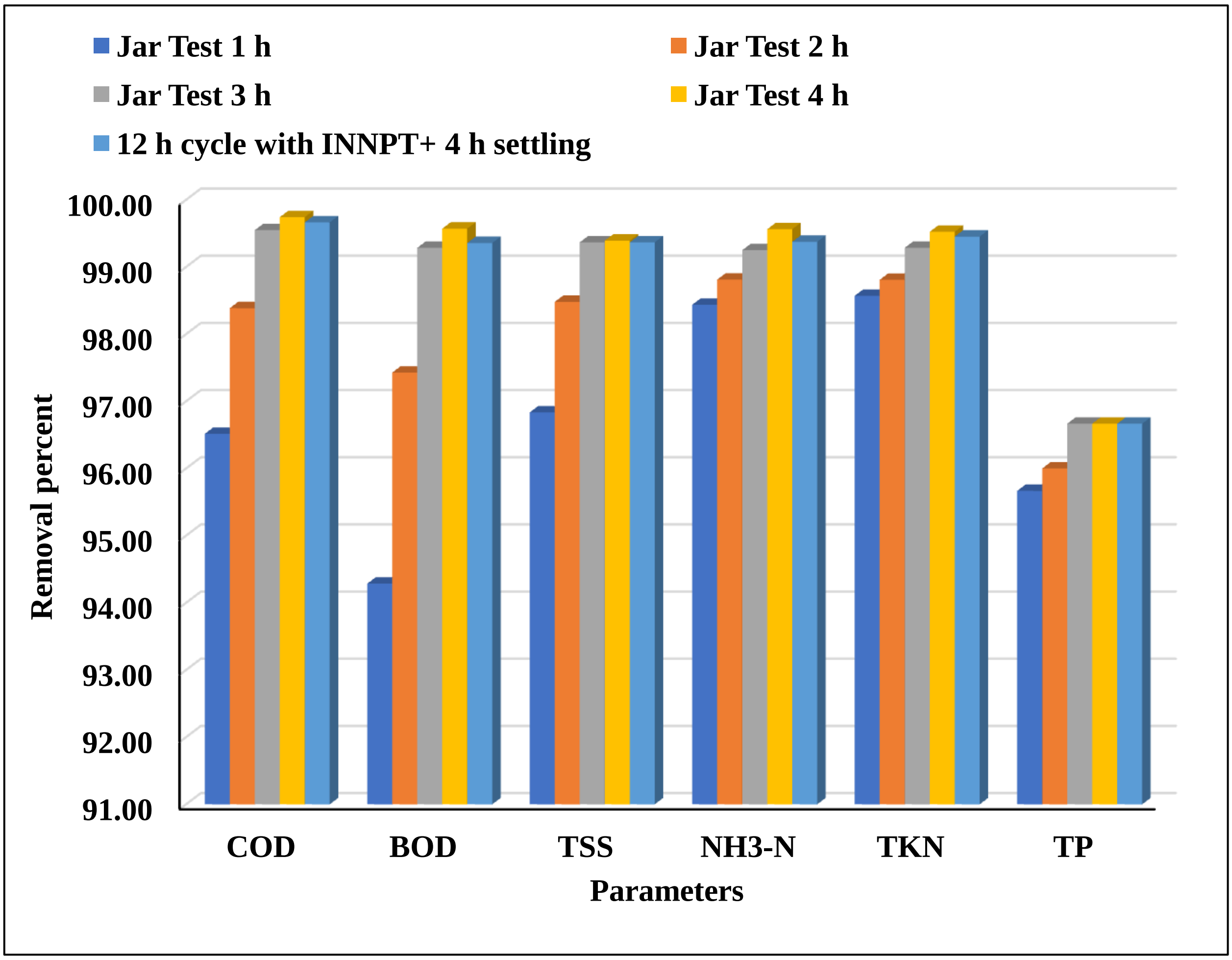

Fig. 6: Removal percentage of SBR model after modified 12-h aeration cycle with INNPT at modified 12-h aeration cycle.

The adsorption effect of nanoparticles demonstrates the significant improvement in the treatment of leachate due to their extremely high specific area and associated sorption sites, tunable pore size, and short intraparticle diffusion distance. The application of nanoparticles in the powdered form into SBR can be highly efficient since all surfaces of the adsorbents are utilized and the mixing process facilitates the mass transfer (Sylvester *et al.* 2007; Qu *et al.* 2013; Ghani and Yusoff, 2015). The presence of magnetic iron (Fe) nanoparticles have proven to be useful for adsorption, reductively transforming or degrading different types of organic pollutants and inorganic contaminants (Noubactep, 2010; Singh *et al*. 2012; Palanisamy *et al*. 2013; Němeček *et al*. 2014; Peeters *et al*. 2015).

Conclusions:

From the obtained results during the present study, it can be concluded that:

- The increasing in the aeration periods in SBR showed increasing in the treatment process and removal of pollutants from leachate but it was not suitable for disposal according to the Egyptian permissible limits mentioned at law 48 of year 1982.
- Increasing the settlement period has no significant effect on the removal of studied physicochemical parameters except in case of TSS.
- Addition of nanoparticles into the SBR improved significantly the treatment of leachate and the quality of treated leachate was suitable for disposal according to the Egyptian permissible limits mentioned at law 48 of year 1982.
- Addition of Nano particles (INNPT) with a dose range of (1-6 mg/l) with variation of settling time periods in SBR cycle from 1 hour to 4 hours enhance the removal efficiency of allstudied physicochemical parameters significantly. The best Nano particles (INNPT) dose from economical point of view and achieving the required Egyptian permissible limits mentioned at law 48 of year 1982 was 4 mg/l with a settling period of 4 hours. The overall removal percentage of measured physicochemical parameters showed more than 99.0% except in case of TP which was 96.67%.

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