



## CIVIL & ENVIRONMENTAL ENGINEERING | RESEARCH ARTICLE

# Application of different magnetic intensities for the treatment of landfill leachate in Egypt

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Received: 10 November 2017  
Accepted: 31 January 2018  
First Published: 05 February 2018

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Reviewing editor:  
Amimul Ahsan, University Putra Malaysia, Malaysia

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**Abstract:** Leachate produced from sanitary landfill should be treated before discharge into the environment, whereas it contains high concentrations of organic pollutants and high counts of pathogenic microorganisms. A bench-scale treatment unit was designed to study the effects of low-strength magnetic field on the physicochemical and bacterial properties of landfill leachate using three different magnetic intensities (120, 240 and 360  $\mu\text{T}$ ). Also, the effect of contact time was examined. Characterization of raw leachate showed high concentrations of organic pollutants and conductivity as well as high counts of both total bacterial count and total coliforms. The results showed the ability of magnetic force to improve the quality of leachate. Moreover, it was observed that, by increasing the magnetic intensity, the removal percent of pollutants increased. The magnetic force of 360  $\mu\text{T}$  showed the maximum removal percent of 38.2, 30.5, 16.0, 32.7, 16.0, 45.2 and 41.2% of Biological Oxygen Demand, Chemical Oxygen Demand, Total Suspended Solids, ammonia-nitrogen, conductivity, total bacterial count, and total coliforms, respectively. Depending on the obtained results, the magnetic force can be used as a clean, cheap and eco-friendly pre-treatment technology for the improvement of physicochemical and bacterial properties of landfill leachate.

### ABOUT THE AUTHORS

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### PUBLIC INTEREST STATEMENT

Leachate is a wastewater produced from sanitary landfill dumping sites. Leachate contains different types of pollutants such as organic materials, heavy metals and pathogenic microorganisms. However, untreated leachate can destroy the environment. This research focusing on the treatment of landfill leachate using magnetic force. The magnetic force is eco-friendly and cheap technology. The application of magnetic force, as a primary treatment stage, improved significantly the quality of leachate.



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**Subjects: Marine & Aquatic Science; Chemical Engineering; Water Science**

**Keywords: landfill leachate; magnetic force; wastewater treatment**

### 1. Introduction

In developing countries, landfills are widely used for solid waste disposal (Torretta, Ferronato, Katsoyiannis, Tolkou, & Airoldi, 2017). The main purpose of municipal landfills designation is the protection of humans and the environment through the collection and safe disposal of solid wastes generated from households and industries inside a managed facility. The standard landfilling process involves the digging of a huge cavity, into which solid wastes deposited then covered with soil. This method is effective in confining solid wastes, it also, produce a liquid by-product which contains high amounts of pollutants, this liquid called landfill leachate (Mohammad-pajoo, Weichgrebe, & Cuff, 2017).

Landfilling offers a cheap operation and maintenance when compared to other technologies. The major problem facing landfill management process is to find an effective technology for the treatment of large quantities of leachate (Othman, Sohaili, Fauzia, & Ni'am, 2009). Many factors determine landfill leachate composition which includes the types of solid wastes, soil characteristics, landfill age and rainfall patterns (Cassano et al., 2011).

Landfill leachate is characterized usually by offensive odor and complex chemical composition. It contains high concentrations of ammonia-nitrogen ( $\text{NH}_3\text{-N}$ ) content, heavy metals, inorganic salts and other organic materials (Ismail & Tawfik, 2016). However, landfill leachate may contain other compounds such as sulfide, barium, borate, arsenate, lithium, cobalt and mercury (Kjeldsen et al., 2002). If these pollutants left without proper control and treatment, it can reach the groundwater and cause serious damage to groundwater aquifers. Consequently, the presence of proper systems for collection and treatment of municipal landfill leachate is essential to reduce the environmental impacts and meet legislated standards for safe discharge into natural water streams or recycling (Nartey, Hayford, & Ametsi, 2012).

Generally, leachate treatment methods are classified into three major groups: (a) chemical and physical methods; (b) biological methods (aerobic or anaerobic); (c) a combination of physical-chemical and biological methods. These methods are summarized in Table 1.

The magnetic field was introduced into water and wastewater treatment after discovering the linkage between the magnetic field properties and all gaseous, liquid and solid matters as well as living organisms (Zhao et al., 2013). Johan, Fadil, and Zularisham (2004) proved that application of magnetic technology is a promising process for sewage treatment that it enhanced separation of suspended particles. In addition, water subjection to a magnetic field caused a significant modification in water properties as the water became more energetic and the flow rate increased (Tai, Wu, & Chang, 2008). Tsouris, DePaoli, Shor, Hu, and Ying (2001) introduced the magnetism into chemical industrial wastewater treatment and they discovered its ability to remove heavy metals. Cho and Lee (2005) reported that the magnetic treatment of water showed significant effects on the physico-chemical properties of water such as, light absorbance, pH and surface tension.

The main aim of the present study is to evaluate the efficiency of magnetic force using three different low-strength magnetic intensities at different contact times on the improvement of physico-chemical and bacterial properties of landfill leachate on the bench-scale level.

**Table 1. Landfill leachate treatment methods and technologies**

Method	Technology used	Reference
1. Chemical and physical methods	Flocculation/coagulation	Assou et al. (2014)
	Membrane filtration	Ameen, Muyibi, and Abdulkarim (2011)
	Air stripping	Silva, Dezotti, and Sant'Anna (2004)
	Adsorption	Ching, Yusoff, Aziz, and Umar (2011)
	Chemical precipitation	Fu and Wang (2011)
	Ion Exchange	Bashir, Aziz, Yusoff, Huqe, and Mohajeri (2010)
	Fenton process	Deng and Englehardt (2006)
	Photo-catalysis	Jia, Wang, Zhang, and Qin (2011)
	Electrochemical processes	Fernandes, Pacheco, Ciriaco, and Lopes (2015)
2. Biological methods		
(a) aerobic methods	Lagoons	Frascari, Bronzini, Giordano, Tedioli, and Nocentini (2004)
	Constructed wetlands	Bulc (2006)
	Rotating Biological Contactors (RBC)	Spengel and Dzombak (1991)
	Sequencing Batch Reactor (SBR)	Aluko and Sridhar (2013)
	Trickling filters	Aluko and Sridhar (2013)
	Moving Bed Bioreactor (MBBR)	Loukidou and Zouboulis (2001)
	Fluidized Bed Bioreactors (FBBR)	Eldyasti, Chowdhury, Nakhla, and Zhu (2010)
	Membrane Biological Reactor (MBR)	Hashisho, El-Fadel, Al-Hindi, Salam, and Alameddine (2016)
	Single Reactor High Activity Ammonium Removal Over Nitrite (SHARON)	Khin and Annachatre (2004)
(b) anaerobic and anoxic methods	Up-Flow Anaerobic Sludge Blanket (UASB)	Lin, Chang, and Chang (2000)
	Submerged Anaerobic MBR (SAMBR)	Saddoud, Ellouze, Dhouib, and Sayadi (2007)
	Anaerobic Filter (AF)	Abbas, Jingsong, Ping, Ya, and Al-Rekabi (2009)
	Anaerobic Ammonium Oxidation (Anammox)	Wang et al. (2016)
3. Combination of physical-chemical and biological methods	Activated sludge, coagulation, photo-Fenton	Silva et al. (2017)
	Photo-Fenton, MBR	Nivya and Minimal Pieus (2016)
	Aerobic SBR, adsorption	Lim et al. (2016)
	Trickling filters, electrocoagulation	Oumar, Patrick, Gerardo, Rino, and Ihsen (2016)
	SAMBR, MBR	Trzcinski and Stuckey (2016)
	SBR, Fenton-like, SBR	Klein et al. (2017)
	Fenton Process–Passive Aerated Immobilized Biomass (PAB)	Ismail and Tawfik (2016)

## 2. Material and methods

### 2.1. Samples and sampling

Four random raw municipal landfill leachate samples (20 l) were collected from El-hammam sanitary landfill site, Alexandria City, Egypt. Samples were collected monthly during May to August 2016. Leachate samples were collected in sterile polyethylene containers and immediately transferred in an ice box to the laboratory. The collected samples were mixed together to form a homogenous mixture. The whole experiments were repeated three times and average values were recorded.

### 2.2. Landfill site description

El-hammam sanitary landfill (13 cells) is located approximately 80 km from Alexandria city and 35 km to the south of the coastal road with a total area of 1.19 km<sup>2</sup> (1,700 m length, 700 m width, and 11.5 m depth). The coordinates of the site are 30°45'22.5" N and 29°25'16.0" E. The site has been in use since 2003. The landfill receives only municipal waste. It receives about 1,800 to 2,600 ton per day. The quantity of leachate produced in El-hammam landfill is about 6,000 m<sup>3</sup> per month. The collected leachate is pumped into lagoons where it is treated by evaporation using mechanical aerators and heat. The collected gases resulted from solid waste biodegradation are burned and used as the heat source for drying the lagoons leachate.

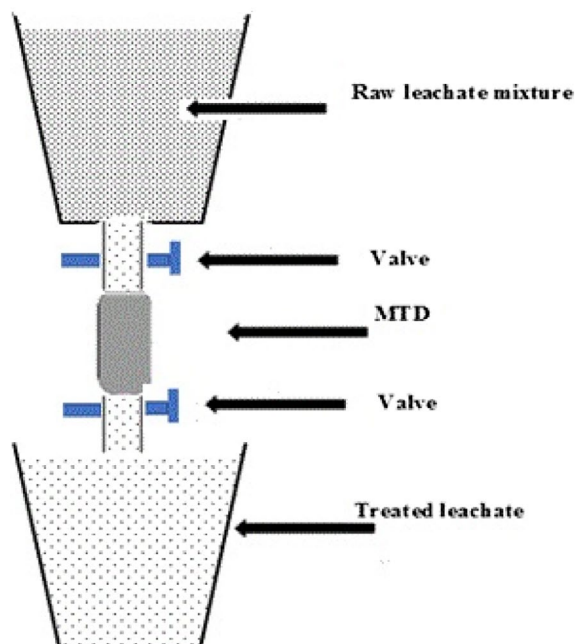
### 2.3. Magnetic treatment device (MTD)

Magnetic Liquid Modifier, model U050 MW (Magnetic Technologies Company, Oxford, USA) used as MTD during the experiments. MTD diameter was 1.27 cm and an effective length of 5 cm with magnetic flux intensity of 0.1 Tesla (T). The bench scale magnetic treatment instrument was showed in Figure 1. The homogenous leachate mixture was subjected to different magnetic intensities (120, 240 and 360  $\mu$ T).

### 2.4. Effect of contact time

The effect of contact time (exposure time) on leachate treatment using the different magnetic intensities (120, 240 and 360  $\mu$ T) was studied. Three different contact times (1, 1.5 and 2 h) were examined.

Figure 1. Schematic diagram of bench scale magnetic leachate treatment.



### 2.5. Chemical and physical analysis

Some physicochemical parameters were measured according to the standard methods for the examination of water and wastewater (APHA, 2010). These parameters include Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), ammonia-nitrogen (NH<sub>3</sub>-N), pH, Total Suspended Solids (TSS) and Electric Conductivity (EC).

### 2.6. Bacteriological analysis

Some bacterial indicators of pollution were examined to study the effect of magnetic fields on bacteria. These bacterial parameters include total bacterial count (TBC) and total coliforms (TC). Nutrient agar (Himedia, India®) and m-Endo agar LES (Himedia, India®) used for detection and enumeration of TBC and TC, respectively according to APHA (2010). The membrane filtration technique was used, and the bacterial counts were represented as colony forming unit (CFU) per millilitre.

## 3. Results and discussion

### 3.1. Characterization of raw landfill leachate

The collected landfill leachate samples were analysed three times before the beginning of the experiments. Table 2 summarizes the values of physicochemical and bacterial parameters of raw landfill leachate. The obtained results (Table 2) indicate that the sampling site was subjected to high levels of suspended solids. The average value of TSS was 3234.6 mg/l. Also, the raw landfill leachate samples showed high concentrations of organic matters, in terms of BOD (777.3 ± 118 mgO<sub>2</sub>/l), COD (4200 ± 1508 mg/l), and NH<sub>3</sub>-N (1429.6 ± 888 mg/l). These values are quite higher than the values reported by Theepharaksapan, Chiemchaisri, Chiemchaisri, and Yamamoto (2011).

In contrast, these obtained results were agreed with the results reported by Ismail and Tawfik (2016) where they reported average values of BOD (847 ± 79 mg/l) and COD (3909 ± 985 mg/l) of landfill leachate collected from Borg El-Arab city, Egypt. This variation in suspended solids and organic materials concentrations maybe attributed to the continuous changes in the disposed waste types and characteristics, the absence of waste separation system before disposal and meteorological conditions of landfill such as pressure and temperature (Abd El-Salam & Abu-Zuid, 2015). The pH of leachate ranged between neutral and slightly alkaline (7.6–8.8). The similar results were reported by Tränkler, Visvanathan, Kuruparan, and Tubtimthai (2005) where they found that the leachate samples had a slightly higher pH (7.0–8.0) which indicated the short acidic phase and early methanogenic phase of the landfill. The alkaline nature of landfill leachate is considered as an indicator of the mature stage of the dumping site (Jorstad, Jankowski, & Acworth, 2004).

The electric conductivity (EC) of leachate was high (3,420–5,228 µs/cm), indicating the presence of high concentrations of dissolved inorganic materials and elements (Mor, Ravindra, Dahiya, & Chandra, 2006). TBC and TC prefer neutral pH. However, although the pH of some leachate samples was slightly alkaline, both total bacterial count (TBC) and total coliforms (TC) which prefer the neutral

**Table 2. Characteristics of the landfill leachate**

Parameters	Unit	Values		
		Min.	Max.	Average ± Standard deviation
BOD	mgO <sub>2</sub> /l	682	910	777.3 ± 118
COD	mg/l	2536	5478	4200 ± 1508
NH <sub>3</sub> -N	mg/l	408	2022	1429.6 ± 888
pH	-	7.6	8.8	8.1 ± 0.6
TSS	mg/l	692	5120	3234.6 ± 2286
EC	µs/cm	3420	5228	4479 ± 943
TBC	CFU/ml	2.3 × 10 <sup>4</sup>	4.2 × 10 <sup>5</sup>	1.7 × 10 <sup>5</sup> ± 2.1 × 10 <sup>5</sup>
TC	CFU/100 ml	5.1 × 10 <sup>2</sup>	8.2 × 10 <sup>3</sup>	3.3 × 10 <sup>3</sup> ± 4.2 × 10 <sup>3</sup>

pH, were detected with high average counts of  $1.7 \times 10^5 \pm 2.1 \times 10^5$  CFU/ml and  $3.3 \times 10^3 \pm 4.2 \times 10^3$  CFU/100 ml, respectively. Obire and Aguda (2002) reported the presence of high counts of total viable bacterial counts ( $2.5\text{--}6.5 \times 10^6$  CFU/ml) in raw leachate. They reported the presence of total coliforms such as *Enterobacter* and *Escherichia coli* beside other kinds of bacteria, including *Pseudomonas*, *Vibrio*, and *Streptococcus* species. The occurrence of high bacterial counts maybe attributed to the availability of nutrients in leachate (Egharevba, Amengialue, Edobor, & Omoigberale, 2013).

### 3.2. Effect of different magnetic intensities

Three different magnetic intensities (120, 240 and 360  $\mu\text{T}$ ) were used to improve both physicochemical and bacterial quality of raw leachate for 30 min as a fixed contact time. The experiments were repeated three times, and average values were recorded. Figure 2 shows the effect of different magnetic intensities on the studied physicochemical and bacteriological parameters of untreated landfill leachate. The obtained results indicated that the three magnetic intensities decreased the levels of physicochemical and bacterial pollutants of the leachate. Also, it was clear that, by increasing the magnetic intensity, the removal percent of pollutants increased. Generally, the removal percent of all examined parameters were less than 50% as shows in Figure 2. Othman et al. (2009) studied the influence of magnetic intensity for the treatment of landfill leachate. They used a circulation flowing system with a magnetic strength of 0.55 T which showed a removal percent over 60% for suspended solids, BOD and COD.

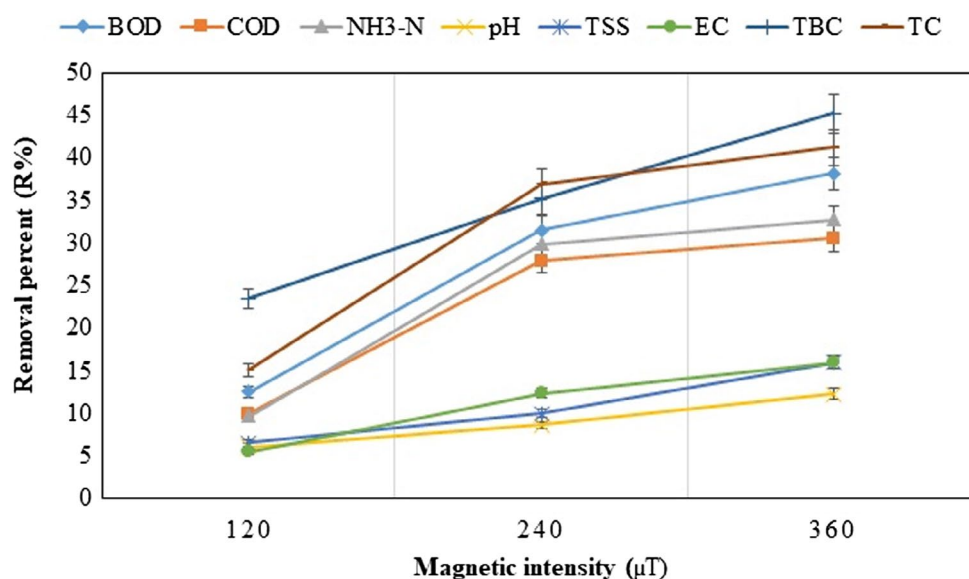
#### 3.2.1. pH

The results show the decrease in pH value with increasing the magnetic intensity. The pH was slightly alkaline (8.1) at a magnetic intensity of 120  $\mu\text{T}$  then decreased gradually to the neutral value (7.1) in magnetic intensity of 360  $\mu\text{T}$ . Maheshwari, Basant, and Grewal (2009) reported the reduction in soil pH after using the magnetically treated irrigation water. The decrease in pH values maybe attributed to the destroying effect of electromagnetic fields on the hydrogen bonds. These changes in hydrogen bonding may affect carbon dioxide hydrolyzation in water and produce carbonic acid. Subsequently, carbonic acid dissociates into bicarbonate and hydrogen ions which acidifies water (Colic & Morse, 1999).

#### 3.2.2. Electric conductivity

The amount and concentration of dissolved inorganic and organic minerals are the main factors influencing electric conductivity in water (Naveen, Mahapatra, Sitharam, Sivapullaiah, & Ramachandra, 2017). The results show a gradual increase in the Electric conductivity (EC) removal percent with increasing the magnetic intensity. The maximum removal percent of EC was 16% at a magnetic

**Figure 2.** Effect of the different magnetic intensities on the leachate quality at 30 min contact time.





intensity of 360  $\mu\text{T}$ . Alkhazan and Saddiq (2010) reported a significant decrease in EC values of lake water with increasing the magnetic intensity and time under both static and shaking conditions. The decrease in EC values maybe attributed to the presence of fine colloidal molecules and electrolytic substances in leachate. The magnetic treatment reduces the ionic hydration for salts and other impurities that present in leachate which in turn, decrease the EC values (Malkin, 2002; Wie, Liyan, Xuehu, & Yu, 2000).

### 3.2.3. Total suspended solids

According to Figure 2, it was clear the gradual decrease in Total suspended solids (TSS) values with the increase in the magnetic intensity. The maximum removal percent of TSS was 16% at a magnetic intensity of 360  $\mu\text{T}$ . Rasit (2006) studied the landfill leachate treatment using subsurface flow constructed wetlands enhanced with magnetic field. It was found that the capability of constructed wetland had a lower removal efficiency in TSS (<48%), however, the removal percent increased to more than 86% after application of the magnetic field. The influencing effect of magnetic force on the removal of TSS was reported by Ni'am and Othman (2014) where they used a combined magnet and electrocoagulation technology for synthetic wastewater treatment. They found that the magnetic field has a major influence on suspended solids removal. The effect of the magnetic field on TSS removal maybe due to the asymmetry of hydrated shells created by the magnetic field and its effect on water molecules located around the charged particles (colloidal particles). The exposure to the magnetic field would increase the electro-kinetic movement among these colloids, which in turn, increases the attraction among particles (Ni'am & Othman, 2014). Malkin (2002) reported two mechanisms for the effect of magnetic field on TSS. The first mechanism is the crystallization since the magnetic field has a strong effect on solid particles crystallization as it reduces the crystallization period and enhances the earlier segregation of solid particles. The second mechanism is the coagulation of solid particles as the magnetic field affecting the degree of hydration and the electro-kinetic potential at the particle surfaces, as well as the changes in the wettability of the solid particles due to the magnetic field.

### 3.2.4. BOD and COD

BOD and COD are the most widely used parameters of organic pollution applied to both surface water and wastewater. From the available literature, some researchers reported lower values for BOD and COD of leachate while others reported higher values. The variation in BOD values was due to the leachate collection systems not due to the biochemical processes inside the mass of wastes (Canziani et al., 2006). Also, Christensen et al. (2001) reported that the difference in COD values maybe due to the solid waste composition, landfill design and age, and site characteristics. During the present study, the effect of magnetic intensity on the removal of BOD and COD was similar, since the removal percent of both BOD and COD increased by increasing the magnetic intensity. The maximum removal percent was 38.2 and 30.5% for BOD and COD, respectively. Othman et al. (2009) reported that the magnetic treatment of leachate could remove BOD and COD in the range of 40–60%. The decrease in COD and BOD values is considered as an indication for the degradation of organic materials in the leachate. The magnetization of wastewater increases the oxygen concentration and decreases the water surface tension. The contact of magnetized water with the atmosphere leads to adsorption of the magnetic particles of oxygen which increases oxygen concentration in water. The presence of high concentrations of molecular oxygen encourages the growth and reproduction of microorganisms as well as the oxidation reactions of organics which in turn, accelerates the degradation of organic materials present in the leachate leading to the decrease in BOD and COD values (Krzemieniewski, Dębowski, Janczukowicz, & Pesta, 2004).

### 3.2.5. Ammonia-nitrogen ( $\text{NH}_3\text{-N}$ )

The presence of ammonia-nitrogen in leachate is a result of slow leaching and the release of soluble nitrogen from solid waste (Tyrrel, Leeds-Harrison, & Harrison, 2002). Ammonia-nitrogen has been identified as one of the major toxicants to most organisms, therefore the removal of ammonia-nitrogen is considered as a critical issue (Jokela, Kettunen, Sormunen, & Rintala, 2002). In the present study, the small magnetic intensity (120  $\mu\text{T}$ ) shows less removal effect on ammonia-nitrogen, with

average removal percent of 9.7%. However, the removal effect enhanced with both magnetic intensities 240  $\mu\text{T}$  (29.9%) and 360  $\mu\text{T}$  (32.7%). Ahamad Nordin (2006) studied the performance of wetland enhanced with magnetic field for the removal of  $\text{NH}_3\text{-N}$  and found that, the magnetic field enhanced the removal process of  $\text{NH}_3\text{-N}$  with maximum removal of 97.35%. Sa'at (2006) explained the proportional relationship between the magnetic field and the removal efficiency as the magnetic field strength increases the magnetic force, which subsequently enhances the removal efficiency. The magnetic field enhances the movement of particles and aggregation process subsequently large flocs are produced. These heavy and large flocs will settle easily and fast which in turn reduce the concentration of ammonia-nitrogen (Sa'at, 2006). In addition, Krzemieniewski et al. (2004) explained that the magnetic force increases the oxidation reactions of wastewater which provoked expelling of the ammonium nitrogen to the atmosphere. The nitrification of ammonia into nitrites then nitrates may also occur as a result for the presence of sufficient concentrations of oxygen in leachate which increase the counts of aerobic microorganisms.

### 3.2.6. Total bacterial count (TBC) and total coliforms (TC)

The landfill leachate contains several pathogenic and saprophytic microorganisms (Egharevba et al., 2013). Naveen et al. (2017) reported the occurrence of different kinds of bacteria in leachate, especially *Bacillus* followed by *Coccus*, *Spirochete* and *Vibrio* species. In the present study, high counts of TBC and TC were detected with average counts of 5 and 3 logs, respectively. The presence of high counts of bacteria in leachate was reported by some authors (Egharevba et al., 2013; Naveen et al., 2017). The gradual increase in removal percent of both TBC and TC with the increase of magnetic intensity was clear (Figure 2). The inhibitory effect of magnetic field on the bacterial growth may be due to the damage caused by magnetic field to bacterial DNA and inhibition of its replication (Lourencini da Silva, Albano, Lopes dos Santos, Tavares-Jr, & Felzenszwalb, 2000). Strašák, Vetterl, and Šmarda (2002) suggested that the effect of magnetic force on *Escherichia coli* is not bacteriostatic since the bacterial cells exposed to magnetic field didn't lose their ability to divide however, the decrease in bacterial counts is attributed to the death of some bacteria in the culture. This decrease in bacterial counts can be attributed to the effect of magnetic force on the physical characteristics of leachate such as pH. Another possible reason is the effect of magnetic field on the permeability of ionic channels in bacterial membrane (Fadel, Wael, & Mostafa, 2003). The ionic channels are responsible for ions transportation into the bacterial cell and this can result in some biological changes inside the bacterial cell. Moreover, the changes in the physicochemical nature of magnetically treated leachate maybe negatively affected the bacterial growth and reproduction (EL-Sayed, Magda, Eman, & Mona, 2006; Shin-Ichiro, Yoshimasa, Kazumasa, Takashi, & Makoto, 2002).

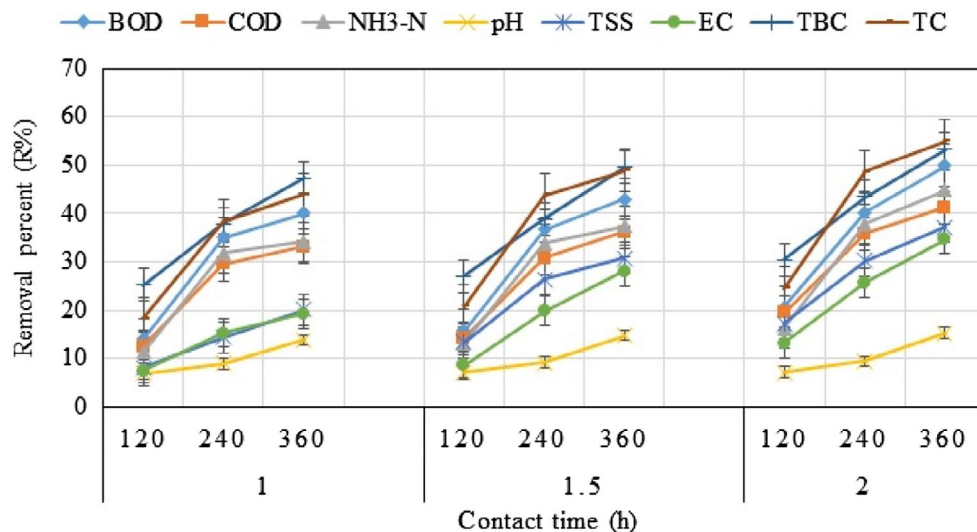
### 3.3. Effect of contact time

The effect of contact time (exposure time) of leachate to the magnetic force was studied. Three different exposure times (1.0, 1.5 and 2.0 h) were used to study the effect of contact time on the treatment process i.e. the removal efficiency. Figure 3 shows the effect of contact time on the bacterial and physicochemical removal efficiencies using the three magnetic intensities (120, 240 and 360  $\mu\text{T}$ ). As appears in Figure 3, it was clear that by increasing the contact time, there was a gradual increase in the removal percent of both bacterial (TBC and TC) and physicochemical (BOD, COD,  $\text{NH}_3\text{-N}$ , pH, TSS and EC) parameters of leachate. The contact time had a significant effect on the removal of chromium (Cr(VI)) from wastewater using magnetic multi-wall carbon nanotubes (Huang, Wang, & Yang, 2015), and on the removal of arsenic (As(V)) from aqueous solutions using iron oxide/activated carbon magnetic composite (Yao, Liu, & Shi, 2014). Zazouli, Yousefi, Eslami, and Ardebilian (2012) studied the effect of some variables such as pH and contact time on the treatment process of municipal solid waste landfill leachate using Fenton, photo-Fenton and Fenton-like processes. They reported that contact time was significantly different between the three processes.

It was suggested that when water molecules are subjected to a magnetic field, the magnetic field changes their kinetic energy which changes the momentum of the dipolar molecules causing particles aggregation (Lychagin, 1974). These aggregates are large enough and stable, making it difficult



**Figure 3. Effect of contact time on treatment process at different magnetic intensities.**



for them to return to their original shapes even after removing the magnetic field. This means that the magnetic memory stored by the aggregates can last almost permanently (Johan, 2003). These results agreed with Colic and Morse (1999) who supposed that magnetic memory caused changes in the molecular structure of particles. However, the effect of magnetic memory on bacteria is not the same as on particles or molecules (Zaidi, Sohaili, Muda, & Sillanpää, 2014). The magnetic memory may improve or hinder bacterial growth activity. This effect depending on the bacterial susceptibility towards the magnetic field (Łebkowska, Rutkowska-Narożniak, Pajor, & Pochanke, 2011; Yavuz & Çelebi, 2000). Consequently, as the contact time increases, the magnetic memory increases resulting in improvement of leachate treatment process.

### 3.4. Cost analysis

For the analysis purpose data such as initial cost, operation and maintenance cost, and energy cost was collected during the operation period (May–August 2016). Table 3 summarizes the total cost analysis. Magnetic treatment of leachate had shown promising potentials in comparison with other treatment technologies whereas magnetic treatment technology is simple, safe and eco-friendly (Ali, Samaneh, Zohre, & Mostafa, 2014). Magnetic treatment of leachate is considered as a low-cost technology because less number of machineries are used in addition to absence of energy cost.

**Table 3. Results of cost analysis**

Description	Cost (US Dollars)
<i>Initial cost:</i>	
MTD	55.0
Polyethylene containers	100.0
Laboratory glasses	150.0
<i>Operation and maintenance cost:</i>	
Transportation	500.0
Laboratory analysis	350.0
Energy cost	0.0
Total cost	1155.0

#### 4. Conclusions

The treatment of leachate is a major problem that facing the operators of sanitary landfill. From the obtained results during the present study, it can be concluded that:

- The application of magnetic force improved physicochemical and bacterial quality of leachate.
- The magnetic intensity had a considerable effect on the removal of pollutants present in leachate.
- Increasing the contact time enhanced the removal efficiency of magnetic force.
- The magnetic force can be applied as a primary treatment to improve the quality of leachate before next treatment process.

#### Funding

The authors received no direct funding for this research.

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#### Citation information

Cite this article as: Application of different magnetic intensities for the treatment of landfill leachate in Egypt, Raed S. Al-Wasify, Mohamed N. Ali & Shimaa R. Hamed, *Cogent Engineering* (2018), 5: 1436114.

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