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Review of Peach (*Prúnus pérsica*) Shell Use to Remove Pollutants from Aquatic Environments

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Abstract: The paper summarizes literature sources data on using peach tree kernel shells and gum (*Prunus persica*) as sorption materials to remove various metal ions (Cd^{2+}, Cr(III) and Cr(VI), Cu^{2+}, Pb^{2+}), dyes, and some organic compounds from aquatic environments. Brief information is provided on the number of shells remaining from peach consumption, their chemical composition, and methods of reuse. The paper presents adsorption process parameters for the pollutants under consideration. Peach fruit shell treatment with various chemicals is proven to improve sorption characteristics. It was found that the Langmuir model, in most cases, accurately describes the pollutant adsorption isotherms and the kinetics of the process in most cases corresponds to the pseudo-second-order model. It has been shown that peach fruit shells are a good precursor for activated carbons production, which is also used to remove various pollutants from aquatic environments.

Keywords: peach shells; metal ions; dyes; adsorption; modification; activated carbon.

1. Introduction

The world community is rapidly developing and studying a new innovative environmental protection area – using lignocellulosic waste from agricultural production and plant biomass components as sorption materials to remove pollutants from water environments [1-13]. This is due to the high cost of activated carbons used in production and the low cost, the large annual renewable biomass, availability, and high efficiency of plant materials.

Of particular interest are the components of woody biomass, such as bark [14], leaves [15, 16], needles [17], cones [18], fruit shells and fruit kernels, etc. Of particular interest are the fruits shells and the fruit kernel shells annually generated in large quantities due to fruit processing. The latter are sources of valuable substances and can be widely used in production as a filler for various composites, activated carbons production, etc.

One of the sustainable applications of the shells and fruit kernels is their use as sorption materials. We have previously shown the prospects for the use of shells of walnuts [19], chestnuts [20], almonds [21], apricots [22], and other trees as effective sorption materials to remove various pollutants from aqueous media.

2. Description of Trees, Volumes of Production, and Chemical Composition of Peach Shells

Peach (*Prúnus pérsica*) is widespread in southern regions. Peach belongs to the Plum (*Prunus*) genus of the *Spiraeoideae* subfamily of the Rose (*Rosaceae*) family of the Rosales order. This is a tree with serrated lanceolate leaves. The flowers are almost sessile, pink, and red, appearing before the leaves. The fruit is flat to elongate-elliptical in shape, with a groove on one side, usually velvety. The kernel (endocarp) is wrinkled-exculpate with dotted dimples and a pointed apex. It is cultivated for its fruit in the southern regions of temperate Eurasia (including the south of Russia, the Transcaucasus and Central Asia, Ukraine, and Moldova) and America. Peaches are widely used as fresh and processed food. The pulp of peaches can be white, red, or yellow. Seeds are used to produce peach oil (*Oleum Persicorum*) used in medicine and cosmetology [23].

The global peach production amounted to 24.665 mln tons in 2018, of which the vast majority was produced in China (15.195 mln tons) [24]. Given that the amount of waste from peach processing is ~ 20% of the raw fruit weight, the amount of waste generated, mainly kernels, on a global scale is more than 5 mln tons per year.

Moisture, carbohydrates, ash, proteins, and fatty acids content in peach kernel shell (PKS) amounts, in particular, to 27.3 ± 0.15%, 68.2 ± 0.04%, 0.46 ± 0.01%, 1.84 ± 0.01%, 2.20 ± 0.02% [25]. Twenty sugars were identified and quantified, including five monosaccharides, seven disaccharides, four trisaccharides, one tetra, penta, hexa, and heptasaccharide, and three sugar alcohols. The overall sugar composition of peach kernels studied herein was roughly 37 % sucrose, 33.4 % glucose, 8.62 % fructose, 6 % maltose, 5.2 % sorbitol, and 9.78 % other minor sugars [26]. In addition to sugars, large amounts of lenolic (48.1%), oleic (41.1%), and palmitic (8.39%) acids were identified in the peach kernel. The content of other saturated and unsaturated acids does not exceed 1% [27]. In addition, various polyphenolic compounds have been identified in the composition of peach fruit kernels (Neochlorogenic acid, 3-O-p-Coumaroyloquinic acid, (+)-Catechin, Chlorogenic acid, Ellagic acid, Quercetin-3-O-glucoside, and others) and Tetraterpenoids (Lutein, Zeaxanthin, β-Cryptoxanthin, β-Carotene, β-Cryptoxanthin-myristate, and β-Cryptoxanthin-palmitate) [27].

There are several PKS biomass applications. In particular, data is given on the use of PKS as a concrete filler [28], as a substrate for growing mushrooms [29], and as a component of a composite material with polypropylene [30, 31].

PKS is a raw material for peach oil production [23, 32]. It was found that the oil content in peach processing by-products is 39.5%. Peach oil contains the following fatty acids: palmitic – 5.93%, oleic – 57.46%, linoleic – 25.44%, arachidic – 6.18% [32]. In addition, 15 polyphenolic compounds were identified in peach kernel oil, of which dithiothreitol, rutin, and caffeic acid were found in the greatest amount [33]. The composition of peach oil has also been shown to contain tetraterpenoids, such as lutein, beta-carotene, zeaxanthin, etc. [34].

Peach oil has the potential for application in the food industry. Due to its specific composition, rich in polyunsaturated fatty acids, including linoleic and oleic acids, as well as antioxidant compounds, it can replace olive and grape seed oils in salads [33]. It was found that the oil shows high antimicrobial, antioxidant, anti-inflammatory, and analgesic effects and can suppress the development of human breast, intestinal, and liver cancer cells [34].

One of the ways to use PKS is the application as a sorption material to remove various pollutants from aqueous media.

3. Use of Peach Shell and Gum to Remove Heavy Metal Ions from Aqueous Media

Several publications are devoted to studying the adsorption of metal ions and metalloids, with the largest number of studies devoted to the removal of Cr(III) and Cr(VI) ions by PKS. The removal of Cr(VI) ions by acid-treated biomass of crushed PKS was investigated at different aqueous solution pH values oat T = 20°C. It is found that the maximum sorption capacity for Cr(VI) ions is 46.64 mg/g. With pH from 2 to 10.5, the kinetics of the process corresponds to the pseudo-first-order model [35].

The removal of Cr(VI) ions from aqueous solutions was studied with two sorption materials: raw PKS (RPS) and activated charcoal made from peach shells (PSAC). The experiment outcomes demonstrate that pH is a key variable for adsorption optimization. The time required to achieve adsorption equilibrium was 120 minutes for coal in the pH range = 2-5.6 and 240 minutes for PKS at pH = 2, with a maximum removal percentage of more than 97% for both adsorbents. It was determined that the adsorption process follows the pseudo-second-order kinetics. Thermodynamic parameters revealed the spontaneous and endothermic nature of the adsorption process for both adsorbents [36].

Studies have been done on the removal of Cr(VI) ions from ethylenediamine-modified simulated PKS solutions. It was found that the maximum sorption capacity of the modified sorption material for Cr(VI) ions was 24.48 mg/g. The Langmuir model more accurately describes the adsorption isotherm, and the kinetics of the process follows the pseudo-second-order model [37]. Citric acid treatment of PKS provides an increase in the maximum sorption capacity to 25.71 mg/g. It was found that the adsorption isotherm is most accurately (R2 = 0.994) described by the Langmuir model, and the process kinetics follows the pseudo-second-order model (R2 = 0.995). Thermodynamic parameters analysis (ΔG^o = -1.632 - -0.358 kJ/mol at T = 298-329 K, ΔH^o = -14.29 J/mol, ΔS^o = -42.46 J/mol·K) made it possible to establish that the adsorption process is endothermic, spontaneous, and of a physical character. [38].

The functionalization of natural peach gum polysaccharide (PGP) secreted from the fruit and trunk of peach trees with multiple amine groups to remove toxic Cr(VI) ions from the water was studied. The obtained PGP-NH_2 gel exhibited high-removal efficiency (>99.5%) toward Cr(VI) ions, especially with a relatively low initial concentration of Cr(VI) ions (≤250 mg/dm^3). The Cr(VI) ion uptake process could be described by pseudo-second-order kinetic and Langmuir isotherm models. The maximum adsorption capacity of PGP-NH_2 gel could reach 188.32 mg/g. Thermodynamic investigation results indicated the spontaneous and exothermic characteristics of the uptake process. Moreover, the PGP-NH_2 gel also exhibited favorable reusability, and 135.52 mg/g of adsorption capacity was retained even after being reused for five times [39].

The focus of this investigation was the adsorption of Cr(VI) ions on nano-ZrO_2/TiO_2-impregnated PKS (ZrTi/PSS). It was found that the equilibrium was reached after 120 minutes of contact time, and the optimal pH value was ~ 2 for the adsorption of Cr(VI) ions. The Langmuir isotherm model showed the maximum adsorption value PSS to be 17.64 mg/g and ZrTi/PSS 31.15 mg/g. It was found that pseudo-second-order kinetic models (R^2 = 0.99) are best suited for describing the process [40].

It has also been looked at whether removing Cu2+ ions from simulated PKS solutions is possible. To do this, PKS were processed in a disc vibration crusher (PKS-D) and an ultracentrifugal crusher (PKS-U). It was shown that the total pore volume was about three times larger, and the volume of micropores was 9.29 times larger in PKS-U than in PKS-D. The

kinetic of Cu(II) sorption was tested through various kinetic models: pseudo-first, pseudo-second-order, Elovich equation, Boyd, Weber Morris, and Urano Tachikawa intraparticle diffusion model. It was shown that Cu^{2+} ions sorption occurs through a combination of intraparticle and film diffusion mechanisms. Equilibrium experimental results were fitted to Langmuir, Freundlich, Sips, Toth, and Dubinin–Radushkevich adsorption isotherms. It is found that the adsorption isotherm is more accurately described by the Sips model, and the kinetics of the process follows the pseudo-second-order model (R^2 = 0.992 at 323 K). Thermodynamic parameters ΔGo, ΔHo, and ΔSo were calculated using equilibrium data at different temperatures. The values of ΔG^o were found to be 75.93, 79.67, 83.42 kJ/mol at 293, 308, and 323 K. The positive value of ΔH^o (65.53 kJ/mol) indicates an endothermic activation process. The negative value of ΔS^o (-249.71 J/mol·K) is supportive of interactions between the Cu^{2+} ions and the PKS. The sorption of Cu^{2+} ions on PKS is a spontaneous and endothermic process with increased randomness during the sorption [41-43].

The influence of pH value on the biosorption of Cu(II) ions by unmodified PKS particles has been studied. Point of zero charge determination was performed with three different KNO_3 ionic strengths: 0.1, 0.01, and 0.001 M. The obtained value for pHPZC was 4.75±0.1 and showed that this biosorbent is non-sensitive to the ionic strength of the electrolyte applied. Biosorption experiments were done with PKS particles of diameters 0.5±0.1 mm at 25 ^oC. The initial copper (II) concentration was 50 mg/dm^3, while the biosorbent concentration was 10 g/dm^3. Experiments were performed with and without keeping the pH constant. The influence of pH on the biosorption process was examined in a pH range of 2–6. The percentage of Cu(II) removed by PKS reached its maximum at pH = 6, with 90.43% removal, but at pH = 2, the retention of copper was equal to 2.62%. The results also indicate that it is necessary to lead the biosorption process with keeping the pH constant at all times [44].

The above data shows that the experiments were carried out under different conditions, which does not allow comparing the results. Experiments on the removal of various pollutants carried out under the same conditions provide more adequate results. For example, the adsorption of Cd^{2+}, Cu^{2+}, and Pb^{2+} by modified citric acid PKS was studied. The results indicated that the adsorption process of Cd^{2+}, Cu^{2+}, and Pb^{2+} ions could be fitted well with the Langmuir isotherm model with high regression coefficients (R^2 > 0.9). In addition, the experimental data of Pb^{2+} and Cu^{2+} ions can be fitted with the Freundlich model, indicating that multiple mechanisms might govern the adsorption process of Pb^{2+} and Cu^{2+} ions. For the adsorption of heavy metal ions, the maximum uptakes evaluated by Langmuir isotherm followed the order: Pb >> Cd > Cu, and were 118.76, 37.48, and 32.22 mg/g, respectively. It was found that the process kinetics follows the pseudo-second-order model [45].

In addition, a simple method for making magnetic gel was reported, based on the concurrent synthesis of Fe_3O_4 nanoparticles and cross-linking of natural peach gum polysaccharide. The produced magnetic gel showed quick and effective adsorption capabilities toward Pb^{2+} and Cd^{2+}ions due to its porous structure, high specific surface area, and many oxygen-containing functional groups. The adsorption isotherms and kinetics showed good agreement with the pseudo-second-order model and Langmuir isotherm, respectively. The magnetic gel has a substantially greater maximum adsorption capacity for Pb^{2+} and Cd^{2+} ions than many other magnetic adsorbents that have been reported, reaching 277.0 and 141.4 mg/g, respectively. The magnetic gel demonstrated outstanding reusability and excellent magnetic separation capabilities for the purpose of adsorption [46].

4. Use of Peach Shell to Remove Dyes from Aqueous Media

The use of waste from processing agricultural raw materials and biomass components of trees, shrubs, and plants to remove dyes, in particular, is widely covered in the world literature, both in the form of separate studies and in reviews [47-52].

PKS, as well as peach gum (PG), have also been studied to remove various dyes from aqueous media [45, 53-58]. In particular, native PKS's capacity to remove the Methylene Blue (MB) dye was examined. The effect of operating parameters: the biosorbent amount (50–1000 mg/100 mL), contact time (10–180 min), solution pH (2–12), and initial concentration (10–100 ppm) on biosorption efficiency was examined. Optimal conditions for MB removal were found to be: the biosorbent amount of 400 mg/100 sm^3 and pH = 5.5. According to the Langmuir model, the maximal biosorption capacity (which corresponds to complete monolayer coverage on the PS surface) is Qmax = 183.6 mg/g, while the same constant calculated from the BET model is 98.6 mg/g. A high efficiency of MB removal was established after 180 min: 99% for [MB]I = 10 ppm and 76% for [MB]I = 100 ppm [53, 54].

MB adsorption by citric acid-modified PKS was also studied. It was found that the adsorption process was more suitable as described by the Freundlich isotherm model (R^2 = 0.9244); the experimental data can be fitted with pseudo-second-order kinetic models (R^2 = 0.9996) well. It was found that the maximum adsorption capacity was 178.25 mg/g [45].

In addition to crushed PKS, there is multiple research on the removal of various dyes by PG [55-58]. In particular, the potential use of natural PG as an alternative adsorbent for the removal of dyes from aquatic solutions was investigated. Shows that PG particles are generally spherical with sizes ranging from 2–10 μm. The PG showed high adsorption capacities and selectivity for cationic dyes (e.g., MB and methyl violet (MV)) in the pH range of 6–10. 98% of MB and MV could be adsorbed within 5 min, and both of the adsorptions reached equilibrium within 30 min. Equilibrium adsorption isotherm data indicated a good fit to the Langmuir isotherm model. The Qmax values of MB (298 mg/g) and MV (277 mg/g) on PG according to the Langmuir isotherm model. The dye uptake process followed the pseudo-second-order kinetic model [55].

In [56] demonstrated the potential of PG polysaccharide-based amine-rich gel (ARG) as an efficient adsorbent for the removal of anionic dyes from water. The adsorption performance of ARG was systematically studied by choosing Methyl Orange (MO) and Amaranth (ART) as representative anionic dyes. The adsorption process reached equilibrium within 10 min and showed a good correlation with the pseudo-second-order kinetic model and Langmuir isotherm. The adsorption capacity of ARG for MO and ART can reach 1949.5 and 1082.2 mg/g, respectively [56].

In [57] presented the simple synthesis of amphiphilic PGP-DC from natural PG polysaccharide (PGP). Compared to other separation methods, PGP-encapsulation DC's capacity for MB (1 mM) can reach as high as 182.67 mg/g under ideal circumstances. Additionally, an acidic solution might be used to renew the MB-encapsulated PGP-DC.

A novel magnetic peach gum bead (MPGB) biosorbent was successfully fabricated by a simple one-step reaction based on the concurrent cross-linking of natural peach gum polysaccharides and the production of magnetic nanoparticles. The influences of pH, ionic strength, initial dye concentration, contact time, and temperature on the adsorption property of MPGB biosorbent were investigated by choosing MB as a representative cationic dye. The Langmuir isotherm fitted the adsorption isotherm well with a maximum adsorption capacity of

231.5 mg/g. Kinetic data (ΔG^o = -1.8 - -2.7 kJ/mol at T = 298-333 K, ΔH^o = -4.7 J/mol, ΔS^o = 22.1 J/mol·K) showed good correlation with pseudo-second-order model. Thermodynamic investigation revealed that the adsorption process was spontaneous and endothermic [58].

International sources also report removing drugs from aqueous media with native and modified PKS. The potential of peach pit biosorption in removing the drug metformin hydrochloride from water is evaluated. Experiments are carried out in a closed batch system to evaluate the effect of the solution pH = 2–10, temperature (25, 35, and 45 °C), stirring (100, 150, and 200 rpm), and chemical treatments. Biosorbent characterization, kinetic tests, equilibrium tests, and thermodynamic parameter calculations are performed during the study. The operating conditions that show the best results for both the raw biosorbent and the biosorbent submitted to acid, basic, and acid followed by basic treatments with removal capacities of 3.17, 10.83, 18.10, and 49.14 mg/g, respectively, are pH = 7, E = 25 °C and 100 rpm, which result in an equilibrium time of 12 h. In the kinetic study, the pseudo-second-order model represents the best fit for the experimental data, while the Langmuir model best represents the equilibrium data. The biomasses submitted to chemical treatments show a significant increase in drug removal capacity related to the raw biosorbent, with the best maximum absorption of 82.54±1.34 mg/g achieved after the application of the acid, followed by basic treatment [59].

In addition, the biosorption potential of PKS was explored as a low-cost biosorbent for petroleum hydrocarbon from an aquatic solution. Biosorption experiments were carried out using a shake-flask technique with a constant amount of (bio) sorbent of 1 g mixed with 100 sm^3 of water contaminated with petroleum hydrocarbons at concentrations of 4, 12, 18, 24, 30, 40, and 80 mg/dm^3. However, by applying nonlinear regression, the value of sorption capacity obtained in this concentration range is 87.27 mg/g [60].

Native and modified PKS is noted as an effective and promising sorption material to remove various pollutants from aqueous media.

5. Activated Carbons from Peach Kernel Shells and their use as Sorption Materials for Various Pollutants

One of the ways to use PKS, given its density, is to make activated carbons (PSAC) [61-66] and use the latter as a sorbent. AC from PKS is characterized by a large total surface area – from 900 to 2100m^2/g [61-66], which allows their use as sorbents to remove various pollutants from aqueous media.

In particular, the preparation of porous AC from PKS by carbonization and H_3PO_4 activation was discussed. The efficiency of AC has been tested for Cr(VI) ions adsorption. The removal amount of Cr(VI) ions was found to be dependent on the initial concentration. The percentage removal was decreased with an increase in the initial concentration. The time necessary to attain adsorption equilibrium was found to be 360 min, and the maximum chromium removal was (99.58%) at pH = 5.6. The Langmuir isotherm model and the pseudo-second-order kinetic well explained the adsorption equilibrium. It was found that under static conditions, the maximum sorption capacity for Cr(VI) ions was 14.05 mg/g [67], and under dynamic conditions – 6.67 mg/g [68].

This study's objective is to remove chromium from tannery wastewater by electrosorption on PSAC thermally treated. Without using potential, the dynamic chromium adsorption research on the resulting material produced a poor clearance rate of 33.7%. Chromium adsorption is increased by up to 90% and 96%, respectively when negative

potentials of -0.7 V and -1.4 V are applied. At the same time, a positive potential of +1.4V allows the desorption of the contaminant of 138% [69].

The removal of Cr(VI) ions from aqueous solutions by PSAC has been investigated as a function of solution pH. The maximum adsorption capacities were obtained at pH = 2 in both cases, and the maximum capacities were 143 mg/g and 150 mg/g for PKS-based and commercial AC, respectively [70].

There are also several publications on removing toxic Pb^{2+} ions from simulated solutions. The potential of PSAC waste as a low-cost biosorbent was investigated for the removal of Pb^{2+} ions from an aqueous solution. The experimental results show that the percentage of biosorption increases with an increase in the biosorbent dose at optimum pH = 5. The adsorption equilibrium was achieved after 100 min. Generally, the maximum percent removal of Pb^{2+} ion was 99.56%. Three models (Langmuir, Freundlich, and Dubinin–Radushkevich) adequately describe adsorption data on the biomass of PSAC. The pseudo-second-order model best described kinetic data with a high correlation coefficient ($R^2 = 0.99$) [71]. Also, carbons were prepared from PKS using different carbonization temperatures (600, 800, and 1000 ˚C). Carbons with and without oxidation were employed to adsorption Pb^{2+} ions in an aqueous solution. Results indicated that the materials with high contents of acidic oxygen groups were more efficient in removing Pb^{2+} ions, values as high as approx. 40 mg/g is obtained for the best-performing carbon. Textural properties of the original, unoxidized carbon were significantly altered only after oxidation under an air atmosphere at 450 ˚C. On the other hand, the samples oxidized with plasma show little changes in the textural parameters, and a slight increase in the specific surface was observed for the sample treated at high RF power (100 W) [72].

The removal of various metal ions under comparable PSAC conditions was considered [73-76]. In particular, PSAC was applied to remove Cd^{2+}, Ni^{2+}, and Pb^{2+} ions from single, binary and ternary aquatic solutions. The carbon was produced by carbonization of H_3PO_4-impregnated PKS at 300 ^oC for 1 hr. The biosorption studies were studied at a pH = 4.84, and the adsorbent dosage was 1g. The initial concentrations ranged from 2 ppm to 50 ppm at room temperature. The metal ions' absorption capacities followed the order Pb^{2+} (20.0 mg/g) > Cd^{2+} (12.5 mg/g) > Ni^{2+} (6.7 mg/g). The behavior of competitive biosorption for Pb-Cd, Cd-Ni, and Pb-Ni combinations was successfully described by Langmuir Competitive Model (CLM). Pb^{2+} ions could still be effectively removed from the aqueous solution in the presence of both Cd^{2+} and Ni^{2+} ions, but the removal of Cd^{2+} and Ni^{2+} ions is suppressed in the presence of Pb^{2+} ions [74].

The synthesis of the functionalized magnetic activated PSAC for simultaneous removal of heavy metal ions from aqueous solutions. The results showed the well-dispersed spherical magnetite nanoparticles with a size of 20 nm were formed over the nano-adsorbent while the surface area was calculated to be 325 m^2/g. The Designed experimental data by employing the response surface method indicated that the adsorption temperature and pH have a synergic effect on the competitive adsorption of Pb^{2+}, Cr(VI), and Hg^{2+} in the liquid phase. The maximum removal efficiencies were calculated to be 91.15, 62.105, and 82.17% for Pb^{2+}, Cr(VI), and Hg^{2+} ions at the optimal operating conditions, respectively [75].

The removal of Cd^{2+}, Cu^{2+}, Hg^{2+}, Mn(II), and Pb^{2+} ions PSAC was studied. The initial concentration of metal ions was 50 mg/dm^3. According to the removal efficiency, metal ions are ranked as follows: Pb^{2+} > Hg^{2+} > Cd^{2+} > Cu^{2+} > Mn(II) [76].

A little more information on the use of PSAC as sorbents of various organic compounds. In particular, the extraction of the MB dye from model solutions was investigated. PSAC, when chemically activated with H3PO4 at 500 °C, proved to be good adsorbent carbon. The increased penetrant concentration generally improved the porosity properties at high surface values, around 1400 m2/g, and pore volumes up to 0.83 sm^3/g. The excellent adsorption capacity of MB dye appears, under equilibrium conditions, to reach values > 400 mg/g (437.8 mg/g) with respect to texture properties [77]. Fixed-bed treatment, in a mini-column, of dye solution at a loading of 100 mg/dm^3 proved promoted performance with raised activation agent concentration to 70% H_3PO_4 [78]. The adsorption isotherm was performed at several operating temperatures, yielding the highest value of MB adsorption capacity, 444.3 mg/g, at the highest temperature, 333 K. Isothermal models of Langmuir, Freundlich, Toth, and Redlich-Peterson were used to test the resulting adsorption equilibrium. The adsorption data were found to be in agreement with the Toth and Redlich-Peterson isotherm models more efficiently. The calculated thermodynamic parameters suggest that an endothermic and spontaneous process occurs [79].

Also, PSAC was utilized to rapidly remove and absorb Acid Red 18 (AR18) from an aqueous solution that follows pseudo-second-order kinetics. The Langmuir isotherm model corresponded well with equilibrium data than the others, implying that the adsorption of AR18 onto prepared PSAC from the aqueous solutions proceeds by a monolayer formation. Thermodynamic investigations showed that the adsorption process is exothermic and spontaneous [80].

Evaluated the performance of PSAC for removal of a textile Procion Red MX-5B dye through the batch adsorption process. In the kinetic study, the contact time was evaluated between 0 and 480 min using two different initial concentrations. Adsorption isotherms of dye onto the adsorbent were investigated in six different temperatures (298–326 K). The thermodynamic parameters of the process indicated spontaneous and exothermic adsorption. The Liu isotherm model best described equilibrium data with maximum removal capacities of 297.2 mg/g for PSAC [81].

PSAC were tested for their adsorption capacity for Acid Red 337 (AR) and 1:2 chromium complex of Acid Blue 349 (AB). The AR dye exhibited higher uptake as compared with the AB dye for all sorbents. The sorption capacity of PSAC with maximum uptake of 98.86 mg AR/g and 45.45 mg AB/g. The adsorption kinetics obeys the pseudo-second-order model. The Langmuir model best fitted the experimental sorption isotherms, and the free adsorption energy calculated from the Dubinin–Radushkevich model indicated physical sorption [82].

PSAC were also utilized as adsorbents for removing imidacloprid pesticide from aquatic media. Two types of activated carbons ($PSAC_{300}$ and $PSAC_{500}$) were synthesized via chemical activation with orthophosphoric acid followed by pyrolysis at 300 and 500 ^oC, respectively. Brunauer, Emmet, and Teller (BET) analysis revealed a mesoporous structure for $PSAC_{500}$ with a lower surface area and pore volume than the microporous $PSAC_{300}$. Both PSAC successfully removed imidacloprid with removal efficiencies of about 80% ($PSAC_{300}$) and 99% ($PSAC_{500}$) at 10 mg/dm^3 of imidacloprid and pH = 5.2, while $PSAC_{500}$ exhibited a maximum adsorption capacity of 39.37 mg/g [83].

The adsorption of three emerging compounds: stimulant (caffeine), anti-inflammatory (diclofenac), and psychoactive drug (carbamazepine), from ultrapure water by dynamic and batch tests was investigated. S-type adsorption isotherms, according to the Giles classification,

were obtained, showing a competitive effect between the aqueous solution and the target adsorbent. The adsorption capacity of carbamazepine (335 mg/g) is greater than that of caffeine (~275 mg/g) and diclofenac (200 mg/g) due to its hydrophobicity and solubility in water. AC oxidation greatly improves the hydrophilicity of the material, reduces the adsorption capacity, and strongly influences the penetration time and adsorption capacity value during the immobilized bed adsorption [84].

PKS were chemically activated using a 12 M H_3PO_4 solution and carbonized under flowing air (400 °C). PSAC is characterized by a high surface development (S_{BET} = 1262 m^2/g) and acidic character (pH_{PZC} = 4.2). A fraction of PSAC was further carbonized under an N_2 atmosphere at 800 °C ($PSAC_{800}$) to remove surface functionalities and increase its basicity (pH_{PZC} = 7.1). The synthesized materials were tested in the catalytic wet peroxide oxidation (CWPO) of highly concentrated solutions of 4-nitrophenol (4-NP, 5 g/dm^3) during 24 h experiments, conducted at relatively mild operating conditions (T = 50–110 °C, pH = 3). The increase of electron-donating functionalities in $PSAC_{800}$ led to the generation of reactive $HO^{\cdot}$ radicals, which effectively attack the pollutant molecules, being the activity towards CWPO twice than that observed with the pristine PSAC. In this case, 80% of 4-NP was removed after 24 h at 110 °C [85].

PSAC was also used to clarify apple juice and discolored red wine [86].

6. Conclusions

The review provides literature sources data on using peach tree kernel shells and gum (*Prunus persica*) as sorption materials to remove various metal ions (Cd^{2+}, Cr(III) and Cr(VI), Cu^{2+}, Pb^{2+}), dyes, and some organic compounds from aquatic environments. Brief information is provided on the number of shells remaining from peach consumption, their chemical composition, and methods of reuse. The paper presents adsorption process parameters for the pollutants under consideration. Peach fruit kernel chemical treatment contributes to improving the sorption characteristics. It was found that the Langmuir model, in most cases, accurately describes the pollutant adsorption isotherms and the kinetics of the process in most cases corresponds to the pseudo-second-order model. It was that peach fruit shell is a good precursor for activated carbons production, which is also used to remove various pollutants from aquatic environments.

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Conflicts of Interest

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