Chapter 8
Date Palm as a Potential Candidate for Environmental Remediation

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Contents

Abstract The water bodies are under continuous stress conditions owing to water pollution, and this problem is increasing continuously in line with industrialization. Consequently, utmost attention is needed to embark upon pollution problems so as to fulfil the dream of sustainable development. In the present era, adsorption has been considered as an efficient method for the removal of suspended and dissolved pollutants from the water resources. It has been confirmed that among the various types of bioadsorbents, date palm emerged as a highly cost-efficient and biodegradable bioadsorbent. A number of recent reports signified the role of date palm as a bioadsorbent. The present review is exploring the use of different by-products of date palm as adsorbent as well as a precursor to activated carbon production. Herein, an in-depth analysis of the role of date palm in the environmental remediation, in terms of removal of different pollutants, viz. dyes, heavy metals and toxins, has been examined.

Keywords Industrialization · Water pollution · Adsorption · Date palms · Adsorption characteristics

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8.1 Introduction

Over the past few decades, the industrial revolution plays an instrumental role in the economic growth and prosperity of the country. But, with the rapid expansion of industries, an enormous pressure is exerted on the environment. It turned out that the residence of environmental contaminants in environmental media, viz. round water, surface water soil and sediments, poses a serious threat to the environment and human health (Ghasemi et al. 2014; Naushad et al. 2016a). Subsequently, the impacts on water resources seem to be more severe which cannot be overlooked. The problem of massive water pollution is demarcated as the consequence of the discharge of industrial wastewater into the water bodies. As a matter of fact, billions of tons of wastewater are generated by industries every year (Sagasta et al. 2015).

The wastewater discharged as such into the rivers, lakes and streams results in health hazards such as eye irritation, skin and neurological problems, degenerative heart disease, gastroenteritis, blue baby syndrome, typhoid fever, shigellosis, salmonellosis, campylobacteriosis, cholera, giardiasis, cryptosporidiosis and hepatitis A and liver cancer in animals (Eynard et al. 2000; Mahmood and Maqbool 2006; Akpor and Muchie 2011). In addition, wastewater effluents are accountable for ruining the quality of receiving water bodies resulting in problems of eutrophication of water bodies, biomagnification in the aquatic life and decreased dissolved oxygen (Welch 1992; Akpor and Muchie 2011). These problems are getting grimmer day by day. So, in order to protect the receiving waters from these obnoxious effects, specialized treatments are needed.

The researcher's works around the clock to develop methods for tackling these profound effects of industrial pollutants are continuously going on. An array of technologies are available for the pollutants remediation, such as advanced oxidation, ozonation, chemical precipitation, ion exchange, coagulation, flocculation, electrodialysis, ultrasonic treatment, reverse osmosis, membrane filtration, solvent extraction and adsorption (Abdulkarim et al. 2002; Al-Ghouti et al. 2010; Bhattacharyya and Gupta 2008; Bratskaya et al. 2009; Chang et al. 2009; El Samrani et al. 2008; Hall et al. 1990; Ku and Jung 2001; Landaburu-Aguirre et al. 2010; Mohsen-Nia et al. 2007; Murthy and Chaudhari 2008; Nataraj et al. 2007; Ostroski et al. 2009; Suzuki et al. 2000; Terry 2010; Al-Othman et al. 2012; Mittal et al. 2016; Naushad and ALOthman 2015; Alqadami et al. 2017; Albadarin et al. 2017). But, many of these technologies are ineffective because of the shortcomings of generation of toxic fumes during chemical precipitation, high power consumption in reverse osmosis method, secondary pollution problem during ion-exchange method, increase sludge volume generation in coagulation/flocculation and membrane fouling during membrane filtration (Dialynas and Diamadopoulos 2009; Fu and Wang 2011; Shafiq et al. 2018). The adsorption process is considered a vivid remediation technology owing to its simplicity, reliability and low maintenance cost. Activated carbon holds a significant promise as an efficient adsorbent for pollutant removal (Ahmad et al. 2012; Naushad et al. 2016b). However, in spite of its high adsorption nature and maximum porous surface area, the problem of high cost of production has inclined the researchers towards the development of low-cost adsorbents.

Date palm is one such low-cost adsorbent which have been extensively used throughout the world for removal of various types of pollutants. In this review, the research advances in the use of date palm for removal of various wastewater pollutants as well as its role in phytoextraction have been documented.

8.2 Chemical Composition and Properties of Date Palm

Date palm known as *Phoenix dactylifera* L. scientifically is one of the major commercially growing crops in Middle East Asia and North Africa (Ahmad et al. 2012). Its global production has observed to be around 7.68 million tons in 2010 (Tang et al. 2013). As far as regional distribution is concerned, it has been seen that around 60 million date palm trees are cultivated in Asia (for instance, Iran, Saudi Arabia, Kuwait, Bahrain, Turkmenistan, UAE, Iraq, Pakistan, Oman and Yemen) and approximately 32.5 million date palm are grown in Libya, Algeria, Mali, Egypt, Mauritania, Morocco and Niger countries of Africa region (Jamil et al. 2016; Shafiq et al. 2018). Besides being used as a fruit, date palm and its products are used for the purpose of pollutant removal over the centuries which are attributable to its chemical composition.

Indeed the chemical study of date palm revealed that it consists of cellulose (40–50%), hemicellulose (20–35%) and lignin (15–35%) as major components along with some minor components such as oil and proteins (Macedo et al. 2008). Cellulose is a crystalline polysaccharide consisting of a linear chain of up to 3000 β(1→4) linked D-glucose units. Hemicellulose though related to cellulose is unbranched and contains a lesser number of saccharide units compared to that of cellulose. The third major component, i.e. lignin, can contribute significantly to the adsorption property of date palm. Structurally, it contains complex and variable constituents. The three polypropylene units are present in its structure which are linked together by ether linkages (C–O–C) and carbon–carbon bonding (C–C). Therefore, its elemental composition has higher carbon percentage of around 62 wt% and lower oxygen percentage of 32 wt%. The presence of a large number of carbon atoms is commonly linked with a lower polarity and thus a better prospect for adsorption. As a consequence, the date palm is an ideal adsorbent for adsorption practices (Jibril et al. 2008).

8.3 Role of Date Palm in Environmental Remediation

Environmental remediation aims to reduce harmful substance exposure from groundwater, surface water and contaminated soil. To help with the remediation of affected sites, date palm has been widely explored as an adsorbent by researchers all around the world. Figure 8.1 depicts the role of date palm as an adsorbent in the removal of various industrial pollutants such as heavy metals, phenols, dyes as well as in phytoextraction.

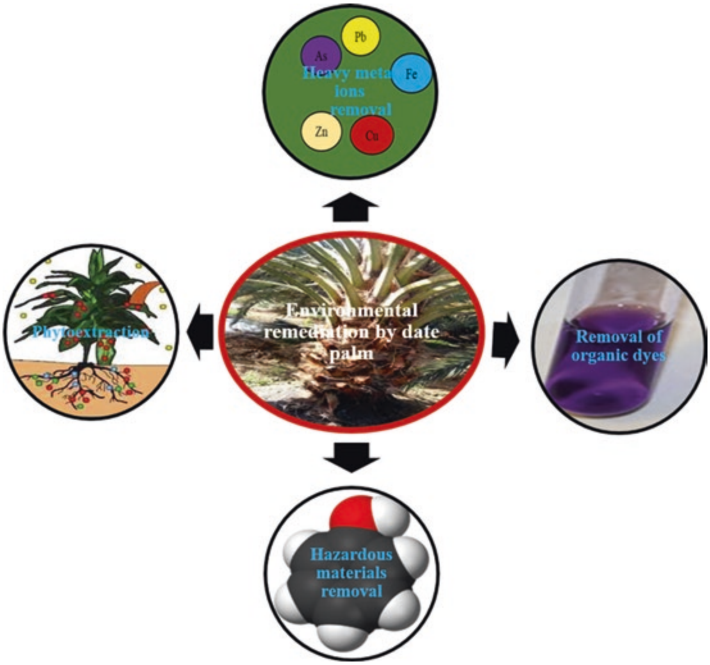

Fig. 8.1 Contribution of date palm in environmental remediation

8.3.1 Removal of Heavy Metals

Contamination of water bodies by heavy metals is of serious environmental concern. Industries such as pulp and paper, tannery, mining, electroplating, smelting and textiles generate substantial amounts of heavy metals from wastewater which is discharged into the rivers and streams. Above their threshold limits, they tend to accumulate in the food chain, causing neurological disorders, cancer and accumulative poisoning (Abdulkarim and Al-Rub 2004; Al-Jlil 2010). Since the toxicity of heavy metals is one of the severe health issues for decades, therefore, efficacious recovery of heavy metals from the water bodies is the need of the time (Naushad et al. 2017). Date palm and its by-products have been investigated as a preferred solution towards removal of these toxic heavy metals by various researchers (Haleem and Abdulgafoor 2010; Al-Haidary et al. 2011).

Al-Jlil (2010) investigated the removal of various heavy metals such as Cr, Co, Cu, Zn, As, Pb and Cd from industrial wastewater by roasted date pits. The results revealed that the heavy metal concentration from industrial wastewater treated with roasted date pits was less than the permissible limits for crop production compared to untreated wastewater except for the Co ion whose concentration was observed to be two times higher than the permissible limits. However, the absence of Co ion was seen when roasted date pits are used in series with other adsorbents, i.e. bentonite clay.

The extent of adsorption of heavy metals is controlled by a number of factors such as contact time, pH, a dosage of the adsorbent, particle sizes, initial metal concentration and temperature. In a study by Al-Haidary et al. (2011), the adsorption of Pb from aqueous solution by date palm fibres and leaf base of palm (petiole) was examined by considering the effect of numerous parameters, for instance, contact time, solution pH, adsorbent dosage, particle sizes of date palm materials, ionic strength and temperature. An increase in adsorption of Pb ions was observed with increase in adsorbent dosage as well as with the increase in contact time. An increase in adsorbent dosage could result in an increase in the surface area, thereby providing more binding sites for adsorption. The linear Langmuir and Freundlich models were used to comprehend the adsorbate-adsorbent interaction. Based on Langmuir isotherm, the adsorption capacity of Pb ion onto date palm fibres and petiole was calculated as 18.622 and 20.040 mg/g, respectively. The pseudo-second-order kinetics model correlated well with the adsorption kinetics of Pb ion from aqueous solution onto palm fibres and petiole. In another study of heavy metal, i.e. Cu removal by date palm from aqueous solutions conducted by Belala et al. (2011a), the effect of adsorbent particle size on removal efficiency was examined. The authors concluded that the removal efficiency was highest with adsorbent particles of small size. Maximum efficiency was in the range between 60% and 80% with the adsorbent particle size below 1 mm. Further, the study performed by Al-Ghamdi et al. (2013) indicated that the adsorption of heavy metal Cd^{2+} increased to 51.1 mg/g from 29.06 mg/g with the decrease in particle size from 875 to 100 μm. However, increasing the solution pH from 1.69 to 3.71 resulted in an increase in adsorption capacity.

Besides being used as an adsorbent, the carbon-rich raw date palm can also be used for the preparation of activated carbon which has been extensively used as adsorbent material for removal of a variety of contaminants. The ability of date palm derived activated carbon to adsorb heavy metals from aqueous metal solutions and wastewater has been reported in several studies (Banat et al. 2003a; Hilal et al. 2012; Chaouch et al. 2013, 2014; Nwakonobi et al. 2018).

El Nemr et al. (2008) prepared activated carbon from date palm seed by dehydrating approaches using concentrated sulfuric acid for removal of Cr(VI) from aqueous solution. The results showed that adsorption capacity increases with a decrease in pH value. The maximum adsorption capacity reported was 120.48 mg/g. Nwakonobi et al. (2018) used activated carbon prepared from the date palm seeds for removal of heavy metals, viz. Pb, Cr and Cd, from brewery wastewater. The adsorption experiments were carried out in batch studies under conditions such as contact time and adsorbent dosage. It has been concluded that at 60 min of contact time, different adsorbent doses of 10×10^3, 20×10^3, 30×10^3 and 40×10^3 mg/L reduced the Cr and Pb concentration below the World Health Organization (WHO) maximum limits of 0.05 and 0.01 mg/L, respectively. Cd concentration was brought within WHO maximum limit (0.003 mg/L) using 30×10^3 mg/L of the adsorbent at 80 min of contact time. A summary of adsorption of different metal ions by date palm-based adsorbents is presented in Table 8.1.

Table 8.1 Removal of heavy metals from water and wastewater by date palm

Adsorbent used	Heavy metals to be removed	Source of heavy metal	Conditions employed	Adsorption capacity	Removal efficiency	References
Date palm and its by-products						
Raw date pits	Zn (II)	Aqueous solutions	pH—3.5 to 5.0 Contact time—2 to 8 h Temperature—25, 40 and 50 °C	5.70 mg/g	–	Banat et al. (2002)
Raw date pits	Cu (II)	Aqueous solutions	pH—3.5 to 5.0 Contact time—2 to 8 h Temperature—25, 40 and 50 °C	9.53 mg/g	–	
Date pits	Cd (II)	Aqueous solutions	pH—2 to 7 Contact time—24 h Temperature—25, 35 and 45 °C	6.5 mg/g	–	Banat et al. (2003a)
Date palm fibres (leaf)	Cr (VI)	Aqueous solutions	pH—7 Biosorbent dose—5 g Contact time—48 h	–	98.7%	Haleem and Abdulgafoor (2010)
Raw date pits	Cu (II)	Aqueous solutions	pH—2 to 11 Contact time—72 h Temperature—20 °C	35.9 mg/g	–	Al-Ghouti et al. (2010)
Raw date pits	Cd (II)	Aqueous solutions	pH—2 to 11 Contact time—72 h Temperature—20 °C	39.5 mg/g	–	

Roasted date pits	Zn	Industrial wastewater	pH—7.67 Temperature—25 °C	–	97%	Al-Jlil (2010)
Roasted date pits	Co	Industrial wastewater	pH—7.67 Temperature—25 °C	–	97%	
Roasted date pits	Cd	Industrial wastewater	pH—7.67 Temperature—25 °C	–	97%	
Roasted date pits	Cr	Industrial wastewater	pH—7.67 Temperature—25 °C	–	97%	
Roasted date pits	As	Industrial wastewater	pH—7.67 Temperature—25 °C	–	97%	
Roasted date pits	Pb	Industrial wastewater	pH—7.67 Temperature—25 °C	–	97%	
Raw date pits	Cu (II)	Aqueous solution	pH—2.1 to 9.05 Adsorbent dose—0.01 to 2 g/L Contact time—200 min Temperature—25 ± 1 °C	7.40 mg/g	–	Hilal et al. (2012)
Raw date pits	Cd (II)	Aqueous solution	pH—2.1 to 9.05 Adsorbent dose—0.01 to 2 g/L Contact time—200 min Temperature—25 ± 1 °C	6.02 mg/g	–	

(continued)

Table 8.1 (continued)

Adsorbent used	Heavy metals to be removed	Source of heavy metal	Conditions employed	Adsorption capacity	Removal efficiency	References
Date palm trunk and leaves	Cu (II)	Aqueous solutions	pH—5 to 10	39.6 mg/g	–	Amin et al. (2017)
			Contact time—15 to 180 min			
			Temperature—30 to 50 °C			
Date palm trunk and leaves	Pb (II)	Aqueous solutions	pH—5 to 10	30 mg/g	94%	
			Contact time—15 to 180 min			
			Temperature—30 to 50 °C			
Date palm trunk and leaves	As (V)	Aqueous solutions	pH—5 to 10	25 mg/g	63%	
			Contact time—15 to 180 min			
			Temperature—30 to 50 °C			
Date seed-derived biochar	Ni (II)	Aqueous solutions	pH—2 to 6	35.7 mg/g	–	Mahdi et al. (2017)
			Temperature—23 ± 2 °C			
Date seed-derived biochar	Pb (II)	Aqueous solutions	pH—2 to 6	74.6 mg/g	–	Mahdi et al. (2018)
			Temperature—23 ± 2 °C			
			Contact time—24 h			
Date pits as a precursor of activated carbon						
Activated date pits	Zn (II)	Aqueous solution	pH—3.5 to 5.0	5.23 mg/g	–	Banat et al. (2002)
			Contact time—2 to 8 h			
			Temperature—25, 40 and 50 °C			
Activated date pits	Cu (II)	Aqueous solution	pH—3.5 to 5.0	8.89 mg/g	–	
			Contact time—2 to 8 h			
			Temperature—25, 40 and 50 °C			

Carbonized date pits (500 °C)	Cd (II)	Aqueous solution	pH—2 to 7 Contact time—24 h Temperature—25, 35 and 45 °C	3.0 mg/g	–	Banat et al. (2003a)
Carbonized date pits (900 °C)	Cd (II)	Aqueous solutions	pH—2 to 7 Contact time—24 h Temperature—25, 35 and 45 °C	1.8 mg/g	–	
Date stone activated carbon	Zn (II)	Aqueous solutions	pH—6 Adsorbent dose—0.2 to 10.0 g/dm Contact time—1 h Temperature—20 °C	10.41 mg/g	–	Mouni et al. (2010)
Date stone activated carbon	Pb (II)	Aqueous solutions	pH—6 Adsorbent dose—0.2 to 10.0 g/dm Contact time—1 h Temperature—20 °C	19.64 mg/g	–	
Activated date pits	Cu (II)	Aqueous solutions	pH—2.1 to 9.05 Adsorbent dose—0.01 to 2 g/L Contact time—200 min Temperature—25 ± 1 °C	33.44 mg/g	–	Hilal et al. (2012)
Activated date pits	Cd (II)	Aqueous solutions	pH—2.1 to 9.05 Adsorbent dose—0.01 to 2 g/L Contact time—200 min Temperature—25 ± 1 °C	17.24 mg/g	–	
Date stone activated carbon	Pb (II)	Aqueous solutions	pH—2 to 10 Contact time—2 h Temperature—25 to 60 °C	11.8 mg/g	–	Chaouch et al. (2014)

(continued)

Table 8.1 (continued)

Adsorbent used	Heavy metals to be removed	Source of heavy metal	Conditions employed	Adsorption capacity	Removal efficiency	References
Mercerized mesoporous date pit activated carbon	Cd (II)	Aqueous solutions	pH—1 to 9 Contact time—1 to 1440 min Temperature—298 K	212.1 mg/g	–	Aldawsari et al. (2017)
Mercerized mesoporous date pit activated carbon	Cu (II)	Aqueous solutions	pH—1 to 9 Contact time—1 to 1440 min Temperature—298 K	194.4 mg/g	–	
Mercerized mesoporous date pit activated carbon	Pb (II)	Aqueous solutions	pH—1 to 9 Contact time—1 to 1440 min Temperature—298 K	133.5 mg/g	–	
Mercerized mesoporous date pit activated carbon	Zn (II)	Aqueous solutions	pH—1 to 9 Contact time—1 to 1440 min Temperature—298 K	111 mg/g	–	

sizes (1.47, 0.8, 0.45 and 0.225 mm) of adsorbent were used for this study. The data of the adsorption kinetics of phenol exhibited a good fit with the pseudo-second-order kinetic equation.

8.3.3 Dye Removal

Dyes are coloured compounds used extensively by textile, tannery, paper, plastic, cosmetics, leather, food and pharmaceutical industries. It is estimated that worldwide over the year, around 7×10^5 tons of synthetic dyes are produced, 10% of which are discharged in the effluent during dyeing operations while 1–2% are known to lose in the effluent during manufacturing operations (Garg et al. 2004). As dyes are toxic and carcinogenic, so such dye-contaminated effluent when discharged into the natural receptor water could make water toxic to aquatic life. In addition, it has been reported that exposure to dye effluent may cause problems such as skin irritation, sore eyes, increased heart rate, jaundice carcinogenicity, chromosomal fractures and respiratory toxicity in humans (Papic et al. 2000; Ahmad and Alrozi 2011). Therefore, it is environmentally imperative to decrease the concentration of dyes in the wastewater before discharging it into the water bodies. Adsorption of dyes onto the date palm has been reported in the literature as a predominately accepted method for removal of different types of dyes including methylene blue, malachite green, crystal violet, eosin, acid black, etc. (Banat et al. 2003b, Belhachemi et al. 2009; Mahmoodi et al. 2010; Alshabanat et al. 2013; Alshabanat et al. 2016; Alzahrani and El-Mouhty 2016).

Table 8.2 summarizes a non-exhaustive list of studies related to the use of date palm and its by-products as well as activated carbon derived date palm for different dye removal. In particular, a study by Belala et al. (2011b) explored the biosorption of methylene blue from aqueous solution by date stones and palm trees waste. The maximum biosorption capacities obtained with date stones and palm trees waste for methylene blue were 43.5 and 39.5 mg/g, respectively. The authors also evaluate the experimental data through kinetic models. Results revealed the involvement of pseudo-second-order kinetics behind the adsorption of methylene blue on to palm trees waste and date stones.

Banat et al. (2003c) impregnated the raw date pits with 30% (wt.) KOH solution prior to carbonization (for 2 h at 600 ° C) and CO_2 activation (for 1 h at 800 ° C) in order to study the effect of chemically activated date pits towards removal of methylene blue. An increase in adsorption capacity from 80.3 mg/g to 123.1 mg/g was observed upon chemical activation. The results were found to be opposite to that obtained during physical activation by Banat et al. (2003b). They reported a decrease in adsorption capacity from 80.3 mg/g to 12.9 mg/g and to 17.3 mg/g during activation of date pits at 500 °C and 900 °C, respectively. This points out that the uptake of dye by the activated carbon is not merely controlled by the surface area but also by the pore-size distribution and the adsorbent's surface chemistry.

Table 8.2 Summary of the removal of various dyes by the date palm

Adsorbent used	Pollutants to be removed	Conditions employed	Adsorption capacity	References
Date fruit pits activated carbon	Methylene blue	Adsorbent dose—0.25 g Contact time—48 h Temperature—25 °C	590 mg/g	Abdulkarim et al. (2002)
Raw date pits	Methylene blue	pH—4 to 8 Adsorbent dose—6 mg/mL Contact time—24 h Temperature—25 to 50 °C	80.3 mg/g	Banat et al. (2003b)
Activated date pits (500 °C)	Methylene blue	pH—4 to 8 Adsorbent dose—6 mg/mL Contact time—24 h Temperature—25 to 5	12.9 mg/g	
Activated date pits (900 °C)	Methylene blue	pH—4 to 8 Adsorbent dose—6 mg/mL Contact time—24 h Temperature—25 to 5	17.3 mg/g	
Date stone activated carbon	Methylene blue	Contact time—20 h Temperature—room temperature	148 mg/g	Alhamed (2006)
Date pits activated carbon	Methylene blue	Adsorbent dose—0.2 g Contact time—36 h Temperature—25 °C	127.3 mg/g	El-Sharkawy et al. (2007)
Chemically modified date pits activated carbon	Methylene blue	Adsorbent dose—10 mg Temperature—25 °C	216.4 mg/g	Belhachemi et al. (2009)
Date stone	Acid green 25	pH—2 to 12 Adsorbent dose—1 to 3 g/L Contact time—30 min Temperature—25 to 65 °C	36.496 mg/g	Mahmoodi et al. (2010)
Date stone	Acid black 26	pH—2 to 12 Adsorbent dose—1 to 3 g/L Contact time—30 min Temperature—25 to 65 °C	39.526 mg/g	
Date stone	Acid blue 7	pH—2 to 12 Adsorbent dosage—1 to 3 g/L Contact time—30 min Temperature—25 to 65 °C	33.784 mg/g	
Raw date pits	Methylene blue	pH—4 to 10 Contact time—72 h Temperature—20 °C	277.8 mg/g	Al-Ghouti et al. (2010)

(continued)

Table 8.2 (continued)

Adsorbent used	Pollutants to be removed	Conditions employed	Adsorption capacity	References
Date palm fibre	Crystal violet	pH—2 to 11 Temperature—25 to 55 °C °C	0.66×10^{-6} Mol/g	Alshabanat et al. (2013)
Date palm fibres	Malachite green	pH—4 to 10 Temperature—25 to 45 °C	0.2136 Mol/g	Alshabanat et al. (2016)
Date palm trunk-derived activated carbon	Eosin dye	pH—1 to 11 Adsorbent dose—0.2 to 1 g Contact time—5 to 50 min Temperature—25 °C	126.58 mg/g	Alzahrani and El-Mouhty (2016)
Date palm fibres	Methylene blue	pH—2 to 10 Adsorbent dose—50 to 250 mg Contact time—20 min Temperature—25 ± 0.5 °C	4.554 mg/g	Shagufta et al. (2018)

8.3.2 Hazardous Materials Removal

Phenol is regarded as one of the noxious pollutants found in the wastewater of ceramic, steel, petrochemical, oil, pharmaceutical, chemical and fertilizer industries (Aksu and Yener 2001). The presence of phenol in water bodies even at low concentration can cause chronic toxic effects. So, to remove phenol from the aqueous solution, adsorption onto the low-cost adsorbent such as date palm is widely employed. Banat et al. (2004) while investigating the adsorption of phenol onto raw and activated date pits concluded that activated date pits had 16 times higher adsorptive capacity compared to raw date pits. Thermodynamic parameters studied showed that the dye removal through adsorption was endothermic. Furthermore, an increase in phenol uptake by activated carbon was observed with an increase in initial phenol concentration from 10 to 200 ppm and temperature from 25 °C to 55 °C. While with an increase in solution pH (from 4 to 12), a decrease in phenol adsorption was noted. However, in a study by Mane et al. (2005), a decrease in the amount of phenol adsorption from 33.12 mg/g to 24.10 mg/g was observed with an increase in temperature from 30 to 60 °C. This indicated the exothermic nature of the reaction.

The research conducted by Abdulkarim et al. (2002) evaluated the phenol adsorption onto the date fruit pit prepared activated carbon. The results showed the high adsorption capacity of activated carbon for phenol, 2-nitrophenol and 2,4- and 2,4,6-trinitrophenol. Moreover, the experimental data for adsorption of phenols were found to fit both the Freundlich and Langmuir isotherms. Alhamed (2009) investigated the adsorption kinetics and performance of packed bed adsorbent for phenol removal using dates stones prepared activated carbon. Four different particle

A comparative study of the removal of methylene blue by adsorption and photocatalytic degradation was reported by El-Sharkawy et al. (2007). Two types of activated carbon – steam-activated carbons and $ZnCl_2$-activated carbons – were prepared from date pits. Among these two, the steam activated carbon was considered more efficient in the methylene blue dye decolourization. The higher surface area, the total pore volume and the basic nature of the surface are responsible for the better decolourization ability of steam activated carbon. Further, when the removal of methylene blue via adsorption and photocatalytic degradation was compared, it can be seen that with photocatalytic degradation, the complete removal of the dye occurs within 10–22 h. On the other hand, the methylene blue adsorbed on the activated carbon might not easily be recovered which therefore contribute to environmental pollution.

As apparent from the literature review, the date palm and its derived activated carbon is highly efficient in removal of methylene blue dye, but its adsorption capacity is not only limited to methylene blue (Table 8.2). The aqueous solutions contaminated with other dyes, for instance, crystal violet, malachite green, eosin and many more, could also be treated through the application of date palm. For example, in a study by Sulyman et al. (2016), adsorptive removal of crystal violet by date palm dead leaflets derived activated carbon was investigated. The equilibrium adsorption of crystal violet was determined under different initial dye concentration, pH contact time and adsorbent dose. The maximum adsorption capacity of date palm dead leaflets derived activated carbon was about 36.63 mg/g. In addition, it was found that dye removal increased with the increase in pH, adsorbent dose and contact time. Also, the isotherm equilibrium was well fitted by the Langmuir and Freundlich models.

8.3.4 Role in Phytoextraction

The content of heavy metals including chromium, copper, cadmium, arsenic, lead, zinc and nickel has increased continuously in the soil as a result of industrial activities. The presence of heavy metals in high concentrations not only inhibits the plant metabolic functions including physiological and biochemical processes, water absorption, photosynthesis, respiration, mitosis and plant's cell organelles degeneration but also affects the size, composition and activity of soil microbes (Yao et al. 2003; Bhattacharyya et al. 2008).

The remediation of heavy metals from the contaminated soil through the phytoextraction method is now receiving research attention. Phytoextraction is one of the subprocesses of phytoremediation which encompasses the use of plants for the extraction of heavy metals from the contaminated soil. Date palms, however, are known to play an indispensable role in phytoextraction process. A huge number of studies have focused on the intercropping of various plant species with date palm for the removal of heavy metals (Hamid 2011; Mohebbi et al. 2012).

Hamid (2011) conducted an experiment to study the possibilities of remediation of heavy metals from the contaminated soil by alfalfa, maize and sunflower grown with and without date palm. He found that monoculture of sunflower had a significantly higher ability of cadmium uptake than alfalfa and corn. The copper and manganese uptake index was found to be higher in the monoculture of corn. Thus it can be seen that intercropping with date palm did not show a significant effect on the accumulation and removal of heavy metals. However, in another study by Mohebbi et al. (2012) on phytoextraction of heavy metals by corn, alfalfa and sunflower grown in monoculture and intercropping with date palm, it can be seen that date palm-intercropped sunflower has high biological concentration factor (BCF) values for Mn and Cu among other crops. The high value of BCF indicated retention of metals in roots thereby results in limiting the mobility of metals from roots to shoots.

Mohebbi (2012) in his study showed that Cu concentration in roots and shoots of corn, alfalfa and sunflower grown with and without date palm was more than 21 and 14 mg/kg, respectively. He concluded that among these three crops, the crop alfalfa exhibited the highest translocation factor when co-planted with date palm. On the contrary, higher translocation factor was recorded in monocropped sunflower compared to date palm co-planted sunflower.

8.4 Conclusion and Future Perspectives

Date palm which is known for its nutritional value has been proven to have considerable potential to remove the harmful substances from the wastewaters. As reported in the literature, the low-cost date palm has considered being a successful replacement for expensive activated carbon. This review is an attempt to cover the different areas where the date palm has been successfully used. Time and again, raw date palm and its by-products were tested as an adsorbent for effectual removal of various pollutants. However, different experimental conditions, such as solution pH, initial dye concentration, adsorbent dosage, contact time and temperature of the system, need to be taken into account during evaluation of the adsorptive capacity of date palm. Since, most of the studies revealed the pollutant removal from aqueous solution, hence, further study is needed to evaluate the pollutant removal from real wastewater. In addition, the actual mechanism behind the interaction between the adsorbent and the pollutant still requires detailed research.

References

Abdulkarim M, Al-Rub FA (2004) Adsorption of lead ions from aqueous solution onto activated carbon and chemically-modified activated carbon prepared from date pits. Adsorp Sci Technol 22(2):119–134. https://doi.org/10.1260/026361704323150908

Abdulkarim MA, Darwish NA, Magdy YM, Dwaidar A (2002) Adsorption of phenolic compounds and methylene blue onto activated carbon prepared from date fruit pits. Eng Life Sci 2(6):161–165. https://doi.org/10.1002/1618-2863(200206)2:6<161::AID-ELSC161>3.0.CO;2-2

Ahmad MA, Alrozi R (2011) Removal of malachite green dye from aqueous solution using rambutan peel-based activated carbon: equilibrium, kinetic and thermodynamic studies. Chem Eng J 171(2):510–516. https://doi.org/10.1016/j.cej.2011.04.018

Ahmad T, Danish M, Rafatullah M, Ghazali A, Sulaiman O, Hashim R, Ibrahim MNM (2012) The use of date palm as a potential adsorbent for wastewater treatment: a review. Environ Sci Pollut Res 19(5):1464–1484. https://doi.org/10.1007/s11356-011-0709-8

Akpor OB, Muchie M (2011) Environmental and public health implications of wastewater quality. Afr J Biotechnol 10(13):2379–2387. https://doi.org/10.5897/AJB10.1797

Aksu Z, Yener J (2001) A comparative adsorption/biosorption study of mono-chlorinated phenols onto various sorbents. Waste Manag 21(8):695–702. https://doi.org/10.1016/S0956-053X(01)00006-X

Albadarin AB, Charara M, Abu Tarboush BJ et al (2017) Mechanism analysis of tartrazine biosorption onto masau stones; a low cost by-product from semi-arid regions. J Mol Liq. https://doi.org/10.1016/j.molliq.2017.07.045

Aldawsari A, Khan MA, Hameed BH, Alqadami AA, Siddiqui MR, Alothman ZA, Ahmed AYBH (2017) Mercerized mesoporous date pit activated carbon-A novel adsorbent to sequester potentially toxic divalent heavy metals from water. PLoS One 12(9):1–17. https://doi.org/10.1371/journal.pone.0184493

Al-Ghamdi A, Altaher H, Omar W (2013) Application of date palm trunk fibers as adsorbents for removal of Cd^{+2} ions from aqueous solutions. J Water Reuse Desalin 3(1):47–54. https://doi.org/10.2166/wrd.2013.031

Al-Ghouti MA, Li J, Salamh Y, Al-Laqtah N, Walker G, Ahmad MN (2010) Adsorption mechanisms of removing heavy metals and dyes from aqueous solution using date pits solid adsorbent. J Hazard Mater 176(1–3):510–520. https://doi.org/10.1016/j.jhazmat.2009.11.059

Al-Haidary AMA, Zanganah FH, Al-Azawi SR, Khalili FI, Al-Dujaili AH (2011) A study on using date palm fibers and leaf base of palm as adsorbents for Pb (II) ions from its aqueous solution. Water Air Soil Pollut 214(1–4):73–82. https://doi.org/10.1007/s11270-010-0405-1

Alhamed YA (2006) Activated carbon from dates' stone by $ZnCl_2$ activation. JKAU Eng Sci 17(2):5–100. https://doi.org/10.4197/eng.17-2.4

Alhamed YA (2009) Adsorption kinetics and performance of packed bed adsorber for phenol removal using activated carbon from dates' stones. J Hazard Mater 170(2–3):763–770. https://doi.org/10.1016/j.jhazmat.2009.05.002

Al-Jlil SA (2010) Removal of heavy metals from industrial wastewater by adsorption using local bentonite clay and roasted date pits in Saudi Arabia. Trends Appl Sci Res 5(2):138–145. https://doi.org/10.3923/tasr.2010.138.145

Al-Othman ZA, Ali R, Naushad M (2012) Hexavalent chromium removal from aqueous medium by activated carbon prepared from peanut shell: adsorption kinetics, equilibrium and thermodynamic studies. Chem Eng J 184:238–247. https://doi.org/10.1016/j.cej.2012.01.048

Alqadami AA, Naushad M, Abdalla MA et al (2017) Efficient removal of toxic metal ions from wastewater using a recyclable nanocomposite: a study of adsorption parameters and interaction mechanism. J Clean Prod. https://doi.org/10.1016/j.jclepro.2017.04.085

Alshabanat M, Alsenani G, Almufarij R (2013) Removal of crystal violet dye from aqueous solutions onto date palm fiber by adsorption technique. J Chem 2013:1–6. https://doi.org/10.1155/2013/210239

Alshabanat M, Al-Mufarij RS, Al-Senani GM (2016) Study on adsorption of malachite green by date palm fiber. Orient J Chem 32(6):3139–3144. https://doi.org/10.13005/ojc/320636

Alzahrani E, El-Mouhty NRA (2016) Preparation of activated carbon from date palm trunks for removal of eosin dye. J Adv Chem 12(9):2540–2550. https://doi.org/10.24297/jac.v10i4.892

Amin MT, Alazba AA, Amin MN (2017) Absorption behaviours of copper, lead, and arsenic in aqueous solution using date palm fibres and orange peel: kinetics and thermodynamics. Pol J Environ Stud 26(2):543–557. https://doi.org/10.15244/pjoes/66963

Banat F, Al-Asheh S, Al-Rousan D (2002) A comparative study of copper and zinc ion adsorption on to activated and non-activated date-pits. Adsorp Sci Technol 20(4):319–335. https://doi.org/10.1260/02636170260295515

Banat F, Al-Asheh S, Al-Makhadmeh L (2003a) Kinetics and equilibrium study of cadmium ion sorption onto date pits- an agricultural waste. Adsorp Sci Technol 21(3):245–260. https://doi.org/10.1260/026361703322404395

Banat F, Al-Asheh S, Al-Makhadmeh L (2003b) Evaluation of the use of raw and activated date pits as potential adsorbents for dye containing waters. Process Biochem 39(2):193–202. https://doi.org/10.1016/S0032-9592(03)00065-7

Banat F, Al-Asheh S, Makhadmeh L (2003c) Preparation and examination of activated carbons from date pits impregnated with potassium hydroxide for the removal of methylene blue from aqueous solutions. Adsorp Sci Technol 21(6):597–606. https://doi.org/10.1260/026361703771953613

Banat F, Al-Asheh S, Al-Makhadmeh L (2004) Utilization of raw and activated date pits for the removal of phenol from aqueous solutions. Chem Eng Technol 27(1):80–86. https://doi.org/10.1002/ceat.200401868

Belala Z, Jeguirim M, Belhachemi M, Addoun F, Trouve G (2011a) Biosorption of copper from aqueous solutions by date stones and palm-trees waste. Environ Chem Lett 9(1):65–69. https://doi.org/10.1007/s10311-009-0247-5

Belala Z, Jeguirim M, Belhachemi M, Addoun F, Trouve G (2011b) Biosorption of basic dye from aqueous solutions by date stones and palm-trees waste: kinetic, equilibrium and thermodynamic studies. Desalination 271(1–3):80–87. https://doi.org/10.1016/j.desal.2010.12.009

Belhachemi M, Belala Z, Lahcene D, Addoun F (2009) Adsorption of phenol and dye from aqueous solution using chemically modified date pits activated carbons. Desalin Water Treat 7(1–3):182–190. https://doi.org/10.5004/dwt.2009.729

Bhattacharyya KG, Gupta SS (2008) Adsorption of a few heavy metals on natural and modified kaolinite and montmorillonite: a review. Adv Colloid Interf Sci 140(2):114–131. https://doi.org/10.1016/j.cis.2007.12.008

Bhattacharyya P, Chakrabarti K, Chakraborty A, Tripathy S, Powell MA (2008) Fractionation and bioavailability of Pb in municipal solid waste compost and Pb uptake by rice straw and grain under submerged condition in amended soil. Geosci J 12(1):41–45. https://doi.org/10.1007/s12303-008-0006-9

Bratskaya SY, Pestov AV, Yatluk YG, Avramenko VA (2009) Heavy metals removal by flocculation/precipitation using N-(2-carboxyethyl) chitosans. Colloid Surf 339(1–3):140–144. https://doi.org/10.1016/j.colsurfa.2009.02.013

Chang Q, Zhang M, Wang J (2009) Removal of Cu^{2+} and turbidity from wastewater by mercapto acetyl chitosan. J Hazard Mater 169(1–3):621–625. https://doi.org/10.1016/j.jhazmat.2009.03.144

Chaouch N, Ouahrani MR, Chaouch S, Gherraf N (2013) Adsorption of cadmium (II) from aqueous solutions by activated carbon produced from Algerian dates stones of *Phoenix dactylifera* by H_3PO_4 activation. Desalin Water Treat 51(10–12):2087–2092. https://doi.org/10.1080/19443994.2013.734558

Chaouch N, Ouahrani MR, Laouini SE (2014) Adsorption of Lead (II) from aqueous solutions onto activated carbon prepared from Algerian dates stones of *Phoenix dactylifera*. L (Ghars variety) by H_3PO_4 activation. Orient J Chem 30(3):1317–1322. https://doi.org/10.13005/ojc/300349

Dialynas E, Diamadopoulos E (2009) Integration of a membrane bioreactor coupled with reverse osmosis for advanced treatment of municipal wastewater. Desalination 238(1–3):302–311. https://doi.org/10.1016/j.desal.2008.01.046

El Nemr A, Khaled A, Abdelwahab O, El-Sikaily A (2008) Treatment of wastewater containing toxic chromium using new activated carbon developed from date palm seed. J Hazard Mater 152(1):263–275. https://doi.org/10.1016/j.jhazmat.2007.06.091

El Samrani AG, Lartiges BS, Villieras F (2008) Chemical coagulation of combined sewer overflow: heavy metal removal and treatment optimization. Water Res 42(4–5):951–960. https://doi.org/10.1016/j.watres.2007.09.009

El-Sharkawy EA, Soliman AY, Al-Amer KM (2007) Comparative study for the removal of methylene blue via adsorption and photocatalytic degradation. J Colloid Interface Sci 310(2):498–508. https://doi.org/10.1016/j.jcis.2007.02.013

Eynard F, Mez K, Walther JL (2000) Risk of cyanobacterial toxins in Riga waters (Latvia). Water Res 34(11):2979–2988. https://doi.org/10.1016/S0043-1354(00)00042-7
Fu F, Wang Q (2011) Removal of heavy metal ions from wastewaters: a review. J Environ Manag 92(3):407–418. https://doi.org/10.1016/j.jenvman.2010.11.011
Garg VK, Kumar R, Gupta R (2004) Removal of malachite green dye from aqueous solution by adsorption using agro-industry waste: a case study of *Prosopis cineraria*. Dyes Pigments 62(1):1–10. https://doi.org/10.1016/j.dyepig.2003.10.016
Ghasemi M, Naushad M, Ghasemi N, Khosravi-fard Y (2014) A novel agricultural waste based adsorbent for the removal of Pb(II) from aqueous solution: kinetics, equilibrium and thermodynamic studies. J Ind Eng Chem 20:454–461. https://doi.org/10.1016/j.jiec.2013.05.00
Haleem AM, Abdulgafoor EA (2010) The biosorption of Cr (VI) from aqueous solution using date palm fibers (leef). Al-Khwarizmi Eng J 6(4):31–36
Hall DW, Sandrin JA, McBride RE (1990) An overview of solvent extraction treatment technologies. Environ Prog 9(2):98–105. https://doi.org/10.1002/ep.670090217
Hamid MA (2011) Growth and heavy metals uptake by date palm grown in mono-and dual culture in heavy metals contaminated soil. World Appl Sci J 15(3):429–435
Hilal NM, Ahmed IA, El-Sayed RE (2012) Activated and nonactivated date pits adsorbents for the removal of copper (II) and cadmium (II) from aqueous solutions. ISRN Phys Chem 2012:1–11. https://doi.org/10.5402/2012/985853
Jamil F, Al-Muhtaseb AH, Naushad M et al (2016) Evaluation of synthesized green carbon catalyst from waste date pits for tertiary butylation of phenol. Arab J Chem. https://doi.org/10.1016/j.arabjc.2017.04.009
Jibril B, Houache O, Al-Maamari R, Al-Rashidi B (2008) Effects of H_3PO_4 and KOH in carbonization of lignocellulosic material. J Anal Appl Pyrolysis 83(2):151–156. https://doi.org/10.1016/j.jaap.2008.07.003
Ku Y, Jung IL (2001) Photocatalytic reduction of Cr (VI) in aqueous solutions by UV irradiation with the presence of titanium dioxide. Water Res 35(1):135–142. https://doi.org/10.1016/S0043-1354(00)00098-1
Landaburu-Aguirre J, Pongracz E, Perämaki P, Keiski RL (2010) Micellar-enhanced ultrafiltration for the removal of cadmium and zinc: use of response surface methodology to improve understanding of process performance and optimisation. J Hazard Mater 180(1–3):524–534. https://doi.org/10.1016/j.jhazmat.2010.04.066
Macedo JS, Otubo L, Ferreira OP, de Fátima Gimenez I, Mazali IO, Barreto LS (2008) Biomorphic activated porous carbons with complex microstructures from lignocellulosic residues. Microporous Mesoporous Mater 107(3):276–285. https://doi.org/10.1016/j.indcrop.2010.05.016
Mahdi Z, El Hanandeh A, Yu Q (2017) Date seed derived biochar for Ni (II) removal from aqueous solutions. In: MATEC web of conferences EDP sciences, p 05005
Mahdi Z, Qiming JY, El Hanandeh A (2018) Removal of lead (II) from aqueous solution using date seed-derived biochar: batch and column studies. Appl Water Sci 8(6):181. https://doi.org/10.1007/s13201-018-0829-0
Mahmood S, Maqbool A (2006) Impacts of wastewater irrigation on water quality and on the health of local Community in Faisalabad. Pak J Water Resour 10:19–22
Mahmoodi NM, Hayati B, Arami M (2010) Textile dye removal from single and ternary systems using date stones: kinetic, isotherm, and thermodynamic studies. J Chem Eng Data 55(11):4638–4649. https://doi.org/10.1021/je1002384
Mane SM, Vanjara AK, Sawant MR (2005) Removal of phenol from wastewater using date seed carbon. J Chin Chem Soc 52(6):1117–1122. https://doi.org/10.1002/jccs.200500160
Mittal A, Naushad M, Sharma G et al (2016) Fabrication of MWCNTs/ThO2 nanocomposite and its adsorption behavior for the removal of Pb(II) metal from aqueous medium. Desalin Water Treat 57:21863–21869. https://doi.org/10.1080/19443994.2015.1125805
Mohebbi A (2012) Capability of heavy metals absorption by corn, alfalfa and sunflower intercropping date palm. Adv Environ Biol 6(11):2886–2893

Mohebbi AH, Harutyunyan SS, Chorom M (2012) Phytoremediation potential of three plant grown in monoculture and intercropping with date palm in contaminated soil. Intl J Agric Crop Sci 4(20):1523–1530

Mohsen-Nia M, Montazeri P, Modarress H (2007) Removal of Cu^{2+} and Ni^{2+} from wastewater with a chelating agent and reverse osmosis processes. Desalination 217(1–3):276–281. https://doi.org/10.1016/j.desal.2006.01.043

Mouni L, Merabet D, Bouzaza A, Belkhiri L (2010) Removal of Pb^{2+} and Zn^{2+} from the aqueous solutions by activated carbon prepared from dates stone. Desalin Water Treat 16(1–3):66–73. https://doi.org/10.5004/dwt.2010.1106

Murthy ZVP, Chaudhari LB (2008) Application of nanofiltration for the rejection of nickel ions from aqueous solutions and estimation of membrane transport parameters. J Hazard Mater 160(1):70–77. https://doi.org/10.1016/j.jhazmat.2008.02.085

Nataraj SK, Hosamani KM, Aminabhavi TM (2007) Potential application of an electrodialysis pilot plant containing ion-exchange membranes in chromium removal. Desalination 217(1–3):181–190. https://doi.org/10.1016/j.desal.2007.02.012

Naushad M, ALOthman ZA (2015) Separation of toxic Pb^{2+} metal from aqueous solution using strongly acidic cation-exchange resin: analytical applications for the removal of metal ions from pharmaceutical formulation. Desalin Water Treat 53(8):2158–2166. https://doi.org/10.1080/19443994.2013.862744

Naushad M, Ahamad T, Sharma G et al (2016a) Synthesis and characterization of a new starch/SnO2 nanocomposite for efficient adsorption of toxic Hg2+ metal ion. Chem Eng J 300:306–316. https://doi.org/10.1016/j.cej.2016.04.084

Naushad M, Khan MR, ALOthman ZA, AAH A-M, Awual MR, Alqadami AA (2016b) Water purification using cost effective material prepared from agricultural waste: kinetics, isotherms, and thermodynamic studies. CLEAN–Soil Air Water 44(8):1036–1045. https://doi.org/10.1002/clen.201600027

Naushad M, Ahamad T, Al-Maswari BM et al (2017) Nickel ferrite bearing nitrogen-doped mesoporous carbon as efficient adsorbent for the removal of highly toxic metal ion from aqueous medium. Chem Eng J. https://doi.org/10.1016/j.cej.2017.08.079

Nwakonobi TU, Onoja SB, Ogbaje H (2018) Removal of certain heavy metals from brewery wastewater using date palm seeds activated carbon. Appl Eng Agric 34(1):233–238. https://doi.org/10.13031/aea.11875

Ostroski IC, Barros MA, Silva EA, Dantas JH, Arroyo PA, Lima OC (2009) A comparative study for the ion exchange of Fe (III) and Zn (II) on zeolite NaY. J Hazard Mater 161(2–3):1404–1412. https://doi.org/10.1016/j.jhazmat.2008.04.111

Papic S, Koprivanac N, Metes A (2000) Optimizing polymer-induced flocculation process to remove reactive dyes from wastewater. Environ Technol 21(1):97–105. https://doi.org/10.1080/09593332108618143

Sagasta MJ, Sally LR, Thebo A (2015) Global wastewater and sludge production, treatment and use. In: Drechsel P, Qadir M, Wichelns D (eds) Wastewater: economic asset in an urbanizing world. Springer, New York, pp 15–24

Shafiq M, Alazba AA, Amin MT (2018) Removal of heavy metals from wastewater using date palm as a biosorbent: a comparative review. Sains Malays 47(1):35–49. https://doi.org/10.17576/jsm-2018-4701-05

Shagufta, Dhar R, Kim BS, Alblooshi A, Ahmad I (2018) Removal of synthetic cationic dye from aqueous solution using date palm leaf fibers as an adsorbent. Intern J Eng Technol 7(4):3770–3776. https://doi.org/10.14419/ijet.v7i4.14332

Sulyman M, Namiesnik J, Gierak A (2016) Adsorptive removal of aqueous phase crystal violet dye by low-cost activated carbon obtained from date palm (L.) dead leaflets. Inżynieria i Ochrona Środowiska 19(4):611–631. https://doi.org/10.17512/ios.2016.4.14

Suzuki Y, Maezawa A, Uchida S (2000) Utilization of ultrasonic energy in a photocatalytic oxidation process for treating waste water containing surfactants. Jpn J Appl Phys 39(5S):2958–2961. https://doi.org/10.1143/JJAP.39.2958

Tang ZX, Shi LE, Aleid SM (2013) Date fruit: chemical composition, nutritional and medicinal values, products. J Sci Food Agric 93(10):2351–2361. https://doi.org/10.1002/jsfa.6154

Terry PA (2010) Application of ozone and oxidation to reduce chemical oxygen demand and hydrogen sulfide from a recovered paper processing plant. Int J Chem Eng 2010:1–6. https://doi.org/10.1155/2010/250235

Welch EB (1992) Ecological effects of wastewater: applied limnology and pollutant effects, 2nd edn. Chapman and Hall, New York

Yao H, Xu J, Huang C (2003) Substrate utilization pattern, biomass and activity of microbial communities in a sequence of heavy metal-polluted paddy soils. Geoderma 115(1–2):139–148. https://doi.org/10.1016/S0016-7061(03)00083-1