

Adsorptive Treatment of Landfill Leachate using Activated Carbon Modified with Three Different Methods

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Abstract

Activated Carbon (AC) is an adsorbent having high surface area which makes the process of removing heavy metals from wastewater (such as landfill leachate) very effective. This study explored the utilization of three methods of modification of AC produced from coconut shell by treating it with nitric acid (HNO_3), potassium permanganate (KMnO_4) and heating at 600°C to improve the adsorption capacity. The AC can remove multi-pollutants in the filtration process which was used to treat landfill leachate. The water quality parameters such as pH, TSS, Ammonia-Nitrogen and a few heavy metals were considered in the present study. Results showed that the removal of these parameters was proportional with the increase of contact time and the bed depth of AC. The isotherm analysis of the adsorption of modified AC showed the best Removal Efficiency (RE) can be achieved when AC treated with KMnO_4 for $\text{NH}_3\text{-N}$, zinc, TSS and sulphide. The morphology of the AC was studied through Scanning Electron Microscopy (SEM), Energy Dispersive X-ray spectroscopy (EDX) pattern analysis and Fourier Transform Infrared (FTIR) analysis. It was found that various types of oxygen functional groups were introduced onto the surface of coconut shell derived AC through oxidation using HNO_3 . FTIR was used to characterize the surface oxygen functional groups. The surface functional groups such as N-H and C-H stretching played a significant role in heavy metals adsorption. Hence, it can be concluded that the hybrid technique by using electrolysis process with AC adsorption be an effective way to remove the suspended solids and heavy metals from landfill leachate and thus able to reduce environmental pollution.

Keywords: Landfill leachate, electrolysis, activated carbon, adsorption isotherm

1. Introduction

The production of landfill leachate is considered as one of the reasons that lead to the contamination of groundwater which is the main source of potable water in many countries. Many harmful and toxic pollutants, e.g. heavy metals, organic and inorganic compounds are found in surface water streams and groundwater. Various technologies are used to remove these contaminants from water sources, e.g. anaerobic treatment, electrocoagulation, filtration, Activated Carbon (AC) adsorption and wetland (Cossu *et al.*, 1998; Kadlec and Knight, 1996;

Alkalay *et al.*, 1998; Welander, 1998; Marselli *et al.*, 2003; Canizares *et al.*, 2005; Wiszniowski *et al.*, 2006; Deng and Englehardt, 2007; Sun and Austin, 2007; Graber *et al.*, 2009; Justin and Zupancic, 2009; Kalmykova *et al.*, 2009; Langergraberet *et al.*, 2009; Faulwetter *et al.*, 2009; Li *et al.*, 2009; Renou *et al.*, 2008; Sonavane and Munavalli, 2009; Vilar *et al.*, 2010; Yuen and Hameed, 2009; Timur *et al.*, 2010).

Adsorption technology is one of the methods used for the treatments of water and wastewater (Hejazifar *et al.*, 2011). The AC is considered as one of the most effective adsorbents which is processed and prepared to have high porosity and very large

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surface area for adsorption. It is generally produced from carbonaceous materials or from biomass substances, e.g. coconut shell, nutshells, peat, wood bagasse, lignite and coal. A great potential form of waste recycling is to convert waste material (e.g. rice husk) to AC. It can improve the human living standards in various ways (Ahsan *et al.*, 2013). The characterization of AC and its potential utilization were studied (Rahman *et al.*, 2013; Shaheed *et al.*, 2015; Tadda *et al.*, 2016; Ahsan *et al.*, 2015; Khaleel *et al.*, 2015). The AC adsorption process can be utilized as a separate unit in wastewater treatment plant. It may be placed after various physicochemical steps such as coagulation, filtration and dissolved air flotation.

The transformation of AC to more polar materials could be done using several methods of treatment that changes the amount of chemical functional groups on the surface of AC. There are various surface modification methods, e.g. chemical (Valdes *et al.*, 2002; Fang *et al.*, 2005; Jiang *et al.*, 2003; Figueiredo *et al.*, 1999), physical (Pereira *et al.*, 2010), microwave treatments (Liu *et al.*, 2010; Menendez *et al.*, 1999; Nabais *et al.*, 2004) and impregnation (Ahn *et al.*, 2009). Depending on the reagents added, the functional sites on the AC are either positively or negatively charged and these functional sites transforms AC to more hydrophilic or hydrophobic and acidic or basic character.

Essentially, hydrophobicity of the AC is associated with the presence of oxygen containing groups on the surface, e.g. carboxylic, phenolic and lactonic groups. Frequently, the most common reagents that used to enhance oxygen content on the surface of AC are nitric acid (HNO_3), sulphuric acid, hydrogen peroxide, ozone and potassium permanganate (KMnO_4) (El-Hendawy, 2003; Yin *et al.*, 2007; Chiang *et al.*, 2002).

Liu *et al.* (2007) reported that coconut-based AC showed excellent adsorption performance for Cr (VI), when it was modified by HNO_3 and sodium hydroxide. The modification of AC increases the total number of surface oxygen acidic groups and decreases the specific surface area. Oxidisation of HNO_3 leads to the production of positively charged acid groups. The acidity can be reduced by treating it with sodium hydroxide which replaces the H^+ of the surface acid groups by Na^+ . The capacity of AC to adsorb Cr (VI) was increased from 7.61 to 13.88 mg/g due to the presence of more oxygen surface acidic groups and suitable surface acidity after modification.

Wibowo *et al.* (2007) modified coal-based AC by chemical treatment with HNO_3 and thermal treatment with nitrogen gas flow. The treatment with HNO_3 caused the introduction of a significant number of oxygenated acidic surface groups onto the carbon surface, while the heat treatment increases the basicity of carbon. The pore characteristics are not significantly changed after these modifications. The dispersive interactions are the most important factor in this adsorption process.

Heat treatment in gaseous or liquid phase normally increases the concentration of oxygen surface groups (Shen *et al.*, 2008). While the heat treatment under inert condition leads to increase in hydrophobicity and pH of the carbon surface (Shafeeyan *et al.*, 2010). Usually, hydrogen is the inert gas of choice over

nitrogen and argon because it is more effective in removing the oxygen functionalities and also stabilizes the carbon surface. Thermal treatment in H_2 at 900°C produced highly stable and basic carbons (Lin and Teng, 2003).

Modification of AC with KMnO_4 was investigated in order to improve the adsorption capacity of AC. KMnO_4 contributes to the formation of AC with higher specific surface area (Kim *et al.*, 2014). Zhang and Yang (2011) studied adsorption of chromium (VI) by modified AC (MAC) with KMnO_4 and they found that the efficiency of AC to adsorb chromium (VI) is about 50%.

The aim of this study was to treat landfill leachate using MAC which was prepared from coconut shell by using three types of modification methods: acid treatment, heat treatment and treatment using KMnO_4 . The best one was determined by comparing the equilibrium adsorption isotherms for each type of AC. This study also investigated the maximum Removal Efficiency (RE) for organic pollutants and heavy metals from landfill leachate.

2. Materials and Methods

The landfill leachate samples used in this study were collected from Jeram Sanitary Landfill (JSL) which is located at Kuala Selangor 20 km North/West of Kuala Lumpur, Selangor, Malaysia, the methodology of the study divided into four steps:

2.1 Raw Leachate Analysis and Primary Electrolysis Treatment

The samples of leachate were collected in plastic containers and taken immediately to the public health laboratory in Faculty of Engineering, University Putra Malaysia and stored in cold room at 4°C . Laboratory analysis of leachate sample characteristics was carried out based on Standard Methods for the Examination of Water and Wastewater. The analysis included different parameters, e.g. pH, TSS, ammonia-nitrogen and heavy metals (zinc, manganese, sulphide and copper). Before the leachate sample was treated using filter of AC, it was treated in a batch type electrolytic cell made of glass container with dimensions of 300 mm length, 200 mm width and 250 mm height with two pairs of electrodes keeping at a distance of 3 cm between each other. Aluminium is used as cathode and iron as anode. The

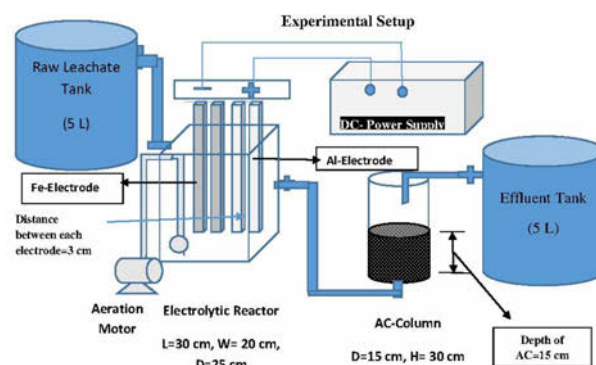


Fig. 1. Schematic of Experimental Setup

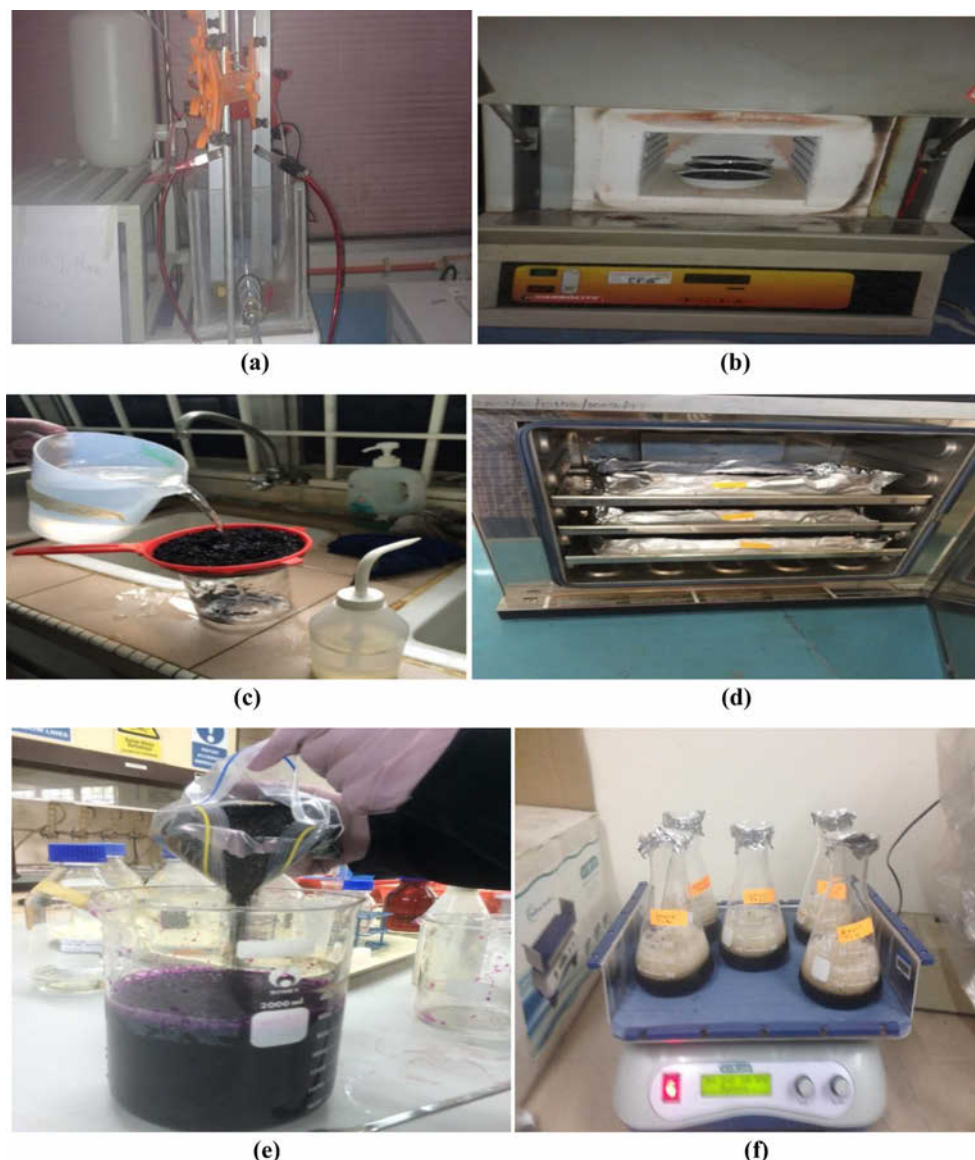


Fig. 2. Electrolytic Reactor and AC Preparation Arrangement: (a) Electrolytic Reactor, (b) Heating AC in Chamber Furnace with 600°C, (c) Washing with Distilled Water, (d) Drying AC in Oven with 110°C, (e) Mixing KMnO_4 with AC Sample, (f) Adsorption Test

electrodes were arranged parallel to each other and connected to the negative and positive outlets of the digital DC power supply (Model RXN-3020 D) that regulates the electricity. The pairs of electrodes were submerged in the glass container which contains sample of leachate. The working condition was set with 40 min electrolysis retention time and 24 V power supply. An aerator with an average flow of 1200 cm^3/min was placed at the bottom of the batch electrolysis cell in order to achieve proper mixing.

2.2 Modification Methods of AC

The Granular Activated Carbon (GAC) with coconut shell as raw material was used in this study. It was directly purchased from local traders, Laqua system Sdn. Bhd., Lot No. 9 & 11, Jalan Industri PBP, Selangor, Malaysia. The GAC has 1150 m^2/g surface area, 8 × 30 mesh particle size distribution, 5% moisture content and 0.45-0.50 g/cm^3 apparent density. A modification

treatment was done on GAC in order to increase the adsorption capacity using three different methods by treating it with nitric acid (HNO_3), potassium permanganate (KMnO_4) and heating at 600°C. These three methods of AC modification were selected in this study due to their high performance of adsorption as reported by many researchers (Liu *et al.*, 2007; Shen *et al.*, 2008; Kim *et al.*, 2014).

2.2.1 GAC Modified with HNO_3

Acid treatment increases the acidity, the amount of oxygen surface groups and the hydrophilic characteristics of the surface of AC. Common oxidizing acids such as HNO_3 and sulphuric acid are used for this purpose. The application of acid treatment is to remove the heavy metals from the aqueous solution. Known quantity of GAC is sieved using 2.35 mm sieve. Oxidation of AC is carried out by boiling it with HNO_3 of 65% concentration.

The weight ratio of carbon to acid is 1: 5% and boiled it for 2 hours in drying oven at 60°C in a round bottom flask. After oxidation, the sample is filtered, washed thoroughly with hot distilled water until it is free from nitrate ions. The sample is then dried in oven at 110°C for 2 hours and placed it in a round bottom flask covered with aluminium papers from top and kept in a dry place until it is used.

2.2.2 GAC Modified with KMnO₄

Modification process of GAC with KMnO₄ is carried out by immersing the GAC (2.0 g) in KMnO₄ solution (30 mg/l) for 6 hours. The sample is then rinsed with distilled water until no colour is obtained and then dried under constant temperature of 100°C in drying oven for 16 hours. After cooling, the sample was kept in a glass beaker and covered it with aluminium paper to prevent any pollution and kept in room temperature until it is used.

2.2.3 GAC Modified with Heating

Heat treatment in gases and liquid phase normally increases the concentration of oxygen surface groups, so the character of porous structure changes as the heating temperature increases. Known amount of GAC is sieved using 2.35 mm sieve. The GAC is heated in a thermal furnace at a temperature of 600°C for 2 hours. After heating, GAC is cooled and washed with distilled water several times to remove any impurities that might be present. The GAC is filtered and then it is placed in a drying oven at 110°C for 24 hours and stored in a dry place until it is used.

An AC filter (column) made of fibre glass with 95 mm diameter and 250 mm height is used to carry out the treatment of leachate samples after electrolysis process. The treated leachate was allowed to pass through the filter of different AC bed depths of 5, 10 and 15 cm. The above method allows AC to adsorb more pollutants such as suspended solids and heavy metals from the treated leachate. After adsorption process the treated leachate was collected into a glass beaker and then analysed according to the standard methods for the examination of water and wastewater.

2.3 Adsorption Process using MAC

2.3.1 RE and Adsorption Capacity of Parameters

The RE for different water quality parameters was investigated by using a known amount of MAC as adsorbent in leachate sample. The percentage of RE of each parameter at different time intervals was calculated using the following equation.

$$RE = \frac{(C_0 - C_e)}{C_0} \times 100 \quad (1)$$

Where, C_0 is the initial concentration (mg/l) and C_e is the concentration at time t (mg/l).

The adsorption capacity (q_e) of AC can be determined as

$$q_e = \frac{(C_0 - V_e)V}{m} \quad (2)$$

Where, V is the volume of sample (l) and m is the mass of adsorbent (g).

2.3.2 Equilibrium Adsorption Isotherm

An adsorption isotherm which represents the relationship between q_e and C_e was plotted to determine the shape of the adsorption equilibrium curve. Adsorption isotherm is fundamentally essential to explain how solutes interact with adsorbents and is critical in optimizing the use of adsorbents (Hameed *et al.*, 2009). The Langmuir (Langmuir, 1916) and the Freundlich (Freundlich, 1906) isotherms were employed in this study for fitting the experimental data at different time intervals of AC. The linearized forms of the two isotherms are as follows.

$$\frac{1}{q_e} = \frac{1}{K_L q_m C_e} + \frac{1}{q_m} \quad (3)$$

$$\ln q_e = \ln K_F + \frac{1}{n} \ln C_e$$

The Langmuir constants, q_m (mg/g) and K_L (l/mg) are related to adsorption capacity and energy of adsorption, respectively. While, K_F and n are the Freundlich constants.

2.4 Characterizations of AC

2.4.1 Porosity Characterisation

To characterise the porosity, N₂ adsorption-desorption isotherms at -195.6°C need to be determined using an automatic adsorption instrument. Evaluation of surface area for sample was done used BET method. (McEnaney, 1987).

2.4.2 SEM and EDX Analysis

The morphology of the AC was identified by Scanning Electron Microscopy (SEM) (model S-3400N, Hitachi, Japan) which was coupled with Energy Dispersive X-ray spectroscopy (EDX) to carry out the elemental analysis of the AC.

2.4.3 FTIR Analysis of AC

Fourier Transform Infrared (FTIR) spectroscopy is the most commonly used spectroscopic technique for the analysis of chemical structure of AC that can provide information about surface functional groups (Chiang *et al.*, 2002). FTIR spectra of three samples of AC treated with three different methods were recorded before and after adsorption for contact time of 2 hours within 400 – 4000 cm⁻¹.

Table 1. Characteristics of Electrolyzed Leachate using Al-Fe Electrodes

Parameters	Unit	Dilution Factor	Initial Concentration (mg/l)
pH		10	8.44
TSS	mg/l	0	491.67
Ammonia-Nitrogen	mg/l	10	40.00
Zinc	mg/l	10	3.50
Copper	mg/l	10	1.5
Sulphide	mg/l	10	2.30
Manganese	mg/l	10	2.66

3. Results and Discussion

3.1 Primary Treatment of Leachate by Electrolysis

The raw landfill leachate sample was treated first with electrolysis process before the filtration in order to decrease the high concentrations of suspended solids, organic and inorganic matters. Concentrations of various parameters of leachate samples after treated by electrolysis process using a pair of Al-Fe electrodes are shown in Table 1.

3.2 Effect of Modification Methods on Porosity Characterizations

Table 2 shows the porosity characterization of MACs after modification with HNO₃, KMnO₄ and heating treatment. AC-KMnO₄ has the highest surface area (1401.07 m²/g) and pore volume (0.509 cm³/g), however, the differences between AC-KMnO₄ and AC-Heating are little. While AC-HNO₃ has the lowest surface area (1348.21 m²/g) and pore volume (0.486 cm³/g). These results are agreement with other studies conducted by Daifullah *et al.* (2007) and Kim *et al.* (2014). They concluded that the surface area of AC increasing with the increase of the

amount of KMnO₄.

3.3 Adsorption Treatment of Leachate using MAC

The adsorption performance of three MACs with various contact times was investigated. The intervals of contact time were 0, 15, 30, 60, 90 and 120 min, which were selected according to previous studies (Babel and Kurniawan, 2004; Huang *et al.*, 2009; Moreno-Pirajan, 2011; Zhang and Yang, 2011). The final concentrations of various parameters after AC adsorption are shown in Table 3. The parameters considered are pH, TSS, ammonia–nitrogen, zinc, manganese, copper and sulphide. The pH values obtained at different time periods for 3 types of AC vary from 8.20 to 8.55 only and it indicates that the modifications of AC did not affect pH value. The final concentrations of TSS, NH₃-N, Zn, Mn, Cu and S²⁻ are decreasing with increasing of contact time for the three types of MAC.

3.4 Effect of Contact time on RE

The RE of three types of MAC at different intervals of contact time is shown in Table 4. The RE of TSS, NH₃-N, Zn, Mn, Cu and S²⁻ are increased with increasing of contact time for three types of MAC. The TSS indicates the higher removal percentage of 91% using KMnO₄ at contact time of 120 min. The maximum removals of NH₃-N using AC-KMnO₄ are 90, 94, 95, 96, 99 and 99%, respectively at contact time intervals of 0, 30, 60, 90 and 120 min, respectively. Also, Zn, Cu and S²⁻ represented the highest removal efficiencies when using AC-KMnO₄ as adsorbent. This can be explained due to the surface modification extent. Modification

Table 2. Porosity Characterizations of MAC

AC type	Surface area (m ² /g)	Pore volume (cm ³ /g)	Micropore surface area (m ² /g)	Micropore volume (cm ³ /g)
AC-HNO ₃	1348.21	0.486	700.18	0.371
AC-KMnO ₄	1401.07	0.509	700.35	0.371
AC-Heating	1392.21	0.503	682.61	0.363

Table 3. Final Concentrations of 3 types of MAC at Different Intervals of contact time

Parameters	Dilution Factor	Type of MAC	Contact Time (min)					
			0	15	30	60	90	120
pH	0	AC-HNO ₃	8.51	8.41	8.36	8.35	8.34	8.33
		AC-KMnO ₄	8.50	8.52	8.52	8.55	8.34	8.48
		AC-Heated (600°C)	8.22	8.44	8.44	8.50	8.28	8.53
TSS (mg/l)	0	AC-HNO ₃	91	81	81	74	69	56
		AC-KMnO ₄	119	110	103	101	69	44.42
		AC-Heated (600°C)	83	79	77	74	67	67
Ammonia–Nitrogen (mg/l)	10	AC-HNO ₃	5.10	5.10	4.60	4.50	4.30	4.10
		AC-KMnO ₄	4	2.4	1.9	1.5	0.47	0.42
		AC-Heated (600°C)	5.2	4.5	4.1	3.8	3.5	3.5
Zinc (mg/l)	10	AC-HNO ₃	2.50	2.28	1.70	1.122	1.00	0.60
		AC-KMnO ₄	1.7	1.5	1.4	1.2	0.88	0.49
		AC-Heated (600°C)	3	2.8	2.6	2.4	2.1	2.0
Copper (mg/l)	10	AC-HNO ₃	1.10	1.00	0.90	0.80	0.70	0.55
		AC-KMnO ₄	1	0.9	0.7	0.5	0	0
		AC-Heated (600°C)	1.2	1.1	1	0.8	0.8	0.8
Manganese (mg/l)	10	AC-HNO ₃	1.44	1.82	1.75	1.72	1.61	1.47
		AC-KMnO ₄	1.75	1.64	1.60	1.60	1.57	1.48
		AC-Heated (600°C)	1.61	1.60	1.48	1.47	1.10	1.14
Sulphide (mg/l)	10	AC-HNO ₃	2.00	1.90	1.50	1.20	1.10	1.04
		AC-KMnO ₄	1.9	1.7	1.6	1.5	1.3	1.0
		AC-Heated (600°C)	1.7	1.7	1.5	1.5	1.43	1.36

Table 4. RE (%) of 3 Types of MAC at Different Intervals of Contact Time

Parameters	Type of MAC	Contact Time (min)					
		0	15	30	60	90	120
TSS (mg/l)	AC-HNO ₃	81	84	84	85	86	89
	AC-KMnO ₄	76	78	79	79	86	91
	AC-Heated (600°C)	83	84	84	85	86	86
Ammonia –Nitrogen (mg/l)	AC-HNO ₃	87	87	89	89	89	90
	AC-KMnO ₄	90	94	95	96	99	99
	AC-Heated (600°C)	87	89	90	91	91	91
Zinc (mg/l)	AC-HNO ₃	29	35	51	65	71	83
	AC-KMnO ₄	51	57	60	66	75	86
	AC-Heated (600°C)	14	20	26	31	40	43
Copper (mg/l)	AC-HNO ₃	27	33	40	47	49	52
	AC-KMnO ₄	33	40	53	67	100	100
	AC-Heated (600°C)	20	27	33	47	47	47
Manganese (mg/l)	AC-HNO ₃	46	32	34	35	39	45
	AC-KMnO ₄	35	38	40	40	41	44
	AC-Heated (600°C)	39	40	44	45	55	57
Sulphide (mg/l)	AC-HNO ₃	13	17	35	48	52	55
	AC-KMnO ₄	17	26	30	35	43	57
	AC-Heated (600°C)	26	26	35	35	38	41

Table 5. Adsorption Capacity (qe) of 3 types of MAC at Different Intervals of Contact Time

Parameters	Type of MAC	Contact Time (min)					
		0	15	30	60	90	120
TSS (mg/l)	AC-HNO ₃	2.0034	2.0534	2.0534	2.040	2.1134	2.1784
	AC-KMnO ₄	1.8634	1.9084	1.9434	1.9534	2.1234	2.2734
	AC-Heated (600°C)	2.0434	2.0634	2.0734	2.040	2.1234	2.1234
Ammonia –Nitrogen (mg/l)	AC-HNO ₃	0.1745	0.1745	0.177	0.1775	0.1785	0.1795
	AC-KMnO ₄	0.18	0.188	0.1905	0.1925	0.1976	0.1979
	AC-Heated (600°C)	0.1740	0.1775	0.1795	0.1810	0.1825	0.1825
Zinc (mg/l)	AC-HNO ₃	0.005	0.0026	0.009	0.0049	0.0125	0.0145
	AC-KMnO ₄	0.009	0.01	0.0105	0.0115	0.0135	0.0165
	AC-Heated (600°C)	0.0025	0.0035	0.0045	0.0055	0.007	0.0075
Copper (mg/l)	AC-HNO ₃	0.002	0.0025	0.003	0.0035	0.004	0.0045
	AC-KMnO ₄	0.0025	0.003	0.004	0.005	0.0075	0.0075
	AC-Heated (600°C)	0.0015	0.0020	0.0025	0.0035	0.0035	0.0035
Manganese (mg/l)	AC-HNO ₃	0.0061	0.0042	0.0046	0.0047	0.0053	0.0060
	AC-KMnO ₄	0.0046	0.0051	0.0053	0.0053	0.0054	0.0059
	AC-Heated (600°C)	0.0053	0.0053	0.0060	0.0061	0.0070	0.0076
Sulphide (mg/l)	AC-HNO ₃	0.0015	0.002	0.0013	0.0055	0.006	0.0021
	AC-KMnO ₄	0.002	0.003	0.0035	0.004	0.006	0.0065
	AC-Heated (600°C)	0.003	0.003	0.004	0.004	0.0014	0.0015

of AC with KMnO₄ increased the negative surface charge of adsorbent which is a favourable condition for removal of positive charge parameters like NH₃-N, Zn and Cu (Babel and Kurniawan, 2004). For Mn, the maximum removal percentage was 57% at 120 min using AC-Heating. This might be due to the high surface area and pore volume of this type of AC.

3.5 Effect of Contact Time on Adsorption Capacity (q_e)

The adsorption capacity (q_e) of three types of MAC at different intervals of contact time is given in Table 5. The maximum

adsorption capacities for TSS, NH₃-N, Zn, Cu and S²⁻ were obtained as 2.2734, 0.1979, 0.0165, 0.0075 and 0.065 mg/g, respectively at 120 min of contact time by using AC-KMnO₄ as adsorbent. It has higher surface area and pore volume than the other two types of MAC.

3.6 Equilibrium Adsorption Isotherms

3.6.1 Adsorption Isotherm for AC-HNO₃

Figure 3 shows the experimental adsorption capacity (q_e)

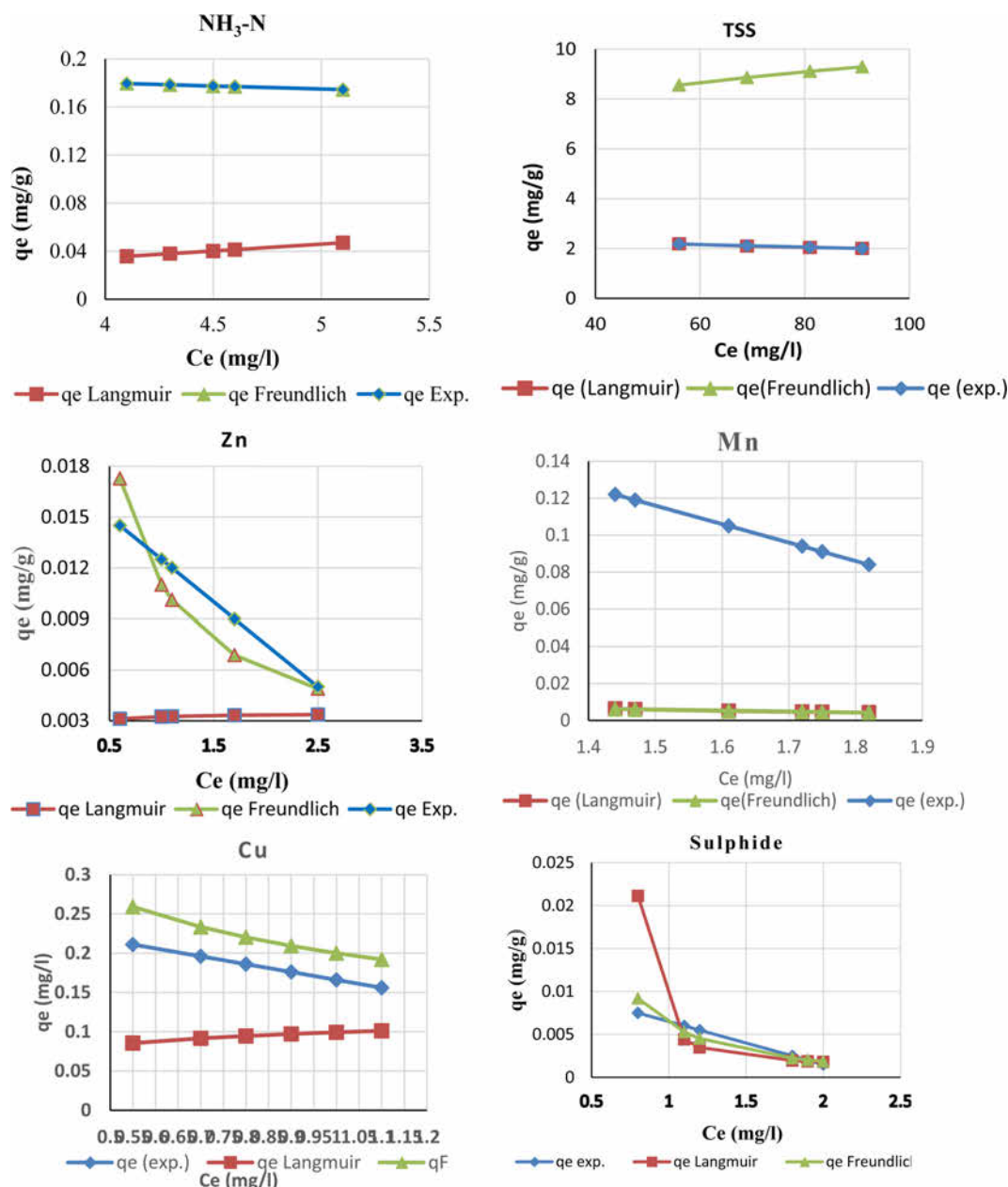


Fig. 3. Adsorption Isotherms of Different Water Quality Parameters using AC-HNO₃

exp.), q_e Langmuir and q_e Freundlich for all the parameters. Table 6 summarizes the Langmuir and Freundlich constants of three adsorbents. The adsorption data of AC-HNO₃ were well fitted to the Langmuir equation with the high value of correlation coefficients as 0.999, 0.999, 0.962, 0.991 and 1 for the TSS, NH₃-N, Zn, Mn and Cu, respectively, where S²⁻ has lower correlation coefficient (0.892). The adsorption data of Freundlich isotherm are characterized by the heterogeneity factor $1/n$, the magnitude of n gives an indication on the favorability of adsorption. Generally, if n is in the range of 2-10 represents good, 1-2 moderately good, and less than 1 poor adsorption characteristics (Aksu and Kutsal, 1991). The Freundlich isotherm constants of AC-HNO₃ are shown in Table 6. The

values of n for Mn, Cu and S²⁻ were less than 1, which indicate the poor adsorption characteristics. The Langmuir isotherm indicates the higher correlation coefficients for all parameters than the Freundlich isotherm. Consequently, the Langmuir isotherms showed better fit to the adsorption data than the Freundlich isotherm.

3.6.2 Adsorption Isotherm for AC- KMnO₄

Figure 4 shows the adsorption isotherms of AC-KMnO₄, where the Langmuir isotherm showed a better fit than the Freundlich isotherm for TSS, NH₃-N, Zn, Mn, Cu and S²⁻ with the high correlation coefficients of these parameters. These were obtained in the range of 0.915-0.999, which

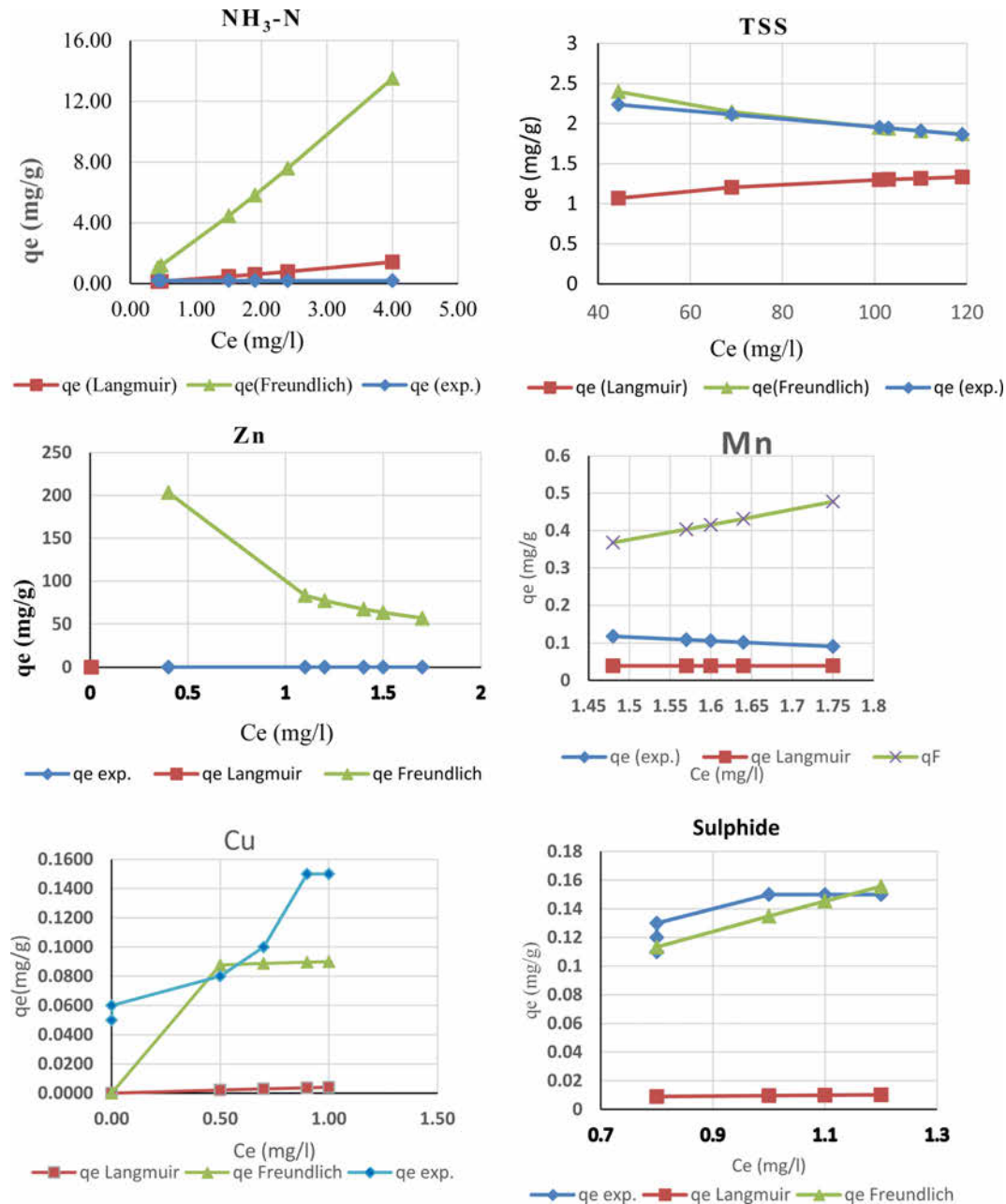


Fig. 4. Adsorption Isotherms of Different Water Quality Parameters using AC- KMnO₄

signify the good correlation between them and the adsorption is monolayer.

3.6.3 Adsorption Isotherm for AC- Heating

Figure 5 illustrates the adsorption isotherms of AC-Heating and the constants of Langmuir and Freundlich isotherms are indicated in Table 6. The obtained n values (from the Freundlich isotherms) of TSS, NH₃-N and Cu are more than 1, which indicate the good adsorption characteristics. For other parameters, e.g. Zn, Mn and S²⁻, the correlation coefficients of Freundlich isotherms are more than the Langmuir isotherms. As a result, Freundlich isotherm shows

the better fitting to experimental data than the Langmuir isotherm for AC-Heating, which implies the heterogeneous nature of heating.

3.7 Effects of AC Bed Depths on RE

Figure 6 shows the RE of various parameters for the three different bed depths (5, 10 and 15 cm) of AC filter and observed that the 15 cm bed depth gives highest RE for most parameters.

3.8 Surface and Chemical Analysis of Adsorbent

The MACs were examined by SEM to analyze the surface of

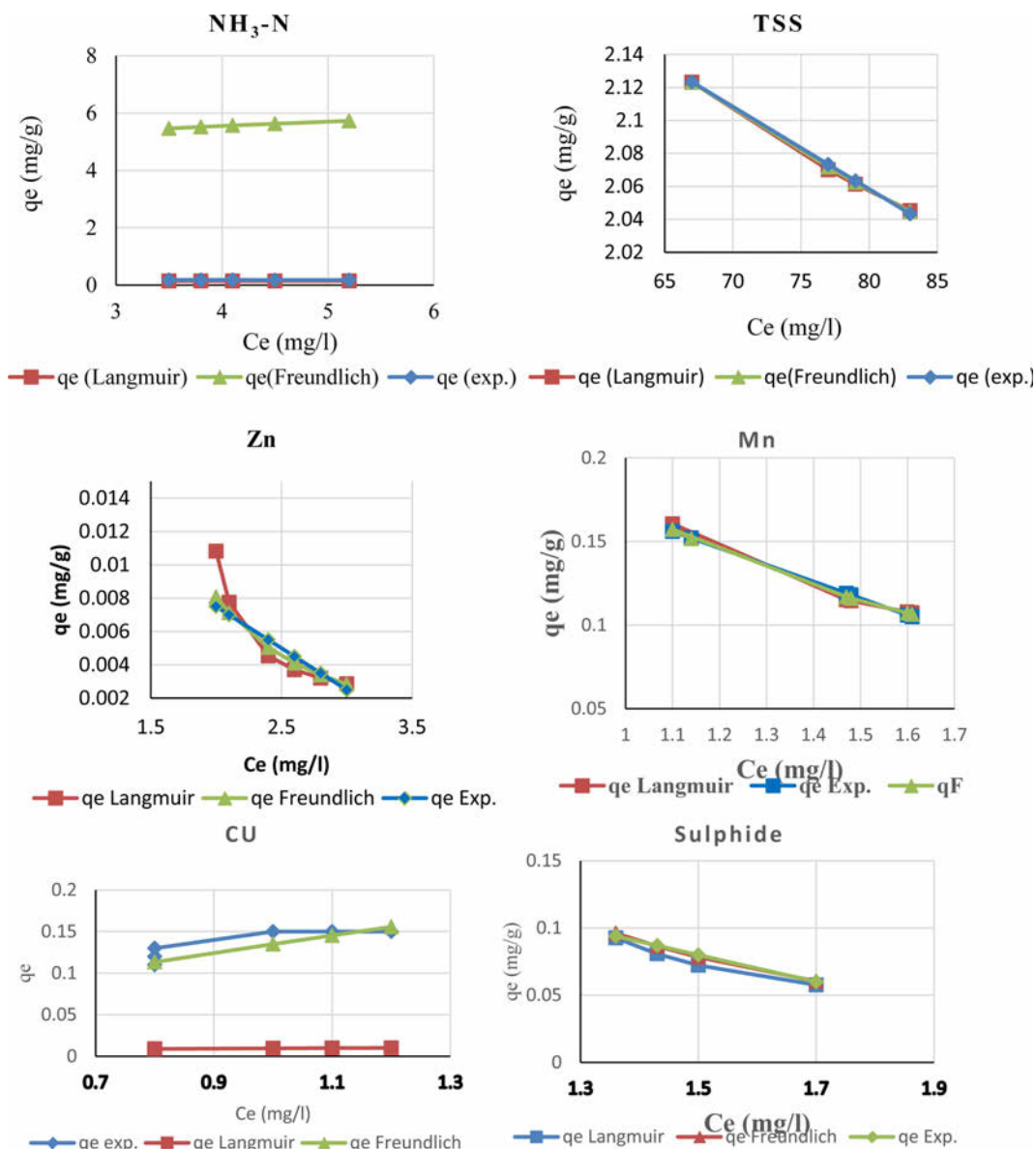


Fig. 5. Adsorption Isotherms of Different Water Quality Parameters using AC- Heating

the adsorbent. The SEM micrographs before and after adsorption for three types of MAC treated with HNO_3 , KMnO_4 and heating are shown in Fig. 7.

In all three cases, well-developed porous surface was observed at higher magnification. The pores observed from SEM images are having diameter in micrometer (μm) range. From the figures, it can be observed that the AC treated with KMnO_4 has pores filled with more adsorbent compared to other types of MAC. Fig. 8 shows the EDX analysis of heavy metals such as Mn, Zn, Cu, and S^{2-} which are adsorbed by MAC from the samples of leachate.

3.8 FTIR Results

The surface chemistry of the AC modified with three different methods before and after adsorption was explained using FTIR spectroscopy as shown in Figs. 9, 10 and 11, respectively. The

spectra of AC were measured within $400\text{--}4000\text{ cm}^{-1}$.

The peak observed at 3713 and 3634 cm^{-1} in Fig. 9 was due to free hydroxyl groups or surface bonded water (Tangjunak *et al.*, 2009). The bands observed at 2917 cm^{-1} suggest the presence of amine groups. The peaks at 2916 and 2847 cm^{-1} indicate the presence of C-H stretching vibrations of methyl group (Farinella *et al.*, 2007).

Figure 10 shows the FTIR analysis before and after adsorption of heavy metals by AC- KMnO_4 . The peaks at 2916 and 2940 cm^{-1} indicate the presence of C-H stretching vibrations of methyl group. Fig. 11 shows the FTIR analysis before and after adsorption of heavy metals by AC-Heating. The peaks at 1626 and 1383 cm^{-1} can be due to N-H functional group after adsorption. From the FTIR analysis, it can be confirmed that the surface functional groups such as N-H and C-H stretching played a very important

Table 6. Adsorption Parameters of Langmuir and Freundlich Isotherms for Different MAC Samples

Parameters	TSS	NH ₃ -N	Zn	Mn	Cu	S ²⁻
AC-HNO ₃						
<i>Langmuir</i>						
K _L (L/g)	0.0951	0.0454	15.634	1.0175	1.526	1.177
q ₀ (mg/g)	1.783	0.156	0.00345	0.00197	0.00082	0.0011
R ²	0.999	0.999	0.962	0.991	1.00	0.892
<i>Freundlich</i>						
K _F	4.322	0.216	0.0111	0.0108	0.0024	0.0062
1/n	0.169	0.131	0.884	1.565	1.974	1.745
R ²	0.993	0.998	0.942	0.994	0.998	0.930
AC-KMnO ₄						
<i>Langmuir</i>						
K _L (L/g)	0.0491	1.86	3.804	20.332	0.080	31.262
q ₀ (mg/g)	1.563	0.16	0.165	0.0402	0.060	0.137
R ²	0.998	0.999	0.968	0.991	0.915	0.977
<i>Freundlich</i>						
K _F	6.237	0.19	0.0111	0.2	0.09	0.176
1/n	0.252	0.04	0.884	1.554	0.04	0.073
R ²	0.979	0.886	0.942	0.994	0.915	0.807
AC-Heating						
<i>Langmuir</i>						
K _L (L/g)	0.0905	0.109	0.561	1.4903	2.448	0.978
q ₀ (mg/g)	1.773	3.185	0.0232	0.0626	0.0743	0.0234
R ²	0.999	0.999	0.904	0.991	0.535	0.987
<i>Freundlich</i>						
K _F	4.456	4.709	0.0483	0.173	0.135	0.182
1/n	0.176	0.119	2.579	1.024	0.782	2.079
R ²	0.999	0.996	0.956	0.994	0.875	0.992

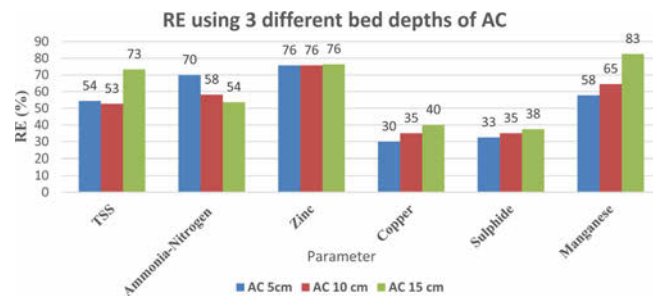


Fig. 6. RE of Various Parameters at Three Different AC Bed Depths

role in heavy metals adsorption.

4. Conclusions

Based on the experimental investigation the conclusions derived are as follows:

1. The modified AC (by three different methods) used in the study as adsorbent showed high microporosity, high percentage of pollutants removal and improve the adsorption capacity.
2. Modification of AC with KMnO₄ contributed to increase surface area and pore volume of resulted AC more than other modification methods like HNO₃ and heating.

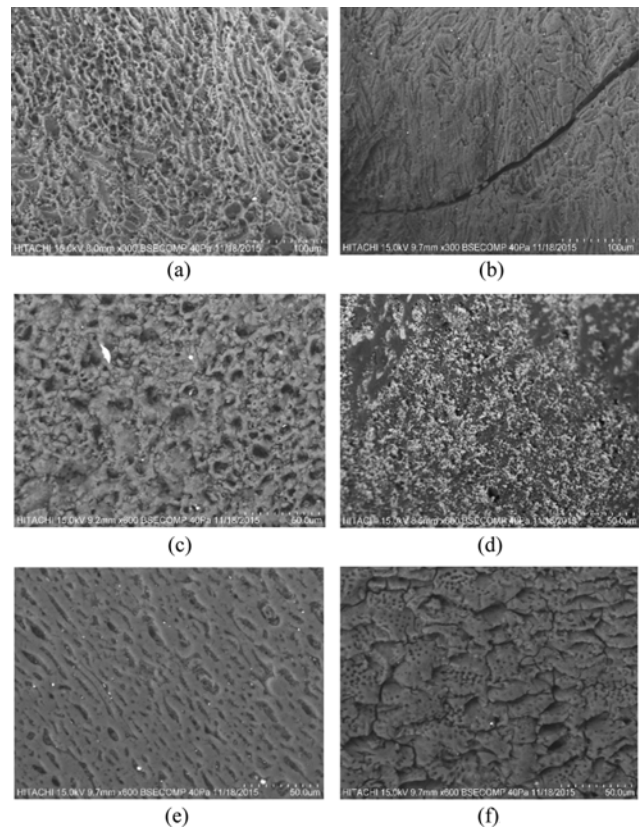


Fig. 7. SEM Images of Three MACs before and after Adsorption: (a) AC-HNO₃ (before adsorption), (b) AC-HNO₃ (after adsorption), (c) AC-KMnO₄ (before adsorption), (d) AC-KMnO₄ (after adsorption), (e) AC-Heating (before adsorption), (f) AC-Heating (after adsorption)

The high porosity characterizations make the AC effective. It is a cheap precursor to use for various wastewater treatments.

3. The highest removal efficiencies of TSS, NH₃-N, Zn, Cu and S²⁻ were obtained as 91, 99 86, 100 and 57%, respectively at 120 min of contact time using AC-KMnO₄ due to the highest surface area and pore volume of AC.
4. The Langmuir isotherm showed better fit to the adsorption data than the Freundlich isotherm for AC-KMnO₄ with high regression coefficient ranged from 0.915 to 0.999 which means monolayer adsorption.
5. The surface functional groups such as N-H and C-H stretching played a significant role in heavy metals adsorption. The adsorption capacities of heavy metals in landfill leachate increased with increasing contact time of AC adsorption. The maximum adsorption capacities for TSS, NH₃-N, Zn, Cu and S²⁻ were obtained as 2.2734, 0.1979, 0.0165, 0.0075 and 0.0065 mg/g, respectively using AC-KMnO₄ as adsorbent at 120 min of contact time.
6. It can be concluded that the hybrid technique by using electrolysis process with AC adsorption be an effective way to remove the suspended solids and heavy metals from landfill leachate and thus it can be applied to treat various types of wastewater.

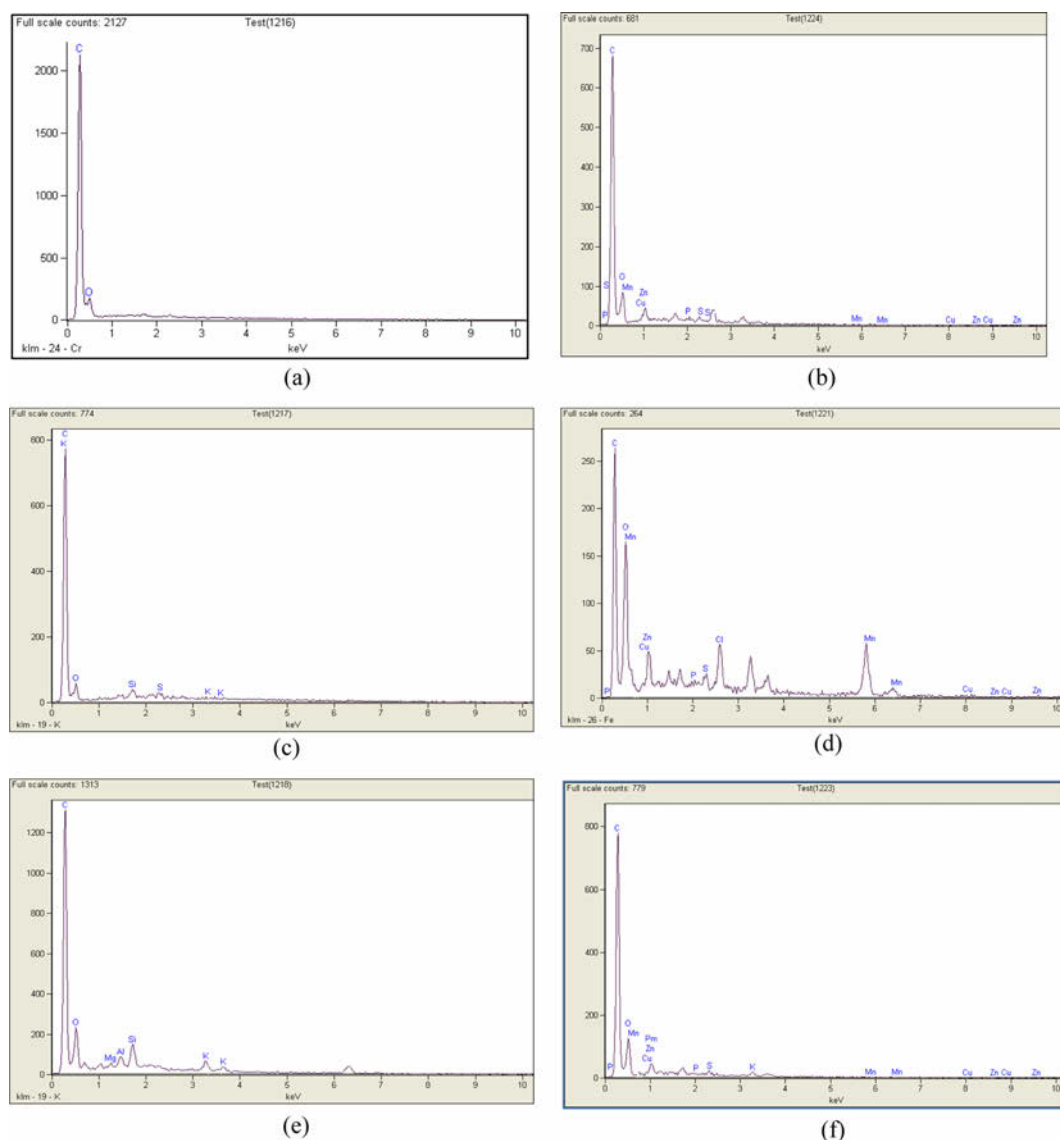


Fig. 8. EDX Analysis of Three MACs before and after Adsorption: (a) AC-HNO₃ (before adsorption), (b) AC-HNO₃ (after adsorption), (c) AC-KMnO₄ (before adsorption), (d) AC-KMnO₄ (after adsorption), (e) AC-Heating (before adsorption), (f) AC-Heating (after adsorption)

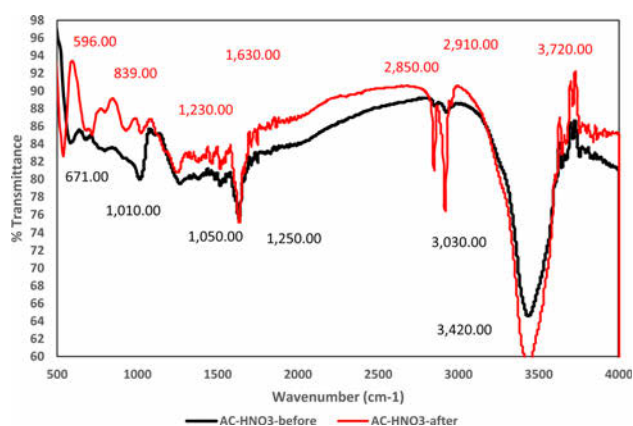


Fig. 9. Surface Functional Groups of AC-HNO₃ before and after Adsorption

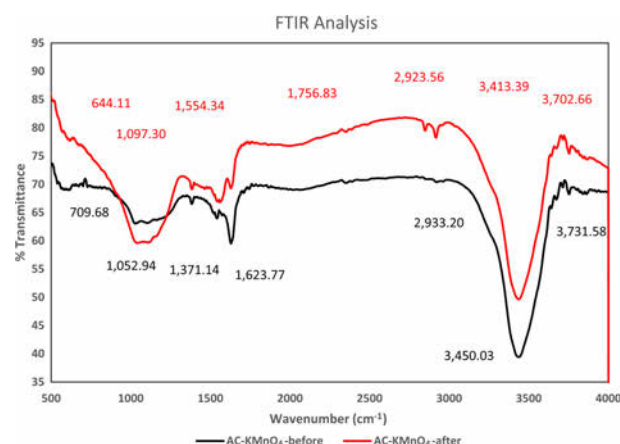


Fig. 10. Surface Functional Groups of AC-KMnO₄ before and after Adsorption

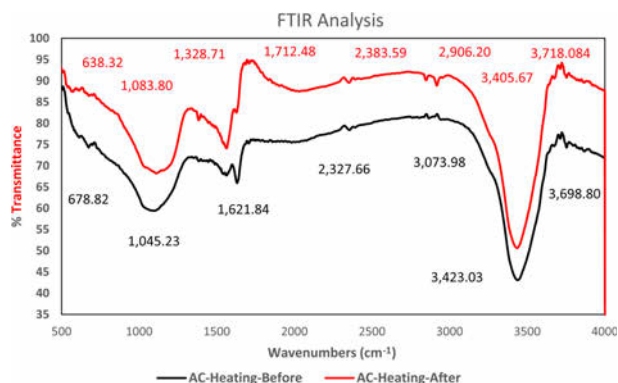


Fig. 11. Surface Functional Groups of AC-Heating before and after Adsorption

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References

- Ahn, C. K., Park, D., Woo, S. H., and Park, J. M. (2009). "Removal of cationic heavy metal from aqueous solution by activated carbon impregnated with anionic surfactants." *J. Hazard. Mater.*, Vol. 164, pp. 1130-1136, DOI: 10.1016/j.jhazmat.2008.09.036.
- Ahsan, A., Kamaludin, M., Rahman, M. M., Anwar, A. H. M. F., Bek, M. A., and Idrus, S. (2014). "Removal of various pollutants from leachate using a low cost technique." *Water, Air, and Soil Pollution* Vol. 225, No. 12, 2163:1-9, DOI: 10.1007/s11270-014-2163-y.
- Ahsan, A., Ismail, N., Rahman, M. M., Imteaz, M., Rahman, A., Mohammad, N., and Salleh, M. A. M. (2013). "Municipal solid waste recycling in Malaysia: present scenario and future prospects." *Fresenius Environmental Bulletin*, Vol. 22, No. 12a, pp. 3654-3664.
- Aksu, Z. and Kutsal, T. A. (1991). "Biseparation process for removing lead (II) ions from waste water by using *C. vulgaris*." *Journal of Chemical Technology and Biotechnology*, Vol. 52, pp. 109-118.
- Alkalay, D., Guerrero, L., Lema, J. M., Mendez, R., and Chamy, R. (1998). "Review: Anaerobic treatment of municipal sanitary landfill leachates: The problem of refractory and toxic components." *World Journal of Microbiology and Biotechnology*, Vol. 14, pp. 309-320, DOI: 10.1023/A:1008876107787.
- Babel, S. and Kurniawan, T. A. (2004). "Cr (VI) removal from synthetic wastewater using coconut shell charcoal and commercial activated carbon modified with oxidizing agents and/or chitosan." *Chemosphere*, Vol. 54, pp. 951-967, DOI: 10.1016/j.chemosphere. 2003.10.001.
- Canizares, P., M. Carmona, J. Lobato, Martinez, F., and Rodrigo, M. (2005). "Electrodissolution of aluminium electrodes in electrocoagulation processes." *Industrial & Engineering Chemistry Research*, Vol. 44, No. 12, pp. 4178- 4185, DOI: 10.1021/ie048858a.
- Chiang, H. L., Huang, C. P., and Chiang, P. C. (2002). "The surface characteristics of activated carbon as affected by ozone and alkaline treatment." *Chemosphere*, Vol. 47, No. 3, pp. 257- 265, DOI: 10.1016/S0045-6535(01)00215-6.
- Cossu, R., Polcaro, A. M., Lavagnolo, M. C., Mascia, M., Palmas, S., and Renoldi, F. (1998). "Electrochemical treatment of landfill leachate: Oxidation at Ti/PbO₂ and Ti/SnO₂ anodes." *Environ. Sci. Technol.*, Vol. 32, 22, pp.3570-3573, DOI: 10.1021/es971094o.
- Daifullah, A. A. M., Yakout, S. M., and Elreedy, S. A. (2007). "Adsorption of fluoride in aqueous solutions using KMnO₄-modified activated carbon derived from steam pyrolysis of rice straw." *Journal of Hazardous Materials*, Vol. 147, pp. 633-643, DOI: 10.1016/j.jhazmat.2007.01.062.
- Deng, Y. and Englehardt, J. D. (2007). "Electrochemical oxidation for landfill leachate treatment." *Waste Management*, Vol. 27, No. 3, pp. 380-388, DOI: 10.1016/j.wasman.2006.02.004.
- El-Hendawy, A. A. (2003). "Influence of HNO₃ oxidation on the structure and adsorptive properties of corncob-based activated carbon." *Carbon*, Vol. 41, pp. 713-722, DOI: 10.1016/S0008-6223(03)00029-0.
- Fang, B., Wei, Y. Z., Suzuki, K., and Kumagai, M. (2005). "Surface modification of car-bonaceous materials for EDLCs application." *Electrochim. Acta*, Vol. 50, No. 18, pp. 3616-3621, DOI: 10.1016/j.electacta.2004.12.032.
- Faulwetter, J. L., Gagnon, V., Sundberg, C., Chazarenc, F., Burr, M. D., Brisson, J., Camper, A. K., and Stein, O. R. (2009). "Microbial processes influencing performance of treatment wetlands: A review." *Ecological Engineering*, Vol. 35, No. 6, pp. 987-1004.
- Farinella, N. V., Matos, G. D., and Arruda, M. A. Z. (2007). "Grape bagasse as a potential bio sorbent of metals in effluent treatments." *Bioresource Technology*, Vol. 98, No. 10, pp. 1940-1946, DOI: 10.1016/j.biortech.2006.07.043.
- Figueiredo, J. L., Pereira, M. F., R., Freitas, M. M. A., and Orfao, J. J. M. (1999). "Modification of the surface chemistry of activated carbons." *Carbon*, Vol. 37, pp. 1379-1389, DOI: 10.1016/S0008-6223(98)00333-9.
- Freundlich, H. (1906). "Over the adsorption in solution." *J. Phys. Chem.*, Vol. 57, No. 385471, pp. 1100-1107.
- Graber, A., Skvarc, R., and Junge-Berberovi, R. (2009). "Elimination of phenols, ammonia and cyanide in wash water from biomass gasification, and nitrogen recycling using planted trickling filters." *Water Science and Technology*, Vol. 60, No. 12, pp. 3253-3259, DOI: 10.2166/wst.2009.728.
- Hameed, B., Salman, J., and Ahmed, A. (2009). "Adsorption isotherm and kinetic modelling of 2, 4-D pesticide on activated carbon derived from date stones." *Journal of Hazardous Materials*, Vol. 163, No. 1, pp. 121-126, DOI: 10.1016/j.jhazmat.2008.06.069.
- Hejazifar, M., Azizian, S., Sarikhani, H., Zhao, Q., and Li, D. (2011). "Microwave assisted preparation of efficient activated carbon from grapevine hytidome for the removal of methyl violet from aqueous solution." *Journal of Analytical and Applied Pyrolysis*, Vol. 92, pp. 258-266, DOI: 10.1016/j.jaap.2011.06.007.
- Huang, G., Shi, J. X., and Langrish, T. A. G. (2009). "Removal of Cr (V) from aqueous solution using activated carbon modified with nitric acid." *Chemical Engineering Journal*, Vol. 152, pp. 434-439, DOI: 10.1016/j.cej.2009.05.003.
- Jiang, Z. X., Liu, Y., Sun, X. P., Tian, F. P., Sun, F. X., Liang, C. H., You, W. S., Han, C. R., and Li, C. (2003). "Activated carbons chemically modified by concentrated H₂SO₄ for the adsorption of the pollutants from waste water and the dibenzothiophene from fuel oils." *Langmuir*, Vol. 19, pp. 731-736, DOI: 10.1021/la020670d.
- Li, W., Peng, J., Zhang, L., Yang, K., Xia, H., Zhang, S., and Guo, S. H. (2009). "Preparation of activated carbon from coconut shell chars in pilot-scale microwave heating equipment at 60kW." *Waste Management*, Vol. 29, No. 2, pp. 756-760, DOI: 10.1016/j.wasman.2008.03.004.
- Justin, M. Z. and Zupančič, M. (2009). "Combined purification and reuse of landfill leachate by constructed wetland and irrigation of grass and willows." *Desalination*, Vol. 246, Nos. 1-3, pp. 157-168, DOI: 10.1016/j.desal.2008.03.049.
- Kadlec, R. H. and Knight, R. L. (1996). *Treatment Wetlands*, CRC Press LLC, Boca Raton, Florida.

- Kalmykova, Y., Strömvall, A., Rauch, S., and Morrison, G. (2009). "Peat filter performance under changing environmental conditions." *Journal of Hazardous Materials*, Vol. 166, No. 1, pp. 389-393, DOI: 10.1016/j.jhazmat.2008.11.062.
- Khaleel, M. R., Ahsan, A., Imteaz, M., El-Sergany, M. M., Daud, N. N. N., Mohamed, T. A., and Ibrahim, B. A. (2015). "Performance of GACC and GACP to treat institutional wastewater: A sustainable technique." *Membrane Water Treatment*, Vol. 6, No. 4, pp. 339-349, DOI: 10.12989/mwt.2015.6.4.339.
- Kim, D.-W., Kim, M.-T., Rhee, K. Y., Kim, S., and Park, S.-J. (2014). "Influence of KMnO_4 oxidation on the electrochemical performance of pitch-based activated carbons." *Res. Chem. Intermed.*, Vol. 40, pp. 2527-2534, DOI 10.1007/s11164-014-1664-z.
- Langmuir, I. (1916). "The constitution and fundamental properties of solids and liquids. Part I. Solids." *Journal of the American Chemical Society*, Vol. 38, No. 11, pp. 2221-2295, DOI: 10.1021/ja02268a002.
- Langergraber, G., Rousseau, D. P. L., Garcia, J., and Mena, J. (2009). CWM1: A general model to describe biokinetic processes in subsurface flow constructed wetlands." *Water Science and Technology*, Vol. 59, No. 9, pp.1687-1697, DOI: 10.2166/wst.2009.131.
- Liu, Q. S., Zheng, T., Wang, N. Li, P., and Abulikemu, G. (2010). "Modification of bamboo-based activated carbon using microwave radiation and its effects on the adsorption on methylene blue." *Appl. Surf. Sci.*, Vol. 256, pp. 3309-3315, DOI: 10.1016/j.apsusc.2009. 12.025.
- Liu, S. X., Chen, X., Chen, X. Y., Liu, Z. F., and Wang, H. L. (2007). "Activated carbon with excellent Chromium (VI) adsorption performance prepared by acid-base surface modification." *Journal of Hazardous Materials*, Vol. 141, pp. 315-319, DOI: 10.1016/j.jhazmat.2006.07.006.
- Marselli, B., Garcia-Gomez, J., Michaud, P. A., Rodrigo, M. A., and Comninellis, Ch. (2003). "Electrogeneration of Hydroxyl radicals on Boron-Doped Diamond Electrodes." *J. Electrochem. Soc.*, Vol. 150, pp. 79-83, DOI: 10.1149/1.1553790.
- McEnaney, B. (1987). "Estimation of the dimensions of micropores in active carbons using the Dubinin-Radushkevich equation." *Carbon*, Vol. 25, No. 1, pp. 69-75, DOI: 10.1016/0008-6223(87)90041-8.
- Menendez, J. A., Menendez, E. M., Iglesias, M. J., Garcia, A., Pis, J. J. (1999). "Modification of the surface chemistry of activated carbons by means of microwave-induced treatments." *Carbon*, Vol. 37, pp. 1115-1121, DOI: 10.1016/S0008-6223(98)00302-9.
- Moreno-Pirajan, J. C. (2011). "The removal and kinetic study of Mn, Fe, Ni and Cu ions from wastewater onto activated carbon from coconut shells." *Adsorption*, Vol. 17, pp. 505-514, DOI: 10.1007/s10450-010-9311-5.
- Nabais, J. M. V., Carrott, P. J. M., Riberiro Carrott, M. M. L., and Menendez, J. A. (2004). "Preparation and modification of activated carbon fibres by microwave heating." *Carbon*, Vol. 42, pp. 1315-1320, DOI: 10.1016/j.carbon.2004.01.033.
- Pereira, L., Pereira, R., Pereira, M. F. R., Van der Zee, F. P., Cervantes, F. J., and Alves, M. M. (2010). "Thermal modification of activated carbon surface chemistry improves its capacity as redox mediator for azo dye reduction." *J. Hazard. Mater.*, Vol. 183, pp. 931-939, DOI: 10.1016/j.jhazmat.2010.08.005.
- Rahman, M. M., Bari, Q. H., Mohammad, N., Ahsan, A., Sobuz, H. R., and Uddin, M. A. (2013). "Characterization of rice husk carbon produced through simple technology." *Advances in Materials Science and Application*, Vol. 2, No. 1, pp. 25-30.
- Renou, S., Givaudan, J., Poulain, S., and Dirassouyan, Moulin, P. (2008). "Landfill leachate treatment: review and opportunity." *J. Hazard Mater.*, Vol. 150, pp. 468-493, DOI: 10.1016/j.jhazmat.2007.09.077.
- Shafeeyan, M. S., Daud, W. M. A. W., Houshmand, A., and Shamiri, A. (2010). "A review on surface modification of activated carbon for carbon dioxide adsorption." *Journal of Analytical and Applied Pyrolysis*, Vol. 89, No. 2, pp. 143-151, DOI: 10.1016/j.jaap.2010.07.006.
- Shaheed, R., Azhari, C. H., Ahsan, A., and Mohtar, W. H. M. W. (2015). "Production and characterisation of low-tech activated carbon from coconut shell." *Journal of Hydrology and Environment Research*, Vol. 3, No. 1, pp. 6-14.
- Shen, W., Li, Z., and Liu, Y. (2008). "Surface chemical functional groups modification of porous carbon." *Recent Patents on Chemical Engineering*, Vol. 1, No. 1, pp. 27-40.
- Sonavane, P. G. and Munavalli, G. R. (2009). "Modeling nitrogen removal in a constructed wetland treatment system." *Water Science and Technology*, Vol. 60, No. 2, pp. 301-309, DOI: 10.2166/wst.2009.319.
- Sun, G. and Austin, D. (2007). "A mass balance study on nitrification and deammonification in vertical flow constructed wetlands treating landfill leachate." *Water Science and Technology*, Vol. 56, No. 3, pp. 117-123, DOI: 10.2166/wst.2007.503.
- Tadda, M. A., Ahsan, A., Shitu, A., ElSergany, M., Arunkumar, T., Jose, B., Razzaque, M. A., and Daud, N. N. N. (2016). "A review on activated carbon: process, application and prospects." *Journal of Advanced Civil Engineering Practice and Research*, Vol. 2, No. 1, pp. 7-13.
- Tangjuank, S., Insuk, N., Udee, V., and Tonrakoon, J. (2009). "Chromium (III) sorption from aqueous solutions using activated carbon prepared from cashew nut shells." *International Journal of Physical Sciences*, Vol. 4, No. 8, pp. 412-417.
- Timur, S., Kantarli, I. C., Onenc, S., and Yanik, J. (2010). "Characterization and application of activated carbon produced from oak cups pulp." *Journal of Analytical and Applied Pyrolysis*, Vol. 89, pp. 129-136, DOI: 10.1016/j.jaap.2010.07.002.
- Valdes, H., Sanchez-Polo, M., Rivera-Utrilla, J., and Zaror, C. A. (2002). "Effect of ozone treatment on surface properties of activated carbon." *Langmuir*, Vol. 18, No. 6, pp. 2111-2116, DOI: 10.1021/la010920a.
- Vilar, A., Eiroa, M., Kennes, C., and Veiga, M. C. (2010). "The SHARON process in the treatment of landfill leachate." *Water Science and Technology*, Vol. 61, No. 1, pp. 47-52, DOI: 10.2166/wst.2010.786.
- Welander, U. (1998). *Characterization and treatment of Municipal landfill leachate*, Published Thesis, Department of Biotechnology, Lund University, Sweden.
- Wibowo, N., Setyadi, L., Wibowo, D., Setiawan, J., and Ismadji, S. (2007). "Adsorption of benzene and toluene from aqueous solutions onto activated carbon and its acid and heat treated forms: Influence of surface chemistry on adsorption." *Journal of Hazardous Materials*, Vol. 146, pp. 237-242, DOI: 10.1016/j.jhazmat.2006.12.011.
- Wisniewski, J., Robert, D., Surmacz-Gorska, J., Miksch, K., and Weber, J. (2006). "Landfill leachate treatment methods: A review". *Environmental Chemistry Letters*, Vol. 4, No. 1, pp. 51-61, DOI: 10.1007/s10311-005-0016-z.
- Yin, C. Y., Aroua, M. K., and Daud, W. M. A.W. (2007). "Review of modifications of activated carbon for enhancing contaminant uptakes from aqueous solutions." *Sep. Purif Technol.*, Vol. 52, pp. 403-415, DOI: 10.1016/j.seppur.2006.06.009.
- Yuen, F. K. and Hameed, B. H. (2009). "Recent developments in preparation and regeneration of activated carbons by microwaves." *Advances in Colloid and Interface Science*, Vol. 149, pp. 19-27, DOI: 10.1016/j.cis.2008.12.005.
- Zhang, J. and Yang, L.-J. (2011). "Notice of reaction study on adsorption of chromium (VI) by modified activated carbon with potassium permanganate." *Paper presented at the Bionformatics and Biomedical Engineering (iCBBE)*, 5th International Conference, DOI: 10.1109/icbbe.2011.5781100.