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Tomasz Kalak, Joanna Dudczak, Elwira Szychowiak, Ryszard Cierpiszewski

Poznań University of Economics and Business, Faculty of Commodity Science, Department of Commodity Science and Ecology of Industrial Products

Corresponding author: Tomasz Kalak, tomasz.kalak@ue.poznan.pl

BIOSORPTION OF Cu(II) AND Cd(II) HEAVY METALS FROM AQUEOUS SOLUTIONS BY PAPRIKA WASTE[1]

Abstract: In this study, the adsorption conditions of Cu(II) and Cd(II) metal ions onto dried paprika residues have been studied. Paprika waste is generated in the food industry and it can be used for removing copper Cu(II) and cadmium Cd(II) from wastewater. Paprika is usually consumed as a fresh fruit or dried and used as ground and natural flavouring in the food industry, but also as a colouring agent for many food products, such as spicy culinary, cheese food coatings, meat products, popcorn oil etc. It is also used in the pharmaceutical and cosmetic industries. Spice pepper is added to dried soups, cheese, chips and spice mixtures. Paprika is a source of biologically active compounds, such as flavonoids, phenols, carotenoids, capsaicinoids and vitamins. Its fruits contain resins, pentosans, cellulose, protein, pungent principles, colouring pigments, mineral elements and small amounts of volatile oil. Seeds include fixed non-volatile oil, which consists of triglycerides (~60%), mainly linoleic acid and other unsaturated fatty acids. All the ingredients exhibit various benefits to human health, antioxidant capacity and other biological activities, but also sorption properties in relation to heavy metal ions. In this research the adsorption of metal ions like Cu(II) and Cd(II) from aqueous solutions at different pH values 2–5 has been investigated. The tests were conducted to study the effects of the mass of biosorbent, various metal ion concentration, pH level, contact time on adsorption isotherms of the metals and a maximum loading capacity. The results showed that the copper and cadmium ions were significantly bound by paprika waste, which was also confirmed by FT-IR

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measurements. The results suggest that paprika waste has the possibility to be used as effective adsorbent for copper and cadmium ions removal.

Keywords: paprika residues, Cu(II) and Cd(II) metal ions, adsorptive removal.

JEL classification: Q53, Q55, Q57.

BIOSORPCJA METALI CIĘŻKICH Cu(II) I Cd(II) Z ROZTWORÓW WODNYCH Z WYKORZYSTANIEM ODPADÓW PAPRYKI

Streszczenie: Celem pracy było wykazanie możliwości wykorzystania suszonych odpadów papryki do adsorpcji jonów metali Cu(II) i Cd(II) w różnych warunkach. Odpady papryki powstają w wyniku przetwórstwa w przemyśle spożywczym i mogą być potencjalnie stosowane do usuwania jonów miedzi i kadmu ze ścieków. Papryka zazwyczaj jest spożywana w postaci świeżych lub suszonych owoców oraz wykorzystywana jako naturalny środek aromatyczny w przemyśle spożywczym, ale także jako barwnik do wielu produktów spożywczych, takich jak powłoki produktów serowych, produkty pikantne, produkty mięsne, oleje itp. Znajduje również zastosowanie w przemyśle farmaceutycznym i kosmetycznym. Przyprawę papryki dodaje się do suszonych zup, serów, chipsów i mieszanek przyprawowych. Papryka jest źródłem związków biologicznie czynnych, takich jak flawonoidy, karotenoidy, fenole, kapsaicynoidy i witaminy. Jej owoce zawierają żywice, pentozany, celulozę, białka, pigmenty barwiące, składniki mineralne, niewielkie ilości olejku eterycznego, a także alkaloid kapsaicynę, który nadaje im ostry smak. Nasiona zawierają nielotne oleje składające się z trójglicerydów (~60%), głównie kwasu linolowego i innych nienasyconych kwasów tłuszczowych. Wszystkie te składniki wykazują korzyści dla zdrowia ludzkiego, właściwości antyoksydacyjne i inne, a także właściwości sorpcyjne w stosunku do jonów metali ciężkich. W pracy przedstawiono wyniki badań adsorpcji jonów metali Cu(II) i Cd(II) z roztworów wodnych w zakresie pH 2–5. Celem badań było wykazanie wpływu masy biosorbentu, stężenia jonów metali, pH, czasu kontaktu na izotermy adsorpcji metali i maksymalną pojemność sorpcyjną. Rezultaty wykazały, że jony miedzi i kadmu były wiązane przez wytłoki papryki, co potwierdzają również wyniki analizy FT-IR. Rezultaty wyraźnie sugerują, że wytłoki papryki mogą być potencjalnie wykorzystane jako efektywny biosorbent do usuwania jonów miedzi i kadmu z roztworów wodnych.

Słowa kluczowe: odpady papryki, jony metali Cu(II) i Cd(II), adsorpcja.

Introduction

Heavy metals exist in the natural environment. However, their increasing presence due to industrialization has created serious global concern in recent years [Sakkayawong, Thiracetyan, and Nakbanpote 2005]. Among the variety of toxic substances present in wastewater, heavy metals are of great importance because of their persistent nature and high toxicity at low levels of concentrations, which in many cases, exceed the admissible sanitary standards [Ozdesa et al. 2009]. They are not biodegradable and have a tendency to accumulate in living organisms and transfer throughout the food chain, causing various diseases and long term disorders, as well as serious ecological effects [Loutseti et al. 2009]. Removing metal ions from wastewater is a difficult problem because of their appreciable solubility in aqueous solutions. Many methods have been proposed for their removal from industrial effluents, such as ion exchange [Dąbrowski et al. 2004], membrane separation [Paaez-Hernaandez et al. 2005], chemical precipitation [Matlock, Howerton, and Atwood 2002] and adsorption onto activated carbon [Moon and Lee 2005], evaporation, electro deposition, coagulation, etc. [Lameiras, Quintelas, and Taveres 2008]. Some of the methods are too expensive or less effective and energy consuming in terms of the removal of metal ions. In addition to these conventional techniques biosorption is promising to be highly effective, inexpensive and easy to use [Wang and Chen 2009]. Agriculture is a rich source for low-cost adsorbents. Agricultural and food industrial wastes like processed fruit and vegetable residues have little economic value and create serious disposal problems. The residues rich in dietary fibre can be effectively used to remove heavy and precious metals from wastewater. The biosorption process is one of the most promising and alternative technologies due to its low cost, easily obtained, minimization of significant quantities of wastes to be disposed of, high efficiency in adsorptive removal of metal ions from very dilute effluents and no nutrient requirements [Raize, Argaman, and Yannai 2004; Sari et al. 2007; Deng and Ting 2005]. In recent years, agricultural and food industrial wastes have been widely studied for metal removal from water. Among them the following biomaterials can be distinguished: wool, wood, sawdust, pine bark, compost and leaves, hazelnut shells, peanut hulls, rice husk, soybean hulls, orange peel, gooseberry fruit, paprika, black currant, aronia, black lilac, raspberry, strawberry, blackberry, wild rose, and brewing grains from the brewing industry etc. [Wan Ngah and Hanafiah 2007].

The use of paprika waste as a biosorbent material shows strong potential due to its content of cellulose, protein, pungent principles, flavonoids, phenols, carotenoids, capsaicinoids and vitamins, resins, pentosans, colouring pigments, mineral elements and small amounts of volatile oil. Seeds contain fixed non-volatile oil, which include triglycerides (~60%), mainly linoleic acid and other unsaturated fatty acids [Tepić et al. 2008]. The substances contain polar functional groups, such as carboxyl, phenolic, hydroxyl, sulfo and amino groups which are capable of binding metal ions. The chemisorption of metals with functional groups may take place as a result of ion exchange, complexation and chelating reaction. On the surface of biosorbents physical adsorption, redox reactions, or micro-precipitation may also occur. This process can also be a combination of all these mechanisms [Patel 2012; Demirbas 2008; Das et al. 2008].

Copper(II) is one of the most common heavy metals found in the wastewater sludge of many industries, such as tanneries, metal plating facilities, mining operations, surface treatment, pyrometallurgical production of metals, and metal flotation, etc. In the waste from industries, copper mainly exists as a divalent metal Cu(II), which is more toxic than the metal itself. The ionic form is soluble in water and can be absorbed into living organisms. The metal is essential for organisms, but in excess it can produce many toxic and harmful effects as a result of accumulation in the brain, liver, pancreas and myocardium [Davis, Volesky, and Vieira 2000; Ekmekyapar et al. 2006]. A serious problem of copper(II) toxicity and its ability to bioaccumulation led the United States Environmental Protection Agency (USEPA) to recommend a threshold concentration limit, named as a maximum contaminant level (MCL) of 1.3 mg/L [USEPA 2001; Harmita, Karthikeyan, and Pan 2009].

Cadmium is found naturally in water, air, soils and foodstuffs. The most common form of the metal is greenockite (CdS), cadmium sulfide (77.6% Cd), otavite ($CdCO_3$), cadmium carbonate (61.5% Cd) and pure cadmium oxide (87.5% Cd). The metal is present in waste from industrial processes, such as: production of alloy, cadmium-nickel batteries, pesticides, fertilizers, plastics, pigments and dyes, smelting, electroplating, mining, refining and textile operations [Rao et al. 2010; Cheung, Porter, and McKay 2000; Wu et al. 2010]. Cadmium belongs to the group of heavy metals, which is toxic to living organisms and a big problem for the environment because of its non-degradability. The World Health Organisation recommends a maximum contaminant level (MCL) of Cd(II) in drinking water up to 0.005 mg/L [Rao et al. 2010].

According to the European Pollutant Release and Transfer Register, the quantitative register of industrial emissions in the European Union, nearly 418 tons of copper(II) and 26.4 tons of cadmium(II) were reported to be released in 2012 into water coming from 873 and 347 facilities respectively of 9 different industrial sectors that exceeded the threshold value for the release of copper(II) and cadmium(II) to water of 50 kg of Cu(II) and 5 kg of Cd(II) per year (Regulation (EC) No. 166/2006) [E-PRTR 2015; European Commission 2006].

The aim of the present work was to study the adsorption properties of paprika waste in relation to Cu(II) and Cd(II) ions present in aqueous solutions. The effect of mass of the biosorbent, various metal ion concentration, pH level and contact time was investigated.

1. Experimental procedure

1.1. Materials

The dried paprika (*Capsicum annuum*) waste used for the study was generated in food industry located in Mazovia Province (Poland). The pomace was crushed into smaller particles in a blender and then it was sieved, and separated into fractions of different thickness. The material was dried to a constant mass at a temperature of 60°C. It was then kept in polyethylene containers in a dessicator before analysis. All experiments were made in triplicate and only deionized water was used.

1.2. Methods

Experiments for the adsorption tests of metal ions were carried out by the conventional batch wise method at room temperature (23 ± 1°C). The paprika from 0.025 to 1.0 g and a portion of $CuCl_2$ or $CdCl_2$ test solution containing 2.5–20 mg/L of metal ions at pH value 2–5 were placed in a conical flask and shaken in a shaker until equilibrium was reached. Then the contents of the flasks were transferred into centrifuge tubes and centrifuged to separate phases for 15 min. at 4,000 revolutions per minute. After that in portions of the biosorbent above the solution concentrations of Cu(II) and Cd(II) were measured by an atomic absorption spectrophotometry (F-AAS) using SpectrAA 800 (Varian, Palo Alto, USA) apparatus at a wavelength λ = 324.8 nm for copper, and λ = 228.8 nm for cadmium. The solutions containing Cu(II) and Cd(II) metal ions were analysed before and after the biosorption procedure.

The surface structure of the paprika waste was examined in infrared spectroscopy using a Fourier transform attenuated total reflection (FT-IR ATR) Spectrum 100 (Perkin-Elmer, Waltham, USA).

2. Results and discussion

After the biosorption procedure the solutions were analysed for the residual Cu(II) and Cd(II) metal ion concentration using an atomic absorption spectrophotometer (SpectrAA 800). The biosorption efficiency A [%] of the metal ion was calculated from equation 1:

$$A = \left[\frac{C_0 - C_e}{C_0} \right] \cdot 100\%. \tag{1}$$

The amount of biosorption (q_e) was calculated by equation 2:

$$q_e = \frac{(C_0 - C_e) \cdot V}{m}, \tag{2}$$

where:
C_0 and C_e [mg/L] are the initial and equilibrium metal ion concentrations, respectively;
V [L] is the volume of the solution and m [g] is the amount of biosorbent used.

2.1. Effect of pH on the sorption of the metal ions

The influence of pH on the biosorption of copper(II) and cadmium(II) on paprika waste (*Capsicum annuum*) was evaluated in experiments with an initial metals concentration of 10 mg/L in the pH range 2.0–5.0. The results are shown in Figures 1 and 2, in which the strong effect of pH on the metal ions removal is indicated. As can be seen from these Figures, adsorption of the metal ions increases with the increasing equilibrium pH of the solutions. It is supposed that these metal ions are absorbed by the cation exchange mechanism. Maximum adsorption was achieved at pH 3 in case of Cu(II) ions treatment (A = 49.7%; q_e = 0.11 mg/g) and at pH 4 in case of Cd(II) ions (A = 45.5%; q_e = 0.1 mg/g). The maximum values were reached at pH around 3–4 and after that it starts to decrease with the further increase of pH. The decrease at pH 2 is due to the formation of copper chloride and cadmium chloride, which may be adsorbed with a greater difficulty. The surface of the paprika particles became positively charged as a result of the excess of H^+ ions. The Cu(II) and Cd(II) ions compete with H^+ ions and do not favour the adsorption of positively charged metal ions due to the electrostatic repulsion. The presence of an excess of H^+ ions caused the protonation of various functional groups present on the surface of paprika particles and decreased the amount of negatively charged surface sites. In case of an increase in pH to 3–4 values, the acidic groups were deprotonated and the possibility of the adsorption of positively charged metal ions increased. Cu(II) and Cd(II) exist as Cu^{2+} and Cd^{2+} at pH 3–4, therefore it can be explained that maximum sorption capacity was in the ionic form of the metals up to pH 3. The decrease in copper(II) and cadmium(II) adsorption at pH above 4 can be explained by the competition of hydroxyl ions for the adsorption centers. The biosorption occurred very slowly because of the formation of other metal species, such as $Cu(OH)^+$, $Cd(OH)^+$ and $Cu(OH)_2$ or $Cd(OH)_2$. The mechanism describing the effect of pH on metal cation biosorption is reported in the literature [Li et al. 2008; Feng, Guo, and Liang 2009; Lu et al. 2009; Vaghetti et al. 2009; Janos et al. 2006; Bulgariu, Bulgariu, and Macoveanu 2012]. The selectivity order of the examined metal ions is as follows: Cu(II) > Cd(II).

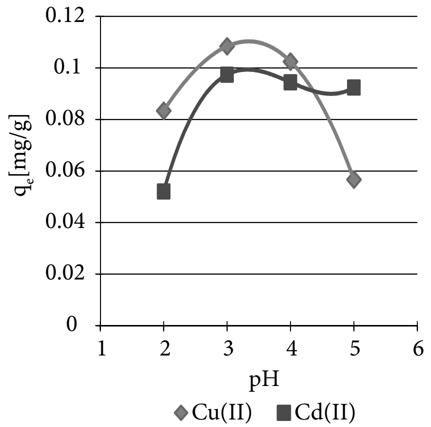

Figure 1. Dependence of q_e of Cu(II) and Cd(II) with pH at 25°C (C_0= 10 mg/L, V = 10 mL, mass of paprika 0.5 g, particle size 0.212 mm, agitation speed 150 rpm, contact time 60 min.)

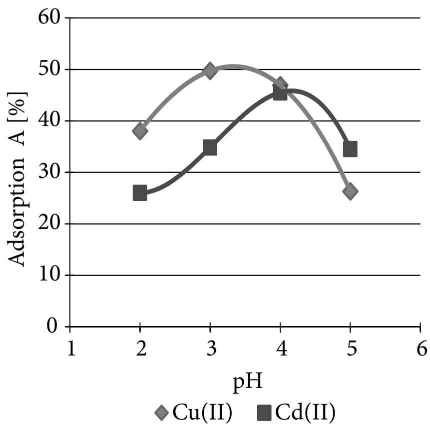

Figure 2. Dependence of A [%] of Cu(II) and Cd(II) with pH at 25°C (C_0 = 10 mg/L, V = 10 mL, mass of paprika 0.5 g, particle size 0.212 mm, agitation speed 150 rpm, contact time 60 min.)

2.2. Effect of the mass of biosorbent

The effect of the mass of biosorbent on sorption efficiency for the tested metal ions was investigated. The studies were carried out to optimize the biosorbent mass. The experiments were carried out in the following conditions: T = 25°C, C_0 = 10 mg/L, constant pH 4, particle size 0.212 mm, agitation speed

150 rpm, contact time 60 min. Biosorbent masses were varied from 0.025 g to 1.0 g for both metal Cu(II) and Cd(II) ions. The removal efficiency varied significantly with the mass of the biosorbents. It can be seen in Figure 3 that the maximum adsorption capacity of Cu(II) and Cd(II) ions was indicated to be 0.66 mg/g and 0.15 mg/g, respectively. The percentage removal due to varied biosorbent masses and the biosorbent are presented in Figure 4. It was observed that metal ions removal efficiency increased with the increase in biosorbent mass. The Cu(II) and Cd(II) removal efficiency reached an optimum mass at 0.5 g and 0.3 g, corresponding to 49.7% and 31.3% removal, respectively. It is supposed that the increase in removal efficiency can be attributed to the greater number of biosorption sites for the ions and high accessibility of metals to the binding sites as the mass increases [Karthikeyan, Balasurbramanian, and Iyer 2007; Lata, Garg, and Gupta 2008; Nuhoglu and Malkoc 2009]. The difference in removal efficiency between Cu(II) and Cd(II) can be due to differences in their physicochemical properties and consequently the ability to adsorb on active centers of the surface of the paprika. The lower removal efficiency was presented at the paprika mass of 0.025 g. The results show that there is no significant difference in adsorption between the mass of 0.5, 0.7 and 1.0 g. The values selected as optimum paprika masses will be utilized in other aspects of the research.

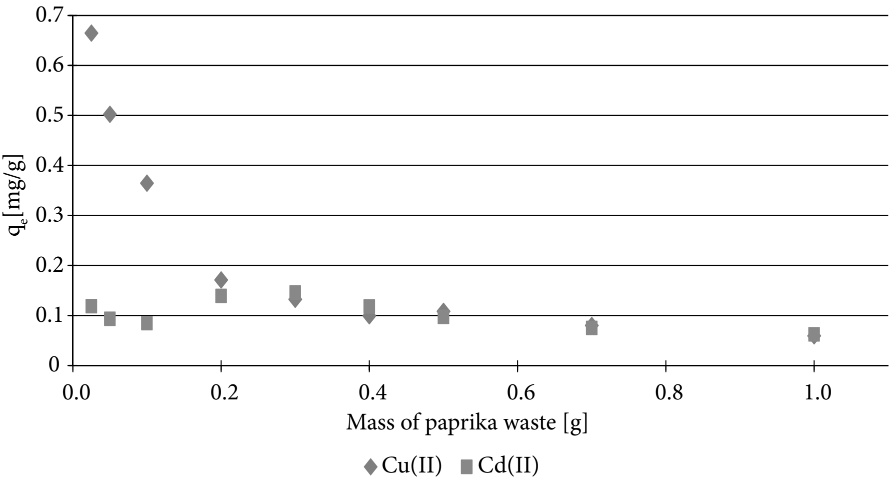

Figure 3. Dependence of q_e of Cu(II) and Cd(II) with the mass of paprika waste at 25°C (C_0 = 10 mg/L, V = 10 mL, pH 4, particle size 0.212 mm, agitation speed 150 rpm, contact time 60 min.)

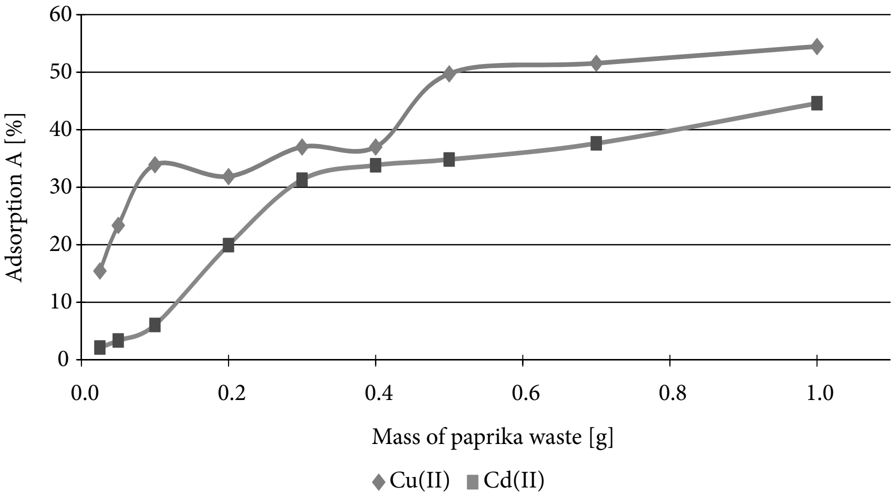

Figure 4. Dependence of adsorption *A* of Cu(II) and Cd(II) with the mass of paprika waste at 25°C (C_0 = 10 mg/L, *V* = 10 mL, pH 4, particle size 0.212 mm, agitation speed 150 rpm, contact time 60 min.)

2.3. Effect of contact time

Contact time is one of the most important parameters that has a significant impact on the practical and successful use of biosorbent in industry [Amini et al. 2008; Inbaraj and Sulochana 2006; Ilhan et al. 2008; Kargi and Cikla 2006]. The amount of solutions taken into adsorption processes and their design can be determined by the measurements of such factors as contact time [Bayramoğlu and Arıca 2005]. Batch experiments were carried out by the varying contact time of optimized paprika mass of 0.5 g, at pH 4, initial concentration C_0 = 10 mg/L, particle size 0.212 mm and agitation speed 150 rpm. Contact times were 5, 10, 15, 30, 60, 120, 180, 240 and 300 min. Figure 5 shows removal efficiency versus time for Cu(II) and Cd(II) metal ions removal from aqueous solutions. The maximum sorption capacity of Cd(II) was achieved in the first 5 min. (46.1%) and there were no significant changes in the adsorption process efficiency even after 120 minutes (47.6%). In case of biosorption process of Cu(II) ions the maximum sorption efficiency was reached after 30 minutes (30.7%). The biosorption of most of the metal ions was attained in first 30 min. that may be due to the availability of more sorption sites at the beginning of the process. After the time system reached equilibrium state, wherein the maximum adsorption of Cu(II) ions showed the covering of maximum binding centers with metal ions. Further increase in the contact time showed that there is no significant increase in the removal of metal ions. After 300 minutes of the adsorption process the removal efficiency was estimated at 30.1% and there is no need to further increase the adsorption time due to the complete coverage of active sites to the surface of the paprika particles.

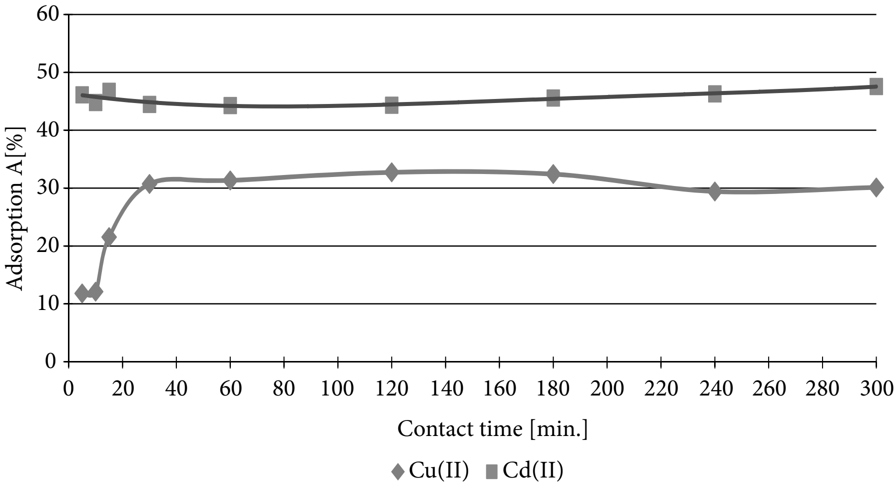

Figure 5. Dependence of adsorption *A* of Cu(II) and Cd(II) with contact time at 25°C (C_0 = 10 mg/L, *V* = 10 mL, mass of paprika 0.5 g, pH 4, particle size 0.212 mm, agitation speed 150 rpm)

2.4. Effect of concentration

The initial metal ion concentration is an important parameter for determining the types of effluents that can be treated with biosorbent. The effect of varying initial concentration (2.5 mg/L – 20 mg/L) of Cu(II) and Cd(II) on the biosorption of paprika waste is presented in Figures 6 and 7. The experiments were carried out under the following conditions: T = 25°C, volume of solutions 10 mL, mass of paprika 0.5 g, pH 4, particle size 0.212 mm, agitation speed 150 rpm and contact time 60 min. The presented results show that the metal uptake capacity of paprika increased with an increase in initial metal ion concentration. As it may be seen the biosorption characteristic suggests that surface saturation depends on the initial metal ions concentrations. Although, at higher concentrations metal ions need to diffuse to the paprika surface by intra-particle diffusion and hydrolyzed ions are able to diffuse at a slower rate. The initial Cu(II) and Cd(II) concentration provided a significant driving force to overcome all of the paprika mass transfer resistance of Cu(II) and Cd(II) between the aqueous and solid phases while the metals concentration increases. The greater mass transfer driving force, the lower resistance to metals uptake and the result is higher metal ions removal [Nouri et al. 2007].

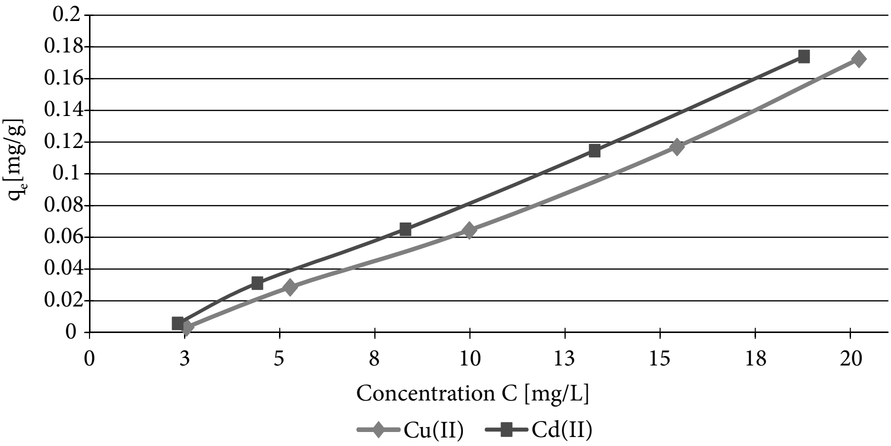

Figure 6. Dependence of q_e of Cu(II) and Cd(II) with the concentration of metal ions at 25°C (V = 10 mL, mass of paprika 0.5 g, pH 4, particle size 0.212 mm, agitation speed 150 rpm, contact time 60 min.)

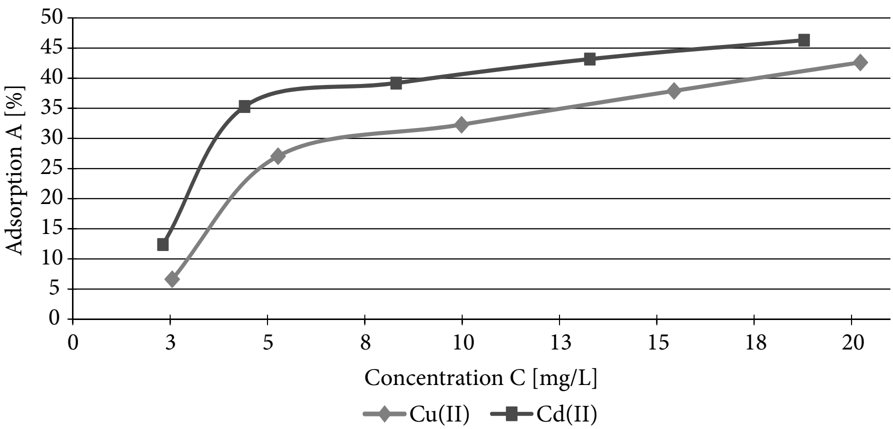

Figure 7. Dependence of adsorption A of Cu(II) and Cd(II) with the concentration of metal ions at 25°C (V = 10 mL, mass of paprika 0.5 g, pH 4, particle size 0.212 mm, agitation speed 150 rpm, contact time 60 min.)

Comparing the adsorption efficiency, the amount of Cd(II) adsorbed by paprika waste was greater than the corresponding amount of Cu(II) ions. The difference between the sorption of the two ions can be ascribed to the difference in their ionic radii. The ionic radius of Cu^{2+} is 75 pm while that of Cd^{2+} is 95 pm. According to literature, the smaller the ionic radius, the greater is the tendency to produce a hydrolysis reaction leading to a reduction in sorption efficiency [Vinod and Anirudhan 2001].

2.5. FTIR Analysis

The mid-infrared analysis of dried paprika waste (particle size 0.212 mm) before and after adsorption with Cu(II) metal ions was carried out with the purpose of identifying characteristic peaks associated to the functional groups involved in metal adsorption. Details of the FT-IR spectra are given in Figures 8–10. Comparing the spectra for paprika biomass before and after Cu(II) adsorption (Figures 8 and 9), on the basis of the differences of the parameters, such as frequency, band shape and relative intensity, the possible interactions with the metal ions were considered. A significant increase in the intensity of the bands of 1159 and 1024–1030 cm^{-1} was observed. The peaks are assigned to C-C aromatic ring stretching and to C-N, C-O stretching, respectively. Other changes of the spectra before and after Cu(II) adsorption occurred at 3280–3291, 2924, 2854, 1742–1737, 1627–1630, 1514–1516, 1367

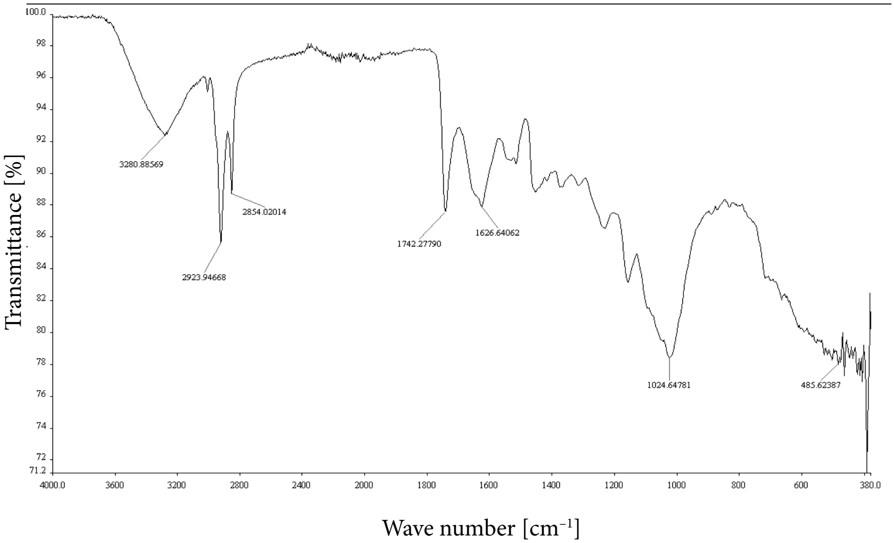

Figure 8. FT-IR spectrum of dried paprika biomass

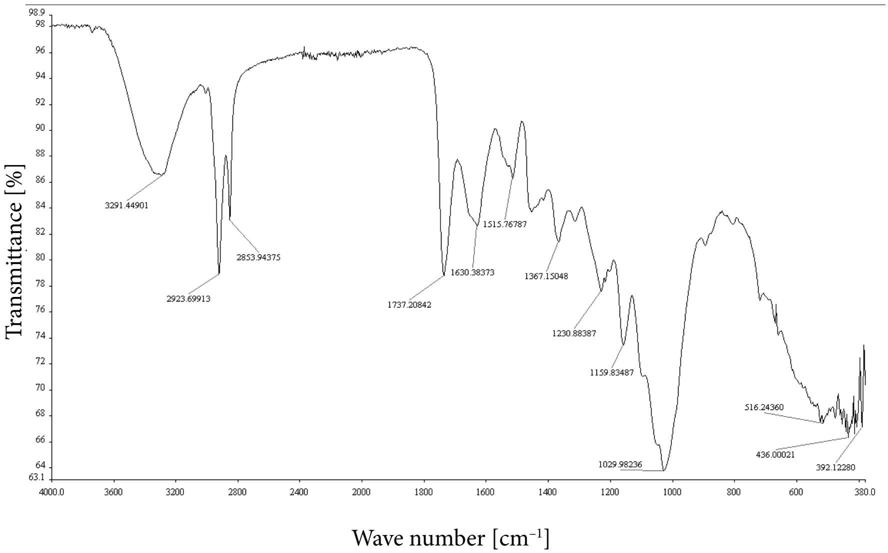

Figure 9. FT-IR spectrum of dried paprika biomass after Cu(II) ions adsorption (pH 4, particle size 0.212 mm, C_0 = 10 mg/L, mass of paprika 0.5 g)

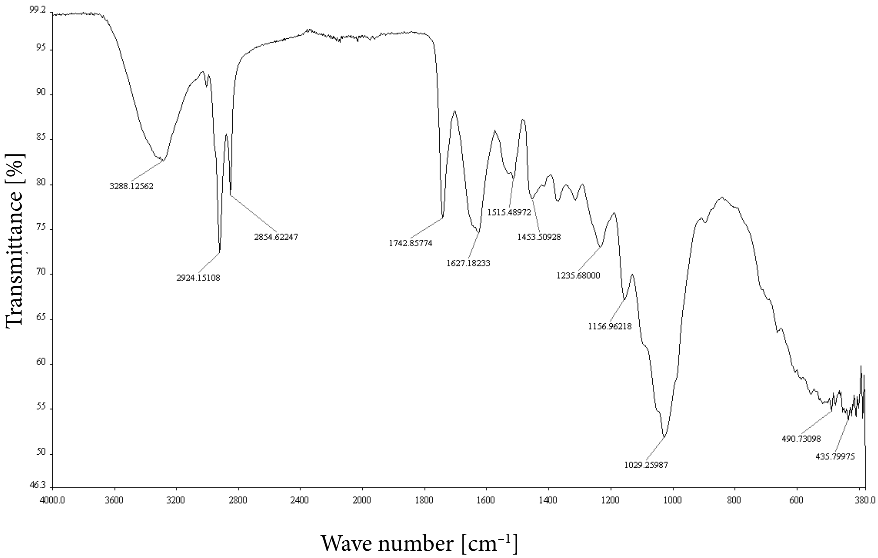

Figure 10. FT-IR spectrum of dried paprika biomass after Cd(II) ions adsorption (pH 4, particle size 0.212 mm, C_0 = 10 mg/L, mass of paprika 0.5 g)

and 1231 cm^{-1} wave numbers (Figures 8–9). Similar changes of the spectra before and after Cd(II) adsorption can be seen in Figure 10. The increase in intensity of peaks was observed due to the presence of the metal ions interacting with the functional groups of compounds present in paprika biomass.

FT-IR study for Cu(II) and Cd(II) adsorption peaks

Functional groups assigned	Paprika biomass before adsorption Wave number [cm^{-1}]	Paprika biomass after loaded with Cu(II) Wave number [cm^{-1}]	Paprika biomass after loaded with Cd(II) Wave number [cm^{-1}]
Stretching O–H and N–H	3280.88	3291.45	3288.13
Stretching C–H symmetric	2923.95	2923.70	2924.15
Stretching C–H symmetric	2854.02	2853.94	2854.62
Stretching C=O	1742.28	1737.21	1742.86
Stretching C–O	1626.64	1630.38	1627.18
Bending N–H; stretching C=C	1513.67	1515.77	1515.49
Bending O–H	–	1367.15	1453.51
Bending O–H; stretching C–O and C–N	1230.68	1230.88	1235.68
Stretching C–O, C–N and C–C	1159.01	1159.83	1156.96
Stretching C–O, C–N and C–C	1024.65	1029.98	1029.26

Conclusions

Paprika waste (*Capsicum annuum*) is a low-cost and readily available biosorbent for the removal of Cu(II) and Cd(II) from aqueous solutions. The adsorption of the metal ions depends on the pH of solution, contact time, mass of the biosorbent and concentration of metal ions. These factors affect the metals removal from aqueous solutions. The results indicated that maximum adsorption was obtained at pH 3 in case of Cu(II) ions treatment (A = 49.7%; q_e = 0.11 mg/g) and at pH 4 in case of Cd(II) ions (A = 45.5%; q_e = 0.1 mg/g). The metal ions removal efficiency increases with the increase in paprika mass. As a result of the Cu(II) and Cd(II) removal experiments there was possible to determine an optimum mass at 0.5 g and 0.3 g, corresponding to 49.7% and 31.3% removal, respectively. There was no significant difference between the mass of 0.5, 0.7 and 1.0 g in the adsorption of the metals. The obtained optimum mass values of paprika can be utilized in other aspects of any further research.

The maximum sorption capacity of Cu(II) and Cd(II) was achieved in first 30 min. (30.7%) and 5 min. (46.1%) in the agitation process, respectively, and there were no significant changes up to 300 min. due to the complete coverage of active sites to the surface of paprika particles.

The metal adsorption capacity of paprika increases with an increase in initial metal ion concentration, which provides a driving force to overcome all the paprika mass transfer resistance of Cu(II) and Cd(II) between the aqueous and solid phases in case of the metals concentration increase. The amount of Cd(II) adsorbed by paprika waste was greater than the corresponding amount of Cu(II) ions probably due to the difference in their ionic radii.

According to the FT-IR spectra analysis, it was confirmed that the adsorption sites on the paprika biomass are related to carboxyl, carbonyl, hydroxyl and amido groups, which could be responsible for Cu(II) and Cd(II) biosorption.

The results show that paprika waste as a low-cost biosorbent can be used effectively for the removal of Cu(II) and Cd(II) ions from aqueous solutions.

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