

Research Article

Activation of Jordanian Bentonite by Hydrochloric Acid and Its Potential for Olive Mill Wastewater Enhanced Treatment

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Received 7 December 2017; Revised 19 January 2018; Accepted 4 February 2018; Published 12 March 2018

Academic Editor: Wenshan Guo

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Jordanian bentonite was activated by hydrochloric acid at room temperature. FTIR, XRD, TGA, and BET surface area analyses of the samples were carried out to examine the structure of bentonite before and after acid activation. It is found that the octahedral cations were removed, which altered the chemical composition of the bentonite. Difference of surface area was noticed (66.2 to $287.8\text{ m}^2\text{ g}^{-1}$), which was caused by structural changes in the bentonite. We aimed to investigate the effectiveness of activated bentonite in OMWW treatment. Batch and column techniques were applied. Crude and treated OMWW samples were characterized; physicochemical parameters, total phenolic compounds, and heavy metal ions concentrations were measured. Several parameters that affected the adsorption capacity were studied: the pH value of the solution, temperature, and the adsorbent dose. It was found that the maximum removal of total phenolic compounds and heavy metal ions (Zn, Fe, and Mn) was at pH 6. Adsorption capacity of phenolic compounds was enhanced with an increase in the temperature of the solution and also with the adsorbent dose. The optimum adsorbent concentration needed for the maximum removal of total phenolic compounds is 1 g of activated bentonite/0.01 L of OMWW. The percentage removal exceeded 99% for Zn, Fe, and Mn ions, while it reached 65.2 and 61.5 for K^+ and Na^+ ions, respectively. Finally, the percentage removal of pollutants was increased by using activated bentonite. This study will provide valuable insight into the effect of activated bentonite towards the treatment and recyclability of OMWW, which is essential for the local olive mill industry.

1. Introduction

The production of olive oil has been a well-known and established practice in the Mediterranean region for hundreds of years. The production of olive oil generates three products: olive oil (20%), wet solid waste (30%) called “crude olive cake,” and an aqueous waste called “olive mill wastewater, OMWW” (50%) [1]. These wastes cause an important environmental problem, when they are generated in large quantities over short periods of time. OMWW has a high amount of hazardous pollutants which are highly toxic/phytotoxicity-associated compounds, and they resist biological degradation [2]. OMWW contains an appreciable content of phenolic compounds, consisting of monocyclic aromatic molecules, such as tyrosol, catechol, and caffeic acid [3]. Moreover, it also contains a considerable content of inorganic compounds, such as heavy metals, phosphorus, potassium, and nitrogen [4]. Its uncontrolled disposal into water sources leads to severe problems for the whole ecosystem and especially

for natural water life. If it is disposed directly onto soil, it damages the properties of the soil, and it can be toxic for microorganisms, algae, plants, and insects [5]. For example, a high content of phosphorus content accelerates the growth of algae resulting in eutrophication [6]. Furthermore, a high concentration of potassium affects the cation exchange capacity of the soil, leading to a change of environmental conditions for soil microorganisms and this situation results in changes in the fertility of the soil [7]. In addition, increasing the concentration of nitrogen generally has a negative effect on microbial biomass in soil, such as direct inhibition, resulting in soil imbalance. It also affects some plants and often they die [8].

Different approaches have been developed to minimize the risks resulting from the use of OMWW including chemical oxidation [9]: adsorption on active carbon [10], ion exchange [11], membrane technologies and reverse osmosis [12], chemical reduction [13], and electrochemical methods [14]. However, most current technologies are often found to

be expensive and time consuming, as well as sometimes being ineffective. Adsorption, on the other hand, has a great potential in the area of wastewater treatment, due to its low maintenance costs, high efficiency, and ease of operation [15]. Some researchers used synthesized and commercial adsorbents for the removal of phenolic compounds from OMWW; amine-modified mesoporous silica and activated carbon adsorbents were used for actual OMWW [16]. Macroreticular aromatic polymer (FPX66) and the macroporous polystyrene cross-linked with divinylbenzene (MN202) were used to adsorb phenol and hydroxytyrosol and other phenolic compounds [17]. In addition, green process based on resins adsorption/ion exchange (strong-base anionic Amberlyst A26®, weak-base anionic Dowex 66®, and nonionic macroreticular Amberlite XAD4®) was also studied [18]. Moreover, batch and continuous flow adsorption of phenolic compounds from OMWW were applied using nonionic and ion exchange resins [19].

Currently, in many Mediterranean countries, especially Jordan, olive mills are usually small-scale factories, owned by low educated farmers, who cannot afford the cost of suitable wastewater treatment, unless they are provided with a low level of operating technology. Furthermore, an environmentally safe, cost-effective solution to OMWW treatment has yet to be found. Hence, this article provides a simple procedure as well as a regenerated process that can take place at the location where the water is being produced, hence no transportation costs. In addition, there is less sludge generation.

Jordanian bentonite has important physical and chemical properties, making this bentonite of special interest for industrialists, environmentalists, and engineers. It is a green nontoxic and low-cost adsorbent with local availability. In addition, it has the capability to undergo modification, in order to enhance its adsorptive properties, since the ideal adsorbent should consist of particles with a large surface area, high cation exchange capacity (CEC), chemical and mechanical stability, small diffusion resistance, and high reactivity and affinity for the pollutant [20]. One modification method is acid treatment. Acid activation of clay has been studied by many researchers [21, 22] and the process depends considerably on the nature and concentration of the acid and treatment time and temperature [23]. In general, the acid activation of clay minerals causes an increase in the specific surface area and number of active sites of the adsorbents [24].

The purposes of this present work are activation of Jordanian bentonite with hydrochloric acid and characterizing its physical and chemical properties. Special emphasis has been put on the OMWW, physicochemical characterization and treatment, and studying the ability of both raw and acid activated bentonite to remove phenolic compounds, Zn(II), Fe(II), and Mn(II) ions, from OMWW under various experimental conditions.

2. Materials and Methods

2.1. Purification of Bentonite. The natural Jordanian bentonite used in this study was collected from the airport region (Al Azraq). The sample was crushed to particle size $> 250 \mu\text{m}$ using a ball mill instrument (clay fractions were obtained by

wet sedimentation). The sample was purified in a laboratory, in order to remove quartz, carbonates, calcites, and iron hydroxide. It was dispersed in distilled water at 22°C and the clay fraction was recovered by centrifugation. This process was repeated four times for each sample, in order to guarantee obtaining samples in a pure form. The samples were dried in an oven at 60°C, then ground and sieved using a 63 μm mesh, and stored in tightly closed plastic bottles for use in the experiments.

2.2. Activation of Bentonite by Hydrochloric Acid. The hydrochloric acid (HCl) (98%, $d = 1.98 \text{ g/cm}^3$) and other chemicals used are of analytical grade.

The purified bentonite was prepared for acid activation: 15 g \pm 0.01 g of the purified sample was weighed into a flask and 200 mL of 1.0 M HCl was added. The resulting suspension was stirred at room temperature for 24 hrs. At the end of the mixing duration, the resulting slurry was poured into a Buchner funnel, in order to separate the acid and bentonite. The residual bentonite was washed with deionized water several times, until it was released from Cl^- ions against 5% AgNO_3 solution. After drying the sample at 100°C for two hours, it was calcined in the oven at 450°C for four hours and the activated sample was cooled in a desiccator, then regrinded to reach 63 μm particles size, and stored in tightly closed plastic bottles to be used in adsorption studies.

2.3. Collection, Preservation, and Pretreatment of OMWW Samples. OMWW was obtained from a centrifuge processing plant located at Jerash city. Samples were kept refrigerated at -2°C in tightly closed plastic containers and used when required. As a pretreatment, aliquots of 1 L of OMWW were centrifuged at 10,000 rpm for 30 minutes and double simple filtration was undertaken, in order to obtain a clear and dark (brownish) solution.

2.4. Characterization of the OMWW. Fresh OMWW was characterized before and after pretreatment. pH, electrical conductivity (EC), dissolved oxygen (DO), oxidation reduction potential (ORP), total dissolved solids (TDS), and salt were measured using a Crison PL-700AL meter. Chemical oxygen demand (COD), alkalinity, total nitrate, total phosphate, and total chlorine concentrations were determined using a COD and multiparameter bench meter, PN HI83099-02.

The total phenolic compounds were evaluated by spectrophotometry using the Folin-Ciocalteu method. Briefly, a 2.5 mL portion of Folin-Ciocalteu reagent 0.2 N was mixed with 0.5 mL of the sample. The reaction was kept in the dark for five minutes. Then, 2 mL of a sodium carbonate solution (75 g/L) was added to the mixture and the reaction was kept in the dark for one hour. The absorbance was measured at 765 nm in AAS. Contents of the total phenolic compounds in OMWW were expressed as gallic acid equivalents in grams per litre (g GAE/L residue) [25]. K^+ and Na^+ concentrations were determined using a flame photometer (Corning 400).

For the heavy metal ions determination tests, Zn, Fe, and Mn, a standard solution of each metal ion concentration was prepared in NaClO_4 at pH = 6. The pH of these solutions

was adjusted using 0.1 M HCl and 0.1 M NaOH, in order to achieve the desired values. Concentrations of the metal ions were determined using a Varian Spectra AA-250 pulse atomic adsorption spectrometer (AAS).

2.5. Adsorbent Characterization. The activated bentonite was characterized by FTIR spectroscopy (Thermo Nicolet NEXUS 670 Spectrophotometer), XRD (Philips X'Pert Pro), and TGA (NETZCH STA 409 PG/PC Thermal Analyzer). BET surface area analysis was determined using Gemini VII from micromeritics. The pH point of zero charge (PZC) of activated bentonite was carried out using a Zeta Meter 3.0 (Zeta Meter Inc.). Concentrations of total phenolic compounds were determined using a UV-VIS Spectrophotometer (Varian Cary 100).

2.6. Adsorption Methodology. The adsorption experiments were carried out by a batch technique. Effects of solution temperature and mass of acid activated bentonite on the percentage removal of total phenolic compounds were studied. Moreover, the activated bentonite was tested for the adsorption of heavy metal ions from OMWW using a column technique. Adsorption processes were carried out in a 560 mm long glass column with 12 mm inner diameter. The column was packed with $1.00 \text{ g} \pm 0.0001 \text{ g}$ of adsorbent. 100 mL of OMWW was passed through the column. The effluent was collected in 10 separate samples; each has a volume of 10 mL. Finally, all analytical experiments were applied at least in duplicate and the mean values are presented in Figures 4–9.

Concentration of metal retained in the adsorbent phase ($q, \text{mg g}^{-1}$) was calculated by the following equation:

$$q = \frac{(C_i - C_e)}{M} * V, \quad (1)$$

where q is the adsorbent phase concentration after equilibrium (mg/g), C_i and C_e are the initial and final equilibrium concentrations (mg/L) of metal ion in solution, V is the solution volume (L), and M is the adsorbent mass (g). Mass percent of the removal metal ion was calculated using the following equation:

$$\% \text{ Removal} = \frac{(C_i - C_e)}{C_i} * 100. \quad (2)$$

3. Results and Discussion

3.1. Characterization of Adsorbent

3.1.1. FTIR Spectrum Analysis. The FTIR analyses of the raw and activated bentonite were taken in the range of $400\text{--}4000 \text{ cm}^{-1}$. The FTIR spectra of both are shown in Figure 1. It can be seen that the FTIR spectra are very sensitive to the modification of bentonite structure upon acid treatment.

The spectrum of the raw bentonite exhibits absorption bands at 3450 and 1650 cm^{-1} assigned to the stretching and bending vibrations of the OH groups for the water molecule of hydration, which adsorbed on the bentonite surface, and

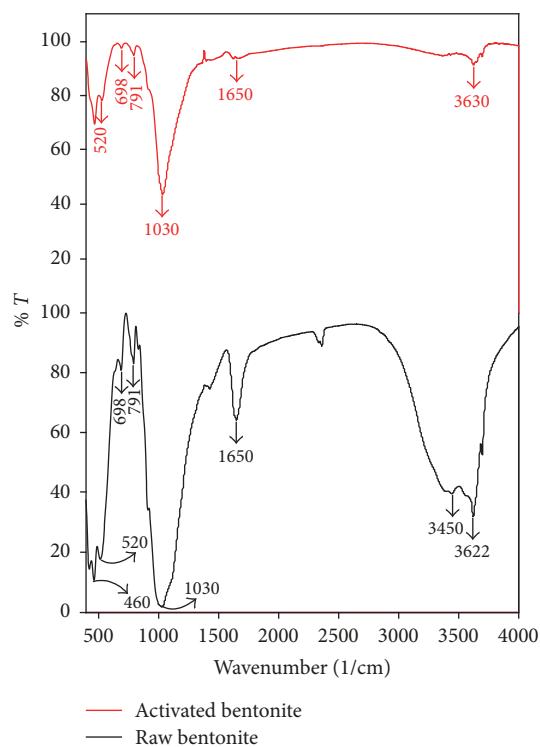


FIGURE 1: FTIR spectra of raw and acid activated Jordanian bentonite.

a band at 3620 cm^{-1} representing the stretching vibration of the hydroxyl groups coordinated to octahedral Al^{3+} cations. Very strong absorption band at 1030 cm^{-1} is recognized for stretching vibration Si-O bands, which is strong evidence for a silicate structure. The bands are at 520 for Si-O-Al (octahedral) and 460 cm^{-1} for Si-O-Si bending vibrations. The spectrum also contains a band at 791 and 698 cm^{-1} which is attributed to cristobalite and quartz, respectively [40, 41].

During the acid activation of bentonite, a decrease in the intensity of stretching and bending bands (a characteristic of octahedral sheet for Al-Al-OH) is observed at 1650 cm^{-1} , which reflects the leaching of octahedral cations, such as Al^{3+} and Mg^{2+} , from the bentonite structure, thus indicating the destruction of the octahedral layer. Moreover, a sharp decrease in the absorption band attributed to the OH vibration at 3630 cm^{-1} is due to the removal of the octahedral cations, thus causing the loss of water and hydroxyl groups coordinated to them [22]. This might indicate the presence of free OH sites on activated bentonite. The most significant change was a decrease in the intensity of the band at 1030 cm^{-1} , due to the formation of three-dimensional networks of amorphous silica, which may expose more adsorption sites. In addition, the distortion in the intensity of the band at 791 cm^{-1} indicates there is an amount of amorphous silica, as acid dissolution progresses to the deterioration of tetrahedral layer. This treatment leaves material rich in amorphous silica [42]. The bands at 520 , 698 , and 791 cm^{-1} associated with Si-O-Al vibration decreased after the acid treatment of the bentonite sample and this result

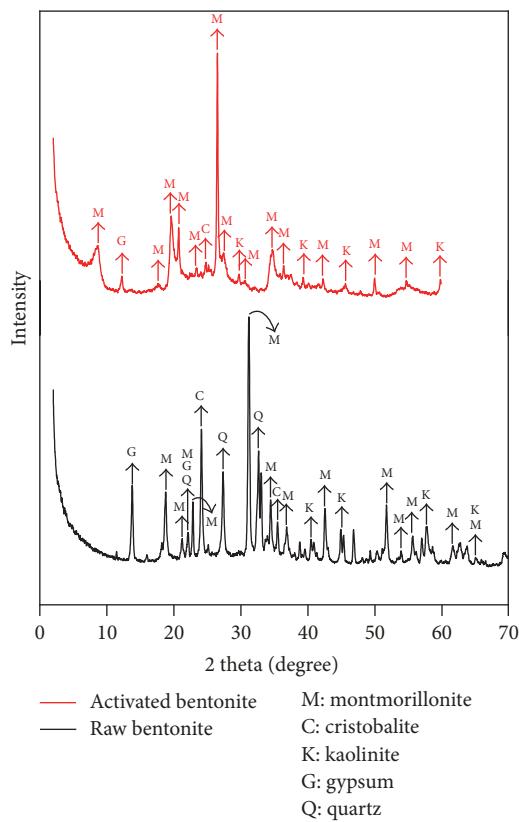


FIGURE 2: X-ray diffractograms of raw and acid activated Jordanian bentonite.

suggests the partial depletion of Al, Mg, and Fe from the clay structure, in accordance with the changes in chemical composition [43]. Furthermore, acid activation caused the disappearance of the stretching bands at 3450, 2360, and 1430 cm^{-1} assigned to the H-O-H stretching, which indicates that modification was affected in this position. During the acid activation process, the protons from the acid medium penetrated into the bentonite structure and attacked the OH groups, thereby causing alterations in the adsorption bands attributed to the OH vibration and octahedral cations, as mentioned earlier [44]. Finally, following the activation process, most band positions did not change, thus suggesting that the basic bentonite structure did not collapse.

3.1.2. X-Ray Diffractograms. XRD analysis of raw bentonite shows the presence of montmorillonite as the major component. Gypsum, cristobalite, and quartz are also present [45]. Activation of bentonite by hydrochloric acid clearly causes a decrease in peak intensity. This mostly occurs for the montmorillonite, which means a reduction in its content. Also, the quartz content, which is seen as an impurity, disappears after activation. The reduction in intensity and the increase in the width of peak at 24.1 \AA indicate that the crystallinity of the bentonite is considerably affected by acid activation and the bentonite crystalline structure is decomposing, which means that the activation process is accompanied by the appearance of an amorphous phase, as shown in Figure 2.

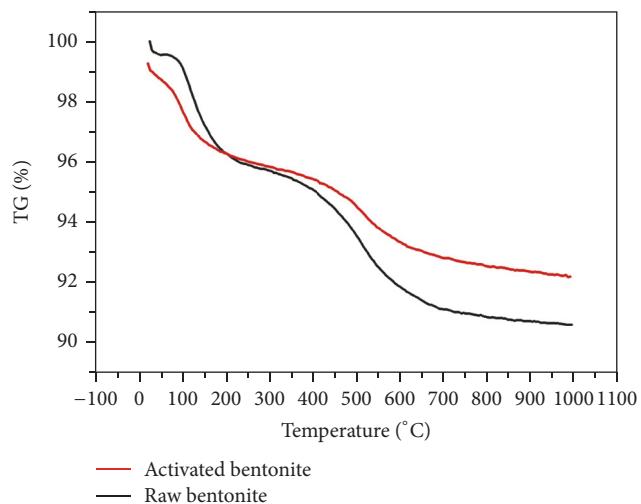


FIGURE 3: TGA curves of raw and acid activated Jordanian bentonite.

Similar results have already been described in the literature [44]. Moreover, X-ray results of activated bentonite show that there is a change in the position of a few peaks (e.g., 31.2 to 26.5 \AA), which is related to the change of distance between layers. This is an indication of dissolution of the tetrahedral and octahedral sheets and subsequent release of the structural cations; that is, these cations have been eliminated from the octahedral positions thereby leaving some vacancies. Notice that the rates of depletion of the octahedral cations follow the order $\text{Mg}^{2+} > \text{Fe}^{2+} > \text{Fe}^{3+} > \text{Al}^{3+}$. Amorphous SiO_2 appears on the edges and flats of flakes of bentonite are an indication of a grown delamination of the original particles [46].

Distinctly, XRD analysis provides good evidence that the adsorptive power of acid activated bentonite has increased.

3.1.3. Thermogravimetric Analysis (TGA). Temperature treatment of raw and activated bentonite was carried out in the region of 100 – 1000°C in air for 90 min. Figure 3 shows that the samples present double endothermic changes between 30 and 200°C , related to the presence of free and absorbed water and the dehydration process. The presence of double endothermic changes up to 200°C is related to the presence of coordinated water to Ca^{2+} and Mg^{2+} [47]. A significant weight loss is observed in the raw bentonite in the range between 325 and 720°C , with a maximum at 350°C , which can be attributed to the dehydroxylation of the clay minerals present in the clay, whereas, for the activated bentonite, the weight loss has taken place in a smaller range, from 410 to 645°C . This means a constant weight of bentonite is achieved and there is no more decomposition of clay minerals, even if a further increase in temperature is performed. This gives an indication that the activated bentonite shows more thermal stability than the raw bentonite, which enhances its properties towards using it in different applications. Furthermore, the TGA result is in clear agreement with the FTIR and XRD studies, which indicate consecutive changes of the bentonite sheet upon acid activation.

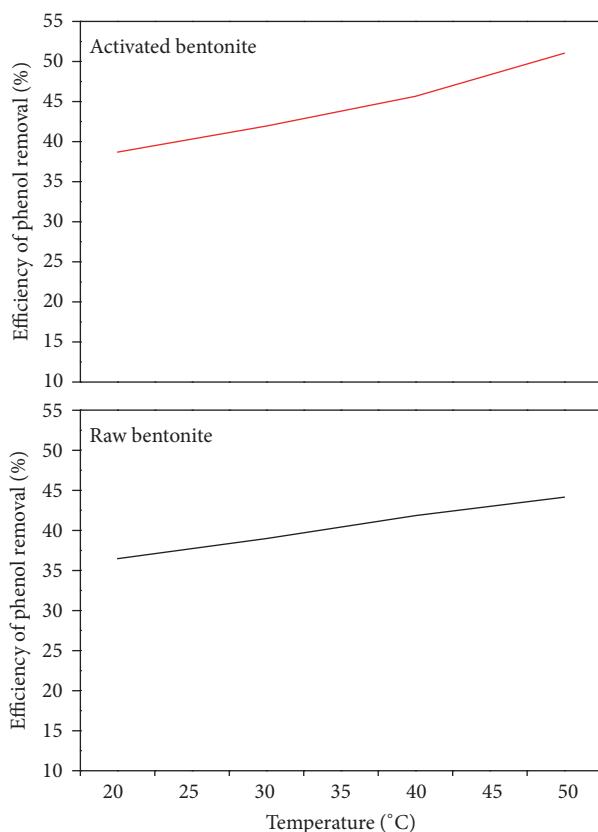


FIGURE 4: Comparison of percentage removals of total phenolic compounds by raw and activated bentonite. Operation conditions: 10 mL of OMWW, mass of activated bentonite = 1.0 g, and contact time = 3 hrs.

3.1.4. Determination of BET Surface Area. The surface area of bentonite shows a significant increase with activation by acid. Measured values are 66.2 and $287.8 \text{ m}^2 \text{ g}^{-1}$ for raw and activated bentonite, respectively. Since this increase is a result of removing impurities, replacement of exchangeable cations, such as K^+ , Na^+ , and Ca^{2+} , with H^+ ions, and leaching out Al^{3+} , Fe^{3+} , and Mg^{2+} from the octahedral and tetrahedral sheets, which expose the edges of the plates [48], now, the surface area becomes very high, and this shows the generation of microporosity during the activation, thus providing a relatively suitable surface for phenolic compounds and heavy metal ions adsorption. On the other hand, the presence of a metal oxides component in the clay mineral decreases the Bronsted surface acidity and thus affects the adsorption capacity and selectivity. Therefore, the bentonite clay was pretreated with acids to improve the surface acidity and acidic sites of the clay. It possesses strong Lewis acid sites, which makes it suitable for heavy metal ions adsorption and the removal of phenolic compounds.

3.1.5. Measurement of Point of Zero Charge (PZC). The pH of the solution has an important effect on the adsorption process, since the pH of the solution controls the magnitude of electrostatic charges and the degree of ionization of the

adsorbate [49]. Therefore, the PZC of the adsorbent should be measured, and it was 3.2 and 2.3 for raw and activated bentonite, respectively. It can be clearly reasoned that the value and signs of the surface potential of a specific adsorbent are directly determined by the nature of specifically adsorbed ions. As the solution pH decreases, more protons are expected to adsorb to the surface of the bentonite, which results in an increase of surface potential. The measured PZC values offer a good indication for activated bentonite by HCl. Indeed, the surface area measurement and PZC studies are consistent with previous results, thus supporting the consideration that the bentonite is activated by acid.

3.1.6. Characteristics of OMWW. The OMWW samples were analyzed prior to treatment for different physicochemical properties and the results of the analysis are shown in Table 1. It is worth noting here that the parameter values are in good agreement with those reported in the literature. Furthermore, a simple comparison was made between the raw and activated adsorbent, in order to study their effect on OMWW properties. As seen, there is an increase in the percentage removal when activated bentonite was used, which means that this simple treatment of bentonite can lead to a good result, in regard to its adsorption capacity, and therefore, it can reduce the concentration of different present parameters, thus making OMWW eco-friendly.

3.2. Adsorption Experiments

3.2.1. Total Phenolic Compounds Removal. Acid activated bentonite for the total removal of phenolic compounds was examined using a batch technique; a series of experiments were performed at pH 6 (pH 6 value was less than the pKa of phenol (≈ 9.92)).

However, when pH value is greater than the pKa of phenol, phenol would dissociate to negatively charged species, such as $\text{C}_6\text{H}_5\text{O}^-$ [50], and then there are more electrostatic repulsions between the dissociated form of the phenol and the activated bentonite and so a decrease in the adsorbed amount of phenol. While pH value is 6, activated bentonite has more removal efficiency, as its particles have active sites with negative charges at relatively acidic pH and phenol is undissociated. Hence, the dispersion interaction predominated. Furthermore, the higher concentration of H^+ ions within a low solution pH can neutralize those negative sites and reduce the hindrance to diffusion of phenol ions from the aqueous solution and consequently increase the chances of their adsorption. However, at the high solution pH, OH^- -concentration ions dominate, which can, in turn, increase the hindrance to the diffusion of phenol ions and thus reduce the chances of their adsorption; Figure 4 shows these results. A similar trend was also observed in the study conducted by Alkaram et al. [51] for phenol removal from aqueous solutions using surfactant-modified bentonite and kaolinite.

Effect of Adsorbent Dose on Adsorption of Total Phenolic Compounds. The influence of adsorbent dose on the adsorption of total phenolic compounds from the OMWW is shown in Figure 5. An increase in phenolic compounds removal with

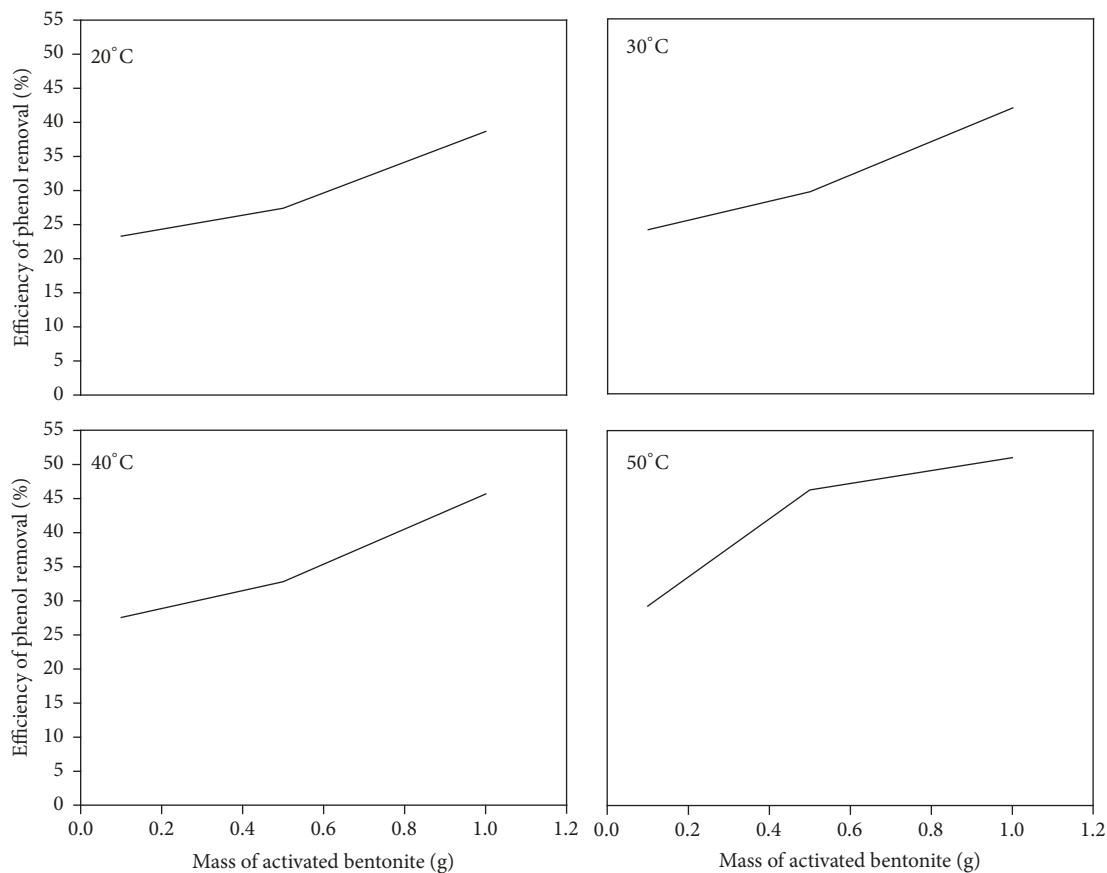


FIGURE 5: Effect of mass acid activated bentonite on percentage removal of total phenolic compounds.

TABLE 1: Main characteristics of OMWW sample, untreated and treated with raw and activated bentonite.

Parameters	Untreated OMWW	Literature ranges values	Reference	Treated OMWW with raw bentonite	Treated OMWW with activated bentonite	% removal using raw bentonite	% removal using activated bentonite
pH	4.63	4.9–6.50	[26]	5.74	5.08	----	----
Conductivity, ms/cm	19.89	13–50	[27, 28]	19.4	16.9	----	----
Sodium (Na^+), mg L $^{-1}$	297.9	200–570	[29, 30]	186.4	114.6	37.4	61.5
Potassium (K^+), mg L $^{-1}$	6366.3	639–10800	[31]	4075.1	2215.7	35.9	65.2
Total phenolic content, g GAE/L	1.34	0.26–10.7	[31, 32]	0.85	0.42	36.6	65.7
Alkalinity (CaCO_3), mg L $^{-1}$	2000	3150–9070	[33]	1500	500	25.0	75.0
Total chlorine, mg L $^{-1}$	20	33.3–142.7	[34]	15	7	25.0	65.0
Phosphate (PO_4^{3-}), mg L $^{-1}$	4120	31.8–1820	[35]	460	155	88.8	96.2
Nitrate (NO_3^- -N), mg L $^{-1}$	360	350–390	[36]	230	28	36.1	92.2
COD, mg L $^{-1}$	12000	1900–220000	[37, 38]	7030	2295	41.4	80.9
DO, mg L $^{-1}$	600	n.d.	----	297	274	50.5	54.3
TDS, mg L $^{-1}$	34700	5900–103200	[37, 39]	13140	11010	62.1	71.2
ORP, mv	259800	n.d.	----	73300	61100	71.8	76.5
Salt, mg L $^{-1}$	26700	11900–32000	[33]	9930	6010	62.8	77.5

n.d.: not determined.

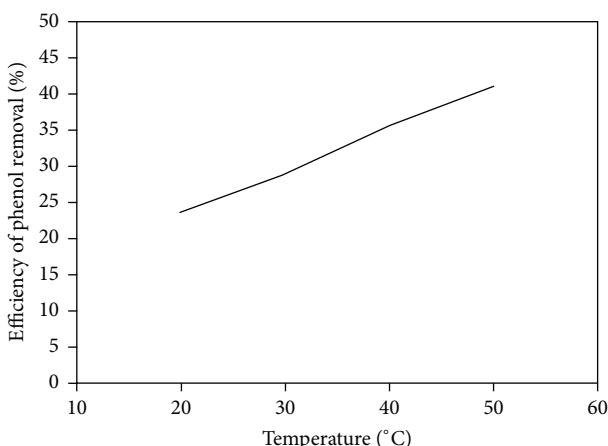


FIGURE 6: Effect of solution temperature on the percentage removal of total phenolic compounds. Operation conditions: 10 mL of OMWW, mass of activated bentonite = 1.0 g, and contact time = 3 hrs.

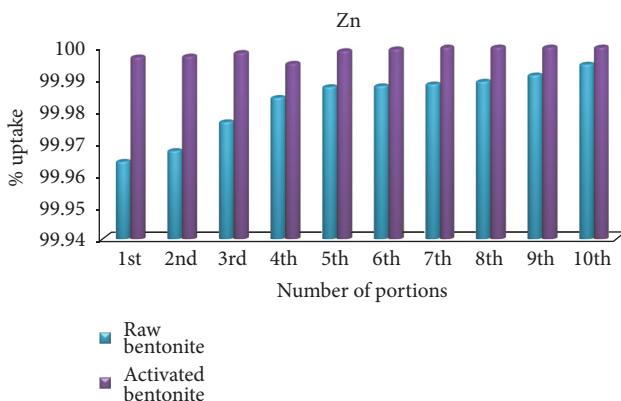


FIGURE 7: Percentage uptake of Zn(II) by raw and acid activated bentonite using column technique.

an increase in adsorbent dose was recorded. This increase may be due to the higher adsorbent dose providing more active adsorption sites or surface areas, so more phenol molecules have the chance to attach to these adsorbent particles, which results in an increase of adsorption capacity of the activated bentonite.

Furthermore, the optimum adsorbent concentration needed for the maximum removal of total phenolic compounds is 1 g of bentonite/0.01 L of OMWW.

Effect of Temperature on Adsorption of Total Phenolic Compounds. Studies have shown that temperature also influences the overall adsorption process. As shown in Figure 6, adsorption efficiency is directly related to temperature. This is because the dissolution rate of cations (K^+ , Na^+ , and Ca^{2+}) in the acid medium increases, as the leaching temperature increases up to the maximum temperature used in this study. The increase in the removal rate of the cation could be a result of high kinetic energy in the system, which speeds up the rate of reaction on the surface of the bentonite. Therefore,

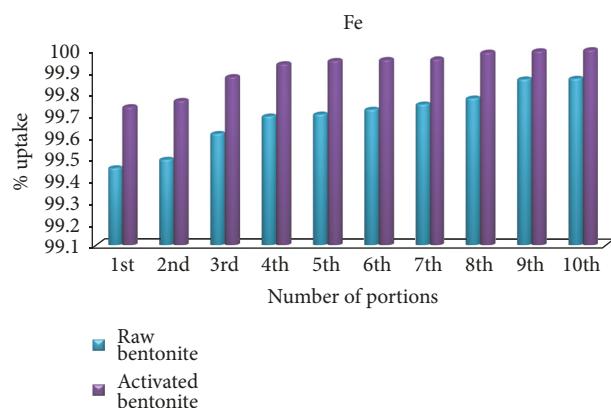


FIGURE 8: Percentage uptake of Fe(II) by raw and acid activated bentonite using column technique.

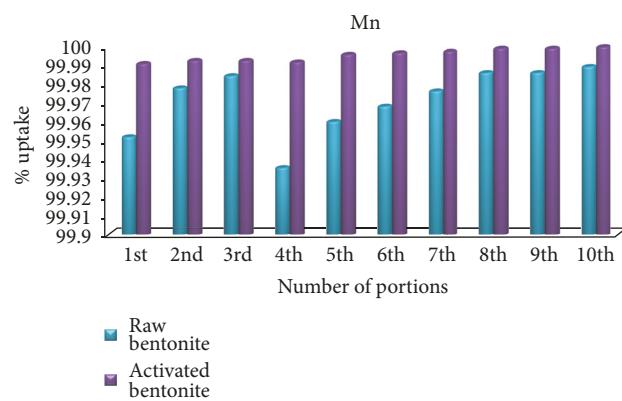


FIGURE 9: Percentage uptake of Mn(II) by raw and acid activated bentonite using column technique.

the higher temperature generates a greater driving force for phenolic compounds to be fixed on the adsorbent. The same trend has been reported by the others [52].

Comparisons between raw and activated bentonite for the total removal of phenolic compounds have been examined in other studies, where it was observed that acid activation of bentonite enhanced its adsorption capacity. Figure 6 supports this observation.

Up to now, OMWW is discharged directly into sewer systems, valleys, and uncontrolled ponds, even though such discarding methods are forbidden in many Mediterranean countries. This is due to the current absence of applicable treating technologies for OMWW. Therefore, we introduce this desirable, low-cost method as an effective treatment of OMWW and other contaminated aqueous solutions.

3.2.2. Heavy Metal Ions Removal. In order to compare the adsorption potentials of raw and activated bentonite, pH 6 was chosen and utilized as optimum adsorption of metal ions from OMWW using a column technique. The significant adsorption occurring at pH values is greater than the PZC, at which the surface of activated bentonite is negative. The adsorption process increased with an increase in pH up to 6, due to a decrease in competition between protons and

metal ions leading to a higher uptake (Akpomie and Dawodu 2016). In addition, avoiding high pH values (>6), metal hydroxide may be precipitated in solution [53]. Also, 1 g of bentonite/0.1 L of OMWW is considered as the optimum adsorbent concentration needed for the maximum removal of all heavy metal ions. Figures 7, 8, and 9 show a comparison of the percentage uptakes of heavy metal ions by raw and activated bentonite.

It can be clearly observed that activated bentonite can completely remove all heavy metal ions from OMWW, regardless of their initial concentrations.

4. Conclusion

OMWW is produced in Jordan and Mediterranean regions in huge amounts and results in heavily polluted waste water that causes negative environmental impacts. Untreated OMWW is characterized by a high content of phenolic compounds, some heavy metals, and other salts.

Bentonite has been successfully activated using hydrochloric acid, as shown by FTIR, XRD, and TGA studies, in addition to an increase in its surface area. Acid activated bentonite shows a great potential for the removal of heavy metal ions and phenolic compounds pollutants. Results show that percentage uptakes exceed 99% for Zn, Fe, and Mn ions. According to phenolic compounds, adsorption efficiency is strongly affected by parameters, such as pH of the solution, temperature, and adsorbent dosage. The efficiency rises with an increase in the temperature of solution and the adsorbent dose.

This method is simple, economical, green, nontoxic, and fast. Therefore, we recommend its use for OMWW treatment in developing countries.

Conflicts of Interest

The author declares that there are no conflicts of interest regarding the publication of this manuscript.

Acknowledgments

The author acknowledges the Support to Research and Technological Development & Innovation Initiatives and Strategies in Jordan (SRTD II), the European Union Funded Project, Budget Line BGUE-2011-19.080101-CI-DEVCO, reference SRTD/2014/GRT/AR/2321, for funding the project, in addition to Jerash University.

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