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Activated carbon for landfill leachate treatment: A review

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Abstract

Landfilling is the most cost-effective, common and preferred method of solid waste management. Despite the various advantages of landfilling, the generation of highly polluted leachate poses a major drawback. The mismanagement of leachate can lead to many health hazards, starting off with groundwater and surface water contamination. There have been many treatment methods of landfill leachate, from biological to chemical and a combination of both treatments. But recent studies have found that adsorption via activated carbon has unique properties able to remove pollutants from landfill leachate. Recognised as the most acceptable method for removal of refractory compounds in aqueous and actual effluent due to its ability in terms of physical and chemical sorption, as the most anticipated treatment method that has been studied using a wide range of precursors originating from natural resources, synthesized materials and agricultural wastes. This paper aims to review the various agricultural wastes used as precursors to produce activated carbon to treat landfill leachate. Moreover, the key advancement of activated carbons adsorption focusing on low-cost precursors, challenges of its implementation and future expectations will be discussed.

Keywords: Landfill; Leachate Treatment; Activated Carbon; Low-Cost; Adsorption

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1. Introduction

Environmental protection has become a topic of major concern recently, especially through the global perspective. The pollution of the environment has reached a stage where it should be examined and acted upon, otherwise it will cause catastrophes within civilisations. There are many types of pollution but, the main concern of researchers and scientists focuses on water pollution. Water is indeed, the most basic requirement in order to sustain the natural ecological processes. However, deteriorating quality of clean water sources have become a major concern because clean and hygienic water source is the only way to ensure healthy lives of human beings and ecosystem longevity. The challenges of removing various types of pollutants from water have become more difficult due to the rapid industrialisation era especially affecting those in developing countries. Pollutants namely heavy metals, phenols, dyes, inorganic ions and pesticides are present in the wastewater streams of many industrial processes which may affect water bodies, groundwater and the environment.

In the past decade, the global population has grown exponentially, although it increases productivity, it also increases the consumption habits that lead to rapid generations of municipal and industrial solid wastes. According to the World Bank (2018), the worlds' cities generated 1.3 billion tonnes of solid waste per year, in 2012 alone. This amounts to approximately 1.2 kilograms per capita per day. Malaysia, in particular, the expected population of the country is 33.4 million by 2020 equating to 0.8 per capita per day (Bong et al., 2017). The MSW management practice in Malaysia highly depends on the use of landfills. According to Tan et al. (2014), 94.5% of generated wastes are disposed into landfills while the remaining generated wastes are recycled, only 5.5%, and composted, 1%.

Worldwide, the most used strategy of MSW management is sanitary landfilling. Landfilling is recognised as a proper method of disposal due to its simpler operations and cost-effectiveness (Kamaruddin et al., 2017). The components of MSW plays an important role in determining the suitability of the disposal systems and methods. According to Visvanathan et al. (2004), the composition of solid wastes generated in most Asian countries are highly biodegradable despite the high moisture content such as food waste, paper, plastic/foam, agriculture waste, rubber/leather, wood, metal, glass and textiles. Therefore, identifying the most suitable alternative for long term solutions for MSW management is crucial such as landfilling, incineration, composting and others. Landfilling of wastes cause two types of pollution; a) leachate, defined as the water that percolates through the wastes from rainwater, which causes contamination to surface and groundwater and b) biogas, produced through the fermentation of organic matter caused by the disposed wastes, contributes to air pollution (Abdulhussain, 2009). Groundwater is one of the major sources of fresh water used for drinking and daily usage in communities around the world. An important renewable resource which is less polluted compared to surface water due to its ability to self-cleanse and ease of treatment (Oluyemi et al., 2009).

Before discharging into open water, the generated leachate must be treated and comply with standards established by the authorised bodies. There are various methods of leachate treatment systems implemented although advanced leachate systems do exist, the stumbling block for landfill operators are the high capital costs and specialised management required for the maintenance of the system. Thus, research is needed to establish a selective and reliable alternative method to treat heavily polluted leachate. Various types of studies have been implemented through adsorption using activated carbon on landfill leachate but, mostly using commercial activated carbon. This review aims to provide an in-depth development of adsorption using activated carbon, particularly activated carbon derived from agricultural wastes.

2. Landfill leachate

2.1. Landfill leachate studies

Landfill leachate is precipitation, usually rainwater the main contributor, percolating through wastes within a landfill or dump gaining dissolved and suspended components from the biodegrading wastes through physical and chemical reactions. The liquid formed by the percolation of precipitation through an open landfill or through the cap of a finished site, may contain enormous amounts of pollutants such as organic substances measured as chemical oxygen demand (COD) and biochemical oxygen demand (BOD), ammonia, high concentrations of heavy metals, and inorganic salts (Renou et al., 2008, Foul et al., 2009, Aziz et al., 2009, Uygur and Kargı, 2004). Generally dark in colour and emits a strong odour, it is generated from the excess water percolating with a mixture of organic and inorganic loads within the waste layers of the landfill, producing a quantity of the leachate depending on the amount of rainfall (Azmi et al., 2015).

Landfill leachate can be classified into three types: young, medium and old also referred to as stabilised leachate based on the different landfill ages (less than a year, 1-5 years and more than 5 years, respectively). Landfill leachate represents one of the most challenging effluents to treat biologically (Matošić et al., 2008). The landfill undergoes chemical and physical changes which is caused by the decomposition of wastes by the soil. Thus, the liquid percolating added with the presence of rainwater undergoes chemical, physical and biochemical reactions with the wastes within that influences the quantity and quality of the leachate produced. As stated by Kamaruddin et al. (2015), the quality and quantity of the produced leachate is dependent on the landfill age, precipitation, weather variations, waste type and composition.

The practice of landfilling has been implemented for a long time, dating back to 1935. Trash was thrown into a hole and covered with dirt, periodically. This method was practiced without a barrier or underlying layer (line), that prevented the percolating water moving through the wastes contaminating the groundwater. The early implementations of landfills were seen as disposal grounds for wastes, but due to the negative impacts on the environment caused by these landfills as found by various studies, this concept has changed. There are various negative environmental impacts from landfilling such as leachate contamination to surface and groundwater, infestation of pests, and emission of environmentally hazardous gases such as hydrogen sulphide and methane to the atmosphere (Ojeda-Benítez and Beraud-Lozano, 2003, Scharff and Jacobs, 2006, Buivid et al., 1981, Haivadakis et al., 1988). In the 1950s, the so-called sanitary landfilling was introduced, defined as an engineered method of disposing of wastes. It was a common practise to dispose refuse by uncontrolled tipping or dumping, an operation in which waste is dumped to fill a pre-existing hole, or on pieces of land that had low economic value, without taking care of the surrounding environment which included the need for daily covers of wastes and the prevention of leachate spreading into waterways (Blight, 2008). Today, the application of scientific, engineering, and economic principles has been adopted towards the framework transformation of landfills of which the monitoring of leachate is routinely performed by landfill operators and prescribed by the authorities.

2.2. Landfill components and environmental effects

With the knowledge of analysing, the composition of leachate produced from landfills indicate the state and types of processes occurring within the landfill. Focusing on the typical types of sanitary landfills that receive industrial, commercial and municipal wastes, the composition of leachate generated from these wastes can be characterised into; dissolved organic matter, inorganic matter, heavy metals and xenobiotic compounds (Christensen et al., 1994). Leachates may contain high amounts of organic contaminants and dissolved organic matter measured in terms of COD and BOD, ammonia, methane (NH_4), humic and fulvic-like compounds representing the degradation of organic wastes in landfills. Furthermore, a significant fraction of landfill leachate is made of inorganic constituents comprising of ions which includes magnesium (Mg^{2+}), calcium (Ca^{2+}), potassium (K^+), sodium (Na^+), iron (Fe^{2+}), chloride (Cl^-), sulphates (SO_4^{2-}) and bicarbonates (HCO_3^-) with the presence of heavy metals (arsenic, cadmium, chromium, cobalt, lead, mercury, copper, nickel and zinc) that are soluble during the degradation process of the wastes. Meanwhile, the presence of xenobiotic compounds originates from the municipal and industrial chemicals (Aziz et al., 2009, Renou et al., 2008).

Landfill leachate has been reported by several researchers to have detrimental effects on the environment which makes it a necessity to treat the leachate to the standards and conditions set by the local government, Department of Environment (DOE), for discharge into receiving waters (Renou et al., 2008). Table 1 illustrates the requirements set by DOE which concerns the discharge into the environment.

Table 1. Parameter limits of leachate discharge (Department of Environment, 2009)

Parameter	Unit	Standard A	Standard B
Temperature	°C	40	40
pH Value		6.0-9.0	5.5-9.0
BOD_5 at 20°C	mg/l	20	50
COD	mg/l	50	100
Suspended Solids	mg/l	50	100
Mercury	mg/l	0.005	0.05
Cadmium	mg/l	0.01	0.02
Chromium	mg/l	0.05	0.05
Cyanide	mg/l	0.05	0.10
Copper	mg/l	0.20	1.0
Nickel	mg/l	0.20	1.0
Iron (Fe)	mg/l	1.0	5.0
Phenol	mg/l	0.001	1.0
Chlorine	mg/l	1.0	2.0
Oil and Grease	mg/l	Not detectable	10

The landfill leachate characteristics is best represented by COD, BOD, BOD/COD ratio, total organic carbon (TOC), pH, suspended solids, ammonium nitrogen (NH_3-N), total Kjeldahl nitrogen (TKN), bacterial count, turbidity and heavy metals content (Gotvajn et al., 2009) to assess the quality of the produced leachate as well as predict the future composition of leachate and the type of design and operation which is the most suitable for treatment. Table 2 below shows the landfill leachate characterisation of young and stabilised leachate.

Table 2. Landfill leachate characterisation according to composition (Lee et al., 2010, Alvarez-Vazquez et al., 2004)

Type of Leachate	Young Leachate	Stabilised Leachate
Age (years)	<5	>10
BOD_5	>6300	<900
COD (mg/L)	>9000	<1500
BOD/COD ratio	0.05-0.66	0.05-0.57
pH	5.9-6.8	6.27-7.38
Total Kjeldahl Nitrogen	<880	<660
Ammonia Nitrogen (mg/L)	<520	>500
Heavy Metals (ms/L)	Low to Medium	Low

3. Landfill leachate treatment technologies

For many years, the emission of organic, inorganic and heavy metals compounds caused by the leachate seepage into waterways, groundwater and surface water, in particular, is a risk to the natural environment and public as highlighted by wastewater treatment industries. Recognised as one of the biggest problems associated with landfilling, causing significant pollution problems to soils, surface and groundwater. Many new advances in research for technologies in leachate treatment focused on the enhancement of coagulation-flocculation processes, clarification and biological methods such as activated sludge, aerated lagoons, sequential batch reactor, etc. but, the main concern for landfill operators are the high capital costs, specialised and costly maintenance and simplicity of the implemented systems.

Due to the exceptionally low biodegradability ratio of the local leachate, which a biological process alone is not effective enough to remove the bulk of refractory pollutants, an integrated leachate treatment with other technologies such as advanced oxidation process (AOP) or physicochemical treatments can increase the removal efficiencies of pollutants such as adsorption which may improve its treatability (Kurniawan and Lo, 2009). Throughout the years, biological treatments and physicochemical methods have been considered as the most appropriate technologies for the treatment of landfill leachates, which are considered high strength effluents. For the treatment of young leachate, biological techniques yield a reasonable treatment performance with respect to COD, NH3-N and heavy metals. But, the situation changes when treating stabilized leachate which are less biodegradable, physicochemical treatments is considered to be the most suitable method, in order to remove organic refractory substances.

The integrated chemical–physical-biological processes upgrade the drawbacks of individual processes contributing to a higher efficiency of the overall treatment. However, with the continuous hardening of the discharge standards in most countries and the aging of landfill sites with more and more stabilized leachates, conventional treatments (biological or physicochemical) are not sufficient enough these days to reach the level of purification needed to fully reduce the detrimental impacts of landfill leachates on the environment. It indicates that new treatment alternatives technologies must be proposed.

4. Landfill leachate treatment via low-cost and commercial activated carbon adsorption process

In the past decade, adsorption, a surface phenomenon which is common in the removal of organic and inorganic pollutants where gas or liquids of the mixture is attracted solid sorbent surfaces and attachments are formed through physical and chemical bonds, recognised as a promising and the most efficient thus far fundamental approach in the wastewater treatment industries (Rashed, 2013). Table 3 presents the researches conducted by various researchers and scientists of landfill leachate treatment using activated carbon adsorption process.

In order to cope with the temporal fluctuations in varying strength and composition of landfill leachate, the development of collaborated multistage treatments, which combine adsorption processes with numerous complementary approaches have received stern attention and various encourages. A substantial amount of simultaneous adsorption and biological treatment investigations have been practiced, offering a number of advantages, including the enhancement of nitrification efficiency, improvement of sludge dewaterability and removal of refractory organic compounds (Aktaş and Ceçen, 2001, Aghamohammadi et al., 2007). Under the co-treatment processes, the existence of activated carbons is believed may contribute a unity effect which provides a surface for attachment for bio-regeneration of microorganisms and serves as a nucleus for floc formation to occur (Çeçen et al., 2003). Furthermore, this phenomenon has always been linked to the supporting medium in the biofilm reactors which benefits by biodegradation and as dampening effects of leachate in the combined domestic wastewater and landfill leachate systems (Kalderis et al., 2008).

Table 3. List of activated carbon in landfill leachate treatment

Activated carbon/precursor	Leachate Type	Pollutant removal	Percentage Removal (%)	Reference
Banana frond	Landfill leachate	Boron	92.73	Foo et al. (2013)
		Total iron		
Banana pseudo-stem	Landfill leachate	Color and COD	91.2	Ab Ghani et al. (2017)
		COD	83	
Carbotech	Intermediate	COD	75	Zajc et al. (2004)

Coconut shell	Young	Ammonia	80	Halim et al. (2010)
		COD	70	
Coconut shell GAC	Young	COD	82	Kurniawan and Lo (2009)
		NH_3-N	59	
Commercial GAC		COD	19.1	Liyan et al. (2009)
		HOC	73.4	
Commercial PAC	Intermediate	COD	75	Uygur and Kargı (2004)
		Ammonia	44	
		Phosphate	44	
	Synthetic	COD	87	Kargı and Pamukoglu (2004)
		Ammonia	16	
	Stabilised	COD	38	Hur and Kim (2000)
	Young	Colour	50	Aghamohammadi et al. (2007)
		Ammonia	78	
		COD	49	
	Intermediate	HOCs	89.2	Liyan et al. (2009)
		COD	24.6	
Oil palm shell	Stabilised	COD	50	Lim et al. (2009)
PAC-SBR	Stabilised	COD	64.1	Aziz et al. (2011)
		Colour	71.2	
		NH_3-N	81.4	
Rice husks	Young	COD	70	Kalderis et al. (2008)
		Colour	60	
	Intermediate	COD	90	Lim et al. (2010)
		Nitrogen		

5. Major challenges and future potential

At the moment, we are facing the worst environmental crisis in the entire history of the world. In the last decade or so, excess waste production and environmental preservation have been the greatest public concern, has been one of the most challenging topics focused by scientists and researchers. With new technology focusing on environment-friendly and sustainability, various research and development efforts have been conducted to completely utilise activated carbon treatments mainly for landfill leachate treatment. During the process of implementing activated carbons, the adsorption capacity is associated closely with the accessibility, stability and surface properties which includes surface area, pore microstructure, and pore size distribution (Li et al., 2007, Gao et al., 2009). Even though there have been successful breakthroughs of industrial-scale applications and implications, there are various challenges that the industry is still facing; the availability of operational technologies that are economical and sustainable natural resources that are obtainable (Yuen and Hameed, 2009).

Despite these shortcomings, the advancing research in evaluating the suitability of natural, renewable and low-cost materials as alternative precursors has currently in progress. A wide range of approaches have been implemented including physical, chemical and biological technologies are attracting positive feedback and high priorities. Depending time, place and context, environmental effectiveness, feasibility, social acceptability and economic affordability are usually the key factors deciding its flexibility, reliability and sustainability. Most importantly, to achieve a well-managed solid waste management system, professional knowledge is crucial to create environmental awareness for adequate financial solutions, engineering and operating standards, responsibility sharing, public involvement, regular opinion survey, site rehabilitation and aftercare maintenance need to be properly assigned and managed because without a proper system, new and complex problems will arise (Bernache, 2003). In addition, full cooperation and support form the government regardless of parties which includes nations, states, local government, private sectors and communities from top to bottom with compatible technologies is a step in the right direction for a well-managed and sustainable solid waste management system.

6. Conclusion

Over the next decade and onwards, factories and processing industries are expanding exponentially which will create overwhelming amounts of solid waste and producing highly polluted wastewaters in the process, worldwide. It is also predicted that for the next 20 years there will be an increase in waste production which will subsequently lead to leachate infiltration. Today, the growing disagreement and limited success of remediation in field applications have raised worries over the use of activated carbon or technologies that are connected to them, as a measure of the environmental pollution control. The development of this new technology has turned from a fascinating alternative approach into a powerful technique which offers a wide range of advantages when implemented. Although there are various drawbacks and challenges which has been identified and clarified, extensive and great progress of work in this area can be expected in the near future.

References

Ab Ghani, Z., Yusoff, M.S., Zaman, N.Q., Zamri, M.F.M.A. and Andas, J. (2017), "Optimization of preparation conditions for activated carbon from banana pseudo-stem using response surface methodology on removal of color and COD from landfill leachate", *Waste Management*, Vol. 62, pp. 177-187.

Abdulhussain, A., Abbas, G.J., Liu Zhi, P., Pan Ying, Y., and Wisaam S.A. (2009), "Review on Landfill Leachate Treatments", *American Journal of Applied Sciences,* Vol. 6 No. 4, pp. 672-684.

Aghamohammadi, N., Abdul Aziz, H., Isa, M.H. and Zinatizadeh, A.A. (2007), "Powdered activated carbon augmented activated sludge process for treatment of semi-aerobic landfill leachate using response surface methodology", *Bioresource Technology*, Vol. 98 No. 18, pp. 3570-3578.

Aktaş, Ö. and Ceçen, F., (2001), "Addition of activated carbon to batch activated sludge reactors in the treatment of landfill leachate and domestic wastewater", *Journal of Chemical Technology & Biotechnology: International Research in Process, Environmental & Clean Technology*, Vol. 76 No. 8, pp. 793-802.

Alvarez-Vazquez, H., Jefferson, B. and Judd, S.J. (2004), "Membrane bioreactors vs conventional biological treatment of landfill leachate: a brief review", *Journal of Chemical Technology and Biotechnology*, Vol. 79 No. 10, pp. 1043-1049.

Aziz, H.A., Daud, Z., Adlan, M.N. and Hung, Y.T. (2009), "The use of polyaluminium chloride for removing colour, COD and ammonia from semi-aerobic leachate", *International Journal of Environmental Engineering*, Vol. 1 No. 1, pp. 20-35.

Aziz, S.Q., Aziz, H.A., Yusoff, M.S. and Bashir, M.J. (2011), "Landfill Leachate treatment using powdered activated carbon augmented sequencing batch reactor (SBR) process: Optimization by response surface methodology", *Journal of Hazardous Materials*, Vol. 189 No. 1-2, pp. 404-413.

Azmi, N.B., Bashir, M.J., Sethupathi, S., Wei, L.J. and Aun, N.C. (2015), "Stabilized landfill leachate treatment by sugarcane bagasse derived activated carbon for removal of color, COD and NH3-N–optimization of preparation conditions by RSM", *Journal of Environmental Chemical Engineering*, Vol. 3 No. 2, pp. 1287-1294.

Bernache, G. (2003), "The environmental impact of municipal waste management: the case of Guadalajara metro area", *Resources, conservation and recycling*, Vol. 39 No. 3, pp. 223-237.

Blight, G. (2008), "Slope failures in municipal solid waste dumps and landfills: a review", *Waste Management & Research*, Vol. 26 No. 5, pp. 448-463.

Bong, C.P.C., Ho, W.S., Hashim, H., Lim, J.S., Ho, C.S., Tan, W.S.P. and Lee, C.T. (2017), "Review on the renewable energy and solid waste management policies towards biogas development in Malaysia", *Renewable and Sustainable Energy Reviews*, Vol. 70, pp. 988-998.

Buivid, M., Wise, D.L., Blanchet, M., Remedios, E., Jenkins, B., Boyd, W. and Pacey, J. (1981), "Fuel gas enhancement by controlled landfilling of municipal solid waste", *Resources and Conservation*, Vol. 6 No. 1, pp. 3-20.

Çeçen, F., Erdinçler, A. and Kiliç, E. (2003), "Effect of powdered activated carbon addition on sludge dewaterability and substrate removal in landfill leachate treatment", *Advances in Environmental Research*, Vol. 7 No. 3, pp. 707-713.

Christensen, T.H., Kjeldsen, P., Albrechtsen, H.J.R., Heron, G., Nielsen, P.H., Bjerg, P.L. and Holm, P.E. (1994), "Attenuation of landfill leachate pollutants in aquifers", *Critical Reviews in Environmental Science and Technology*, Vol. 24 No. 2, pp. 119-202.

Department of Environment, M., (2009), "Regulations 2009. Environmental Quality (Control of Pollution from Solid Waste Transfer Station and Landfill)".

Foo, K., Lee, L. and Hameed, B. (2013), "Preparation of banana frond activated carbon by microwave induced activation for the removal of boron and total iron from landfill leachate", *Chemical Engineering Journal*, Vol. 223, pp. 604-610.

Foul, A.A., Aziz, H.A., Isa, M.H. and Hung, Y.T. (2009), "Primary treatment of anaerobic landfill leachate using activated carbon and limestone: batch and column studies", *International Journal of Environment and Waste Management*, Vol. 4 No. 3-4, pp. 282-298.

Gao, Y., Pan, L., Li, H., Zhang, Y., Zhang, Z., Chen, Y. and Sun, Z. (2009), "Electrosorption behavior of cations with carbon nanotubes and carbon nanofibres composite film electrodes", *Thin Solid Films*, Vol. 517 No. 5, pp. 1616-1619.

Gotvajn, A.Ž., Tišler, T. and Zagorc-Končan, J. (2009), "Comparison of different treatment strategies for industrial landfill leachate", *Journal of Hazardous Materials*, Vol. 162 No. 2-3, pp. 1446-1456.

Haivadakis, C., Findikakis, A., Papelis, C. and Leckie, J. (1988), "The mountain view-controlled landfill project field experiment", *Waste Management & Research*, Vol. 6 No. 1, pp. 103-114.

Halim, A.A., Aziz, H.A., Johari, M.A.M. and Ariffin, K.S. (2010), "Comparison study of ammonia and COD adsorption on zeolite, activated carbon and composite materials in landfill leachate treatment", *Desalination*, Vol. 262 No. 1-3, pp. 31-35.

Hur, J.M. and Kim, S.H. (2000), "Combined adsorption and Chemical precipitation process for pretreatment or post-treatment of landfill leachate", *Korean Journal of Chemical Engineering*, Vol. 17 No. 4, pp. 433-437.

Kalderis, D., Koutoulakis, D., Paraskeva, P., Diamadopoulos, E., Otal, E., Del Valle, J.O. and Fernández-Pereira, C. (2008), "Adsorption of polluting substances on activated carbons prepared from rice husk and sugarcane bagasse", *Chemical Engineering Journal*, Vol. 144 No. 1, pp. 42-50.

Kamaruddin, M.A., Yusoff, M.S., Aziz, H.A. and Alrozi, R., (2016), "Current status of Pulau Burung sanitary landfill leachate treatment, Penang Malaysia", *In AIP Conference Proceedings (Vol. 1774, No. 1, p. 030014)*. AIP Publishing.

Kamaruddin, M.A., Yusoff, M.S., Aziz, H.A. and Hung, Y.T. (2015), "Sustainable treatment of landfill leachate", *Applied Water Science*, Vol. 5 No. 2, pp. 113-126.

Kamaruddin, M.A., Yusoff, M.S., Rui, L.M., Isa, A.M., Zawawi, M.H. and Alrozi, R., (2017), "An overview of municipal solid waste management and landfill leachate treatment: Malaysia and Asian perspectives", *Environmental Science and Pollution Research*, Vol. 24 No. 35, pp. 26988-27020

Kargı, F. and Pamukoglu, M.Y. (2004), "Adsorbent supplemented biological treatment of pre-treated landfill leachate by fed-batch operation", *Bioresource Technology*, Vol. 94 No. 3, pp. 285-291.

Kurniawan, T.A. and Lo, W.H. (2009), "Removal of refractory compounds from stabilized landfill leachate using an integrated H_2O_2 oxidation and granular activated carbon (GAC) adsorption treatment", *Water Research*, Vol. 43 No. 16, pp. 4079-4091.

Lee, A.H., Nikraz, H. and Hung, Y.T. (2010), "Influence of waste age on landfill leachate quality", *International Journal of Environmental Science and Development*, Vol. 1 No. 4, pp. 347.

Li, Q., Li, K., Sun, C. and Li, Y. (2007), "An investigation of Cu2+ and Fe2+ ions as active materials for electrochemical redox supercapacitors", *Journal of Electroanalytical Chemistry*, Vol. 611 No. 1-2, pp. 43-50.

Lim, P.E., Lim, S.P., Seng, C.E. and Noor, A.M. (2010), "Treatment of landfill leachate in sequencing batch reactor supplemented with activated rice husk as adsorbent", *Chemical Engineering Journal*, Vol. 159 No. 1-3, pp. 123-128.

Lim, Y.N., Shaaban, M.G. and Yin, C.Y. (2009), "Treatment of landfill leachate using palm shell-activated carbon column: Axial dispersion modeling and treatment profile", *Chemical Engineering Journal*, Vol. 146 No. 1, pp. 86-89.

Liyan, S., Youcai, Z., Weimin, S. and Ziyang, L. (2009), "Hydrophobic organic chemicals (HOCs) removal from biologically treated landfill leachate by powder-activated carbon (PAC), granular-activated carbon (GAC) and biomimetic fat cell (BFC)", *Journal of Hazardous Materials*, Vol. 163 No. 2-3, pp. 1084-1089.

Matošić, M., Terzić, S., Jakopović, H.K., Mijatović, I. and Ahel, M. (2008), "Treatment of a landfill leachate containing compounds of pharmaceutical origin", *Water Science and Technology*, Vol. 58 No.3, pp. 597-602.

Ojeda-Benítez, S. and Beraud-Lozano, J.L. (2003), "The municipal solid waste cycle in Mexico: final disposal", *Resources, Conservation and Recycling*, Vol. 39 No.3, pp. 239-250.

Oluyemi, E., Makinde, W. and Oladipo, A. (2009), "Potential groundwater contamination with toxic metals around refuse dumps in some parts of Lagos metropolis, Nigeria", *Toxicological and Environmental Chemistry*, Vol. 91 No. 5, pp. 933-940.

Rashed, M.N., 2013. Adsorption technique for the removal of organic pollutants from water and wastewater. *In Organic Pollutants-Monitoring, Risk and Treatment*. IntechOpen.

Renou, S., Givaudan, J., Poulain, S., Dirassouyan, F. and Moulin, P. (2008), "Landfill leachate treatment: review and opportunity", *Journal of Hazardous Materials*, Vol. 150 No. 3, pp. 468-493.

Scharff, H. and Jacobs, J. (2006), "Applying guidance for methane emission estimation for landfills", *Waste Management*, Vol. 26 No. 4, pp. 417-429.

Tan, S.T., Lee, C.T., Hashim, H., Ho, W.S. and Lim, J.S. (2014), "Optimal process network for municipal solid waste management in Iskandar Malaysia", *Journal of Cleaner Production*, Vol. 71, pp. 48-58.

Uygur, A. and Kargı, F. (2004), "Biological nutrient removal from pre-treated landfill leachate in a sequencing batch reactor", *Journal of environmental management*, Vol. 71 No. 1, pp. 9-14.

Visvanathan, C., Tubtimthai, O. and Kuruparan, P. (2004), "Influence of landfill top cover design on methane oxidation: Pilot scale lysimeter experiments under tropical conditions", *3rd Asia Pasific Landfill Symposium*. Kitakyushu, Japan.

World Bank, T. (2018), "What a Waste: An Updated Look into the Future of Solid Waste Management" available at: https://www.worldbank.org/en/news/immersive-story/2018/09/20/what-a-waste-an-updated-look-into-the-future-of-solid-waste-management (Accessed 12 June 2018).

Yuen, F.K. and Hameed, B. (2009) "Recent developments in the preparation and regeneration of activated carbons by microwaves", *Advances in Colloid and Interface Science*, Vol. 149 No. 1-2, pp. 19-27.

Zajc, N.Č., Glancer, M. and Gromping, M. (2004), "Laboratory scale and pilot study of the treatment of municipal landfill leachate", *Chemical and Biochemical Engineering Quarterly*, Vol. 18 No. 1, pp. 77-84.