

A Review of Activated Carbon Production and Its Characterization in the Context of Irrigation Field Applications

Uzeyir YALMAN

Necmettin Erbakan University

Saban BULBUL

Necmettin Erbakan University

Hakan GOKMESE

Necmettin Erbakan University

To Cite This Chapter:

Yalman, U., Bulbul, S., & Gokmese, H. (2025). A review of activated carbon production and its characterization in the context of irrigation field applications. In H. Gokmese, S. Bulbul, & Y. Uzun (Eds.), *Innovative approaches in materials science and applications* (pp. 1–17). ISRES Book Series. ISRES Publishing.

Introduction

Activated carbon is a material used in adsorption studies in many parts of the world. Its ease of obtaining and affordability make it advantageous. It is possible to commercial activated carbon from any product rich in carbon elements. Activated carbon can be produced from many different materials with a high carbon content. Generally, various organic and inorganic wastes such as coal, bone, hazelnut and olive pits, palm and chestnut shells, petroleum derivatives, coconut shells, wood residues, apricot pits, cellulosic materials, almond and orange peels are used as raw materials in activated carbon production and commercial production is carried out for this purpose (Adinata et al., 2007; Gomez-Serrano et al., 2005; Guritno et al., 2016; Hashemian et al., 2014; Hayashi et al., 2002; Kirubakaran et al., 1991; Küçükgül, 2004; Mozammel et al., 2002; Yavuz et al., 2010). Various researches carried out in recent years in the food industry have revealed that some waste materials can be evaluated in activated carbon production and these obtained activated carbons can be used for different purposes (Mohd Radhuwan et al., 2024). In addition, studies carried out in fields such as nanoscience and electrochemistry have shown that activated carbons with electrochemical properties and electromagnetic properties can be produced (Balçık et al., 2020). Activated carbon, produced from orange peels activated with phosphoric acid, was used to reduce volatile compounds such as formaldehyde produced during particleboard production. Experimental data showed that adding activated carbon to particleboards improved mechanical and physical properties and reduced formaldehyde emissions by 28.92% in the first month and 45.25% in the third month (Ergün et al., 2025). Activated carbons were produced by activating Scots pine wood waste with zinc chloride. These products aimed to reduce formaldehyde

emissions from particleboard production and to improve the physical and mechanical properties of the panels. Experiments were conducted by adding the produced activated carbons to particleboard production at 0.5%, 1%, and 1.5%. The results of the tests indicated that the particleboards' mechanical and physical properties improved, and formaldehyde emissions decreased by 24.6% in the first month and 27% in the sixth month, respectively (Ergün et al., 2024). Activated carbons produced from cellulose by activating them separately with ZnCl_2 and H_3PO_4 were applied to nitrile butadiene and natural rubber as fillers at 0%, 5%, 10%, 15% and 20%. According to the results obtained, the mechanical properties of rubber compounds were significantly improved after the addition of activated carbon (Bülbül and Ergün, 2024). In order to investigate the recycling and usability of waste paper, which is economically meaningless, the properties of the produced activated carbons were examined and compared with commercial activated carbons. Experimental results revealed that activated carbons derived from waste paper offer higher pore structure and surface area than commercial products (Özdemir et al., 2023). Within the scope of the study, activated carbon production was successfully carried out from poplar tree waste treated with ZnCl_2 and H_3PO_4 and the results were examined. Density measurements and FE-SEM analyses revealed an activated carbon with lower density and a distinct porous structure. When the EDS results were examined, it was shown that the produced activated carbon had higher purity than the commercial product (Ergün and Bülbül, 2022). Activated carbons produced from waste paper using zinc chloride and phosphoric acid were mixed with a rubber matrix mixture. Experimental data showed that density decreased, hardness increased, and tensile strength decreased as the filler material was increased (Özdemir, 2023).

Its area of use is quite wide. In the food and beverage industry, activated carbons stand out as an effective treatment material in the removal of heavy metals, compounds that cause bad odor and color, amino acids and toxic substances (Roy, 2023). The need for more activated carbon is increasing due to the strict rules and regulations in the treatment of industrial wastewater. (González-García, 2018). The consumption of activated carbon is increasing as a result of food consumers' sensitivity to safety and quality. (Amine et al., 2006). Activated carbon production in Turkey has increased recently. Although this increase has been made, the remaining parts are filled by imports. In 2019, Turkey ranked 22nd in global activated carbon exports with a share of 0.4%. Experts predict that Turkey's activated carbon exports will increase by approximately 60% in the coming years (Orta Anadolu Kalkınma Ajansı, 2021). The global activated carbon market exceeded US\$ 5 billion by 2023 (Helvacı and Korkmaz, 2024). The activated carbon market in Turkey was approximately US\$ 38 million, resulting in a foreign trade deficit of US\$ 35 million (Trade Map n.d.). The market is expected to reach US\$ 4.58 billion in 2025 and US\$ 6.11 billion in 2026. At the same time, it is predicted that the Asia-Pacific region will hold the largest market share by 2025 (mordorintelligence n.d.).

When evaluated according to usage areas, it is estimated that the water treatment sector will hold the largest market share in 2031 (Kingsresearch n.d.).

The objectives of this study are to transform low-economic waste products, such as waste paper and poplar sawdust, into high-value products. Another objective of the study is to compare the effects of zinc chloride and phosphoric acid activation agents on activated carbon properties and to determine which activation agent is most effective. Another important objective of the study is to compare the performance of laboratory-produced activated carbons with commercially available activated carbons and to determine which sample offers the most advantageous adsorption properties.

Materials and Methods

Activated carbon production consists of several processes. Production is achieved through physical and chemical activation. Both production methods have their advantages and disadvantages. If we want higher surface area, porosity, and lower temperatures for the reaction, we use chemical activation. There are multiple chemicals used as activating agents in the production of activated carbon through chemical activation. It is seen in the literature that different activation agents are used in this process. Table 1 shows the different activation agents used in the chemical activation process.

Table 1

Commonly encountered activation agents. (Gündoğdu, 2010; Wigmans, 1989).

Boric Acid	Iron (III) Chloride	Sodium Sulfate	Sulfuric Acid
Calcium Hydroxide	Potassium Carbonate	Nitrite Acid	Zinc Chloride
Calcium Chloride	Potassium Hydroxide	Sodium Chloride	Manganese (II) Chloride

Chemical compounds such as $ZnCl_2$, KOH , H_3PO_4 , $NaOH$ and K_2CO_3 , which generally facilitate the formation of activated carbon by dehydrating the raw material, are among the most frequently used substances in the chemical activation process (Ahmedpour and Do, 1996; Gurten et al., 2012; Kopac and Erdogan, 2009; Kopac and Kırca, 2020; Rouquerol J. and Sing K., 1999; Ruofei et al., 2017; Xia et al., 2016). Potassium-based salts are preferred because they are environmentally friendly and offer a cleaner production process compared to compounds such as $ZnCl_2$ and H_3PO_4 (Tsai et al., 2001).

Physical activation, one of the methods used in activated carbon production, consists of two main stages: the degradation of the organic structure and the activation of the carbon structure. In the first stage, the carbon skeleton is formed by removing the hydrogen

and oxygen elements in the raw material. Activation is then carried out using water vapor, carbon dioxide (CO₂), or a combination of both gases at a temperature between approximately 800-1000°C, and production is completed (Yunus et al., 2022). The chemical activation method is more widely preferred compared to the physical method because it can be applied at lower temperatures and provides higher efficiency (Güneş, 2016; İlçi, 2017). Activated carbon production by chemical activation is a field of study that many researchers worldwide have focused on (Özdemir et al., 2023). Activated carbons obtained by this method have larger surface areas and more developed pore structures. Differences in the physical and chemical properties of the product may occur depending on the chemical activation agent used (Heidarinejad et al., 2020). In practice, activated carbon production is generally carried out by reacting the raw material brought to appropriate sizes either directly with the chemical agent at a temperature of 400-1000 °C or by performing the same process on a pre-carbonized structure (Bülbül, 2021).

Activated Carbon Production with Phosphoric Acid

Waste paper and black poplar sawdust were divided into 3-kilogram pieces according to different processes. 1.5 liters of 50% phosphoric acid solution and 3 liters of distilled water were added to each raw material and mixed until a homogeneous state was achieved. These prepared mixtures were treated at 110°C for 2 hours. Following this process, they were kept in an 80°C oven for 24 hours and dried. These dried samples were carbonized in a 600°C annealing oven under argon gas (50 ml/min) for 1.5 hours. After this process, they were allowed to cool. The obtained products were pre-washed with 0.5 ml of KOH and then rinsed with hot deionized water to adjust the pH value between 6-6.5. Finally, they were dried in a 100°C oven for 6 hours and then ground.

Activated Carbon Production with Zinc Chloride

Waste paper and black poplar sawdust were divided into 3-kilogram pieces according to different processes. 1.5 liters of 50% zinc chloride solution and 3 liters of distilled water were added to each raw material and mixed until a homogeneous state was achieved. These prepared mixtures were treated at 110°C for 2 hours. Following this process, they were kept in an 80°C oven for 24 hours and dried. These dried samples were carbonized in a 600°C annealing oven under argon gas (50 ml/min) for 1.5 hours. After this process, they were allowed to cool. The obtained products were pre-washed with 0.5 ml of KOH and then rinsed with hot deionized water to adjust the pH value between 6-6.5. Finally, they were dried in a 100°C oven for 6 hours and then ground.

Experimental Results

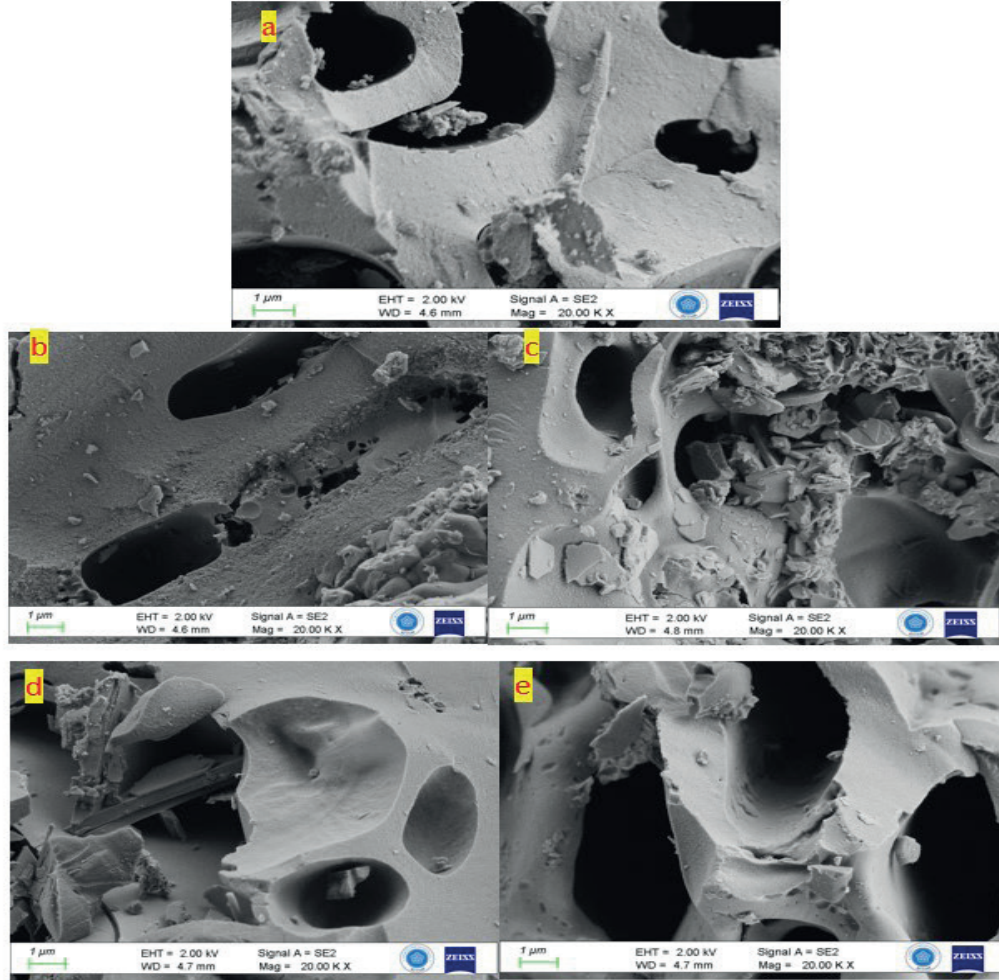
Activated carbons produced using different production methods were first subjected to BET surface analyses, FE-SEM images, and density analyses. Following these studies, adsorption experiments were conducted and the results were evaluated.

Imaging With Field Scanning Electron Microscopy (FE-SEM)

FE-SEM images of the activated carbons were obtained and examined. FE-SEM images of the prepared samples are shown in Figure 1.

Figure 1

FE-SEM images of a) commercial activated carbon sample b) AKA sample c) AKT sample d) OA sample e) OT sample



When FE-SEM images were examined, it was observed that the surface morphology of the activated carbon samples varied. While the porous structure was clearly visible in some samples, macropores were not evident in others. The images showed that the sample shapes were mostly elliptical, while some samples did not exhibit a specific geometric shape. FE-SEM analyses of the commercial activated carbon, AKT, and AKA samples revealed that their surfaces were generally rough, containing distinct indentations and protrusions; however, the amount of pores within these structures was observed to be limited. In the commercial activated carbon sample, in particular, the pores were both few in number and small in diameter, a finding confirmed by BET surface area and density analyses. The AKA sample exhibited a heterogeneous surface area, while the

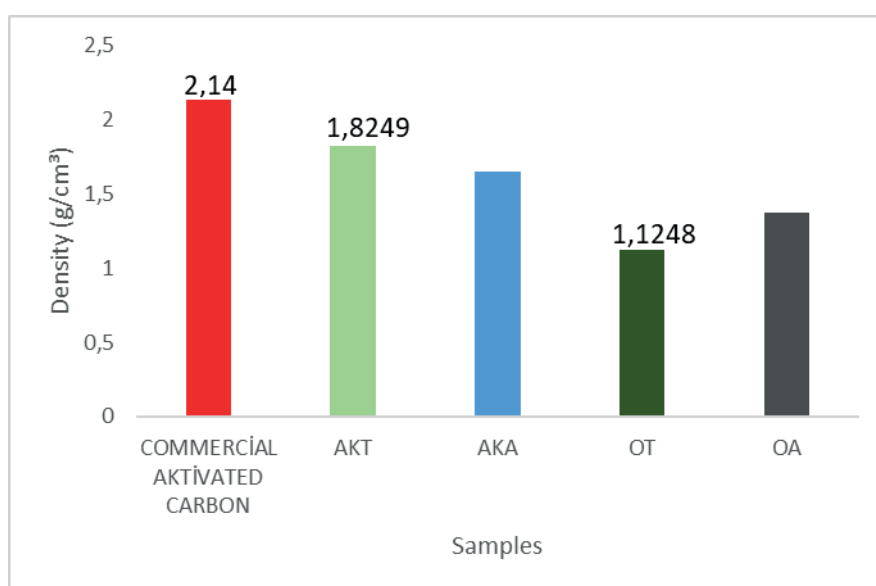
AKT sample exhibited irregular voids and variously sized and irregularly shaped pores. According to BET analysis, the AKT sample had a high number of micropores, indicating a high surface area. These findings indicate that the porous structure was largely formed in the interior of the sample. In OA and OT samples, it was observed that pores were formed more clearly and distinctly and showed a more homogeneous distribution. It is thought that an increase in the number of pores occurred in carbon samples activated with zinc chloride due to the evaporation of this substance during activation (Yagmuret al., 2008). The high BET surface area and dense micropore content of these samples support the development of the porous structure in the inner regions (Jiang et al., 2021; Küçükgül, 2004). In conclusion, it can be said that zinc chloride is a more effective activation agent than phosphoric acid in the formation of micro- and mesopores (Ergün and Bülbül, 2022; Liou, 2010).

Density Analyses

Density analyses of a total of five different activated carbons were performed and interpreted. The density analyses are shown in Figure 2.

Figure 2

Density analysis results.



Density analyses conducted in our study showed that density decreases as porosity increases in activated carbon samples. The OT sample, in particular, provides a clear example of this inverse relationship, having the lowest density (0.24 g/cm³) and the highest total pore volume. This finding is consistent with literature examining the relationships between the physical and structural characteristics of activated carbons (Jiang et al., 2021)

The findings from these studies explain the performance of the OT sample with its low

density and high pore volume. Increasing pore volume not only increases the surface area but also improves the carbon's mass-to-area ratio, offering significant advantages in terms of cost, efficiency, and productivity in various engineering applications.

Surface Analysis And Porosity (BET) Analysis

Experiments were conducted and investigated for BET surface areas and porosities of activated carbons. Table 1 shows the results of the BET surface analysis.

Table 2

BET analysis experimental results.

	Surface Area m ² /g	V _{micro} (cm ³ /g)	V _{meso} (cm ³ /g)	V _{total} (cm ³ /g)	D _p (nm)
Commercial Activated Carbon	270	0.175	0.099	0.274	1.679
Black Poplar Acid OA	957	0.415	0.186	0.601	0.592
Black Poplar Salt OT	996	0.431	0.081	0.512	0.496
Waste Paper Acid AKA	400	0.254	0.099	0.342	0.868
Waste Paper Salt AKT	501	0.344	0.034	0.378	0.584

When examining the surface analyses, the highest BET was obtained in the OT sample. These were followed by the OA, AKT, AKA, and commercial activated carbon samples, respectively. The highest ratio of the number of micropores to the total pore number was obtained in the AKT sample at 91%, while the lowest was obtained in the commercial activated carbon. The high surface area makes the OT sample the most efficient sample for adsorption. The highest average pore diameter was observed with the commercial activated carbon (1.679 nm). This indicates greater macroporosity, while the other samples are more concentrated in micro and mesopores. The OT and OA samples, with the smallest pore diameters, show that they are concentrated in micropores. OA has a high surface area and total pore volume. A balanced ratio of both micro and mesopores provides an advantage for adsorption. Many studies support the effects of microporosity on surface area and adsorption performance.

The effect of activation temperature and active substance on micropore formation was examined and it was stated that more micropores were formed, especially at lower temperatures. (Lua and Yang, 2004). It was stated that phosphoric acid contributed to the formation of more mesopores and micropore development was limited. (Toles et al., 1996). ZnCl₂ has been shown to form micropore structures that are particularly suitable

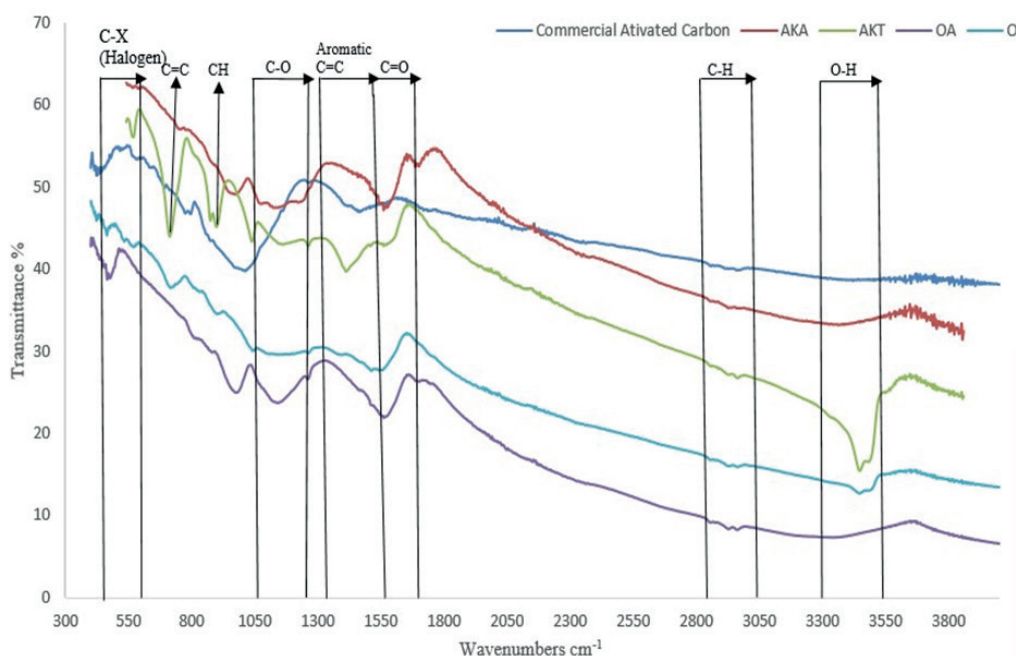
for the removal of micropollutants (Yahya et al., 2015). It has been shown that pore accessibility decreases as a result of the accumulation of acidic groups on the surface of carbons activated with phosphoric acid. (Liou, 2010). It has been stated that ZnCl_2 leaves less residue after carbonization and reduces the need for cleaning. (Namane et al., 2005). Activation with ZnCl_2 was shown to be rapid and effective at low temperatures (Savova et al., 2001).

FT-IR Analysis Results

FT-IR analysis was performed to determine the chemical composition of the commercial activated carbons. Figure 3 shows the FT-IR results of the activated carbons.

Figure 3

FT-IR analysis results



When the commercial activated carbon, OA, OT, AKA and AKT samples are examined, C-X (halogen) stretching vibrations at 450-600 cm^{-1} may contain halogen compounds (C-Cl or C-Br) (Mahapatra et al., 2012). C-O stretching vibrations at 1000-1300 cm^{-1} may indicate the presence of alcohol (R-OH), ester (R-COOR') or ether (R-O-R') groups (unitechlink.com/ftir-analysis n.d.). 1450-1600 cm^{-1} : Aromatic C=C stretching vibrations may contain aromatic rings (benzene derivatives) (Gurten et al., 2012). 1600-1700 cm^{-1} : C=O stretching vibrations. May contain carbonyl groups (ketone, aldehyde, carboxylic acid). 2800-3000 cm^{-1} : C-H stretching vibrations may indicate the presence of alkanes or alkyl groups (Yagmur et al., 2008). 3300-3500 cm^{-1} : O-H stretching vibrations may indicate the presence of alcohol or water groups (unitechlink.com/ftir-analysis n.d.).

Characteristic functional groups such as hydroxyl, aliphatic and aromatic hydrocarbons,

carbonyl groups, esters, and ethers are observed in each graph. No distinct peaks associated with inorganic compounds are present in these spectra. The presence of C=C, OH, and C-O bonds within activated carbon allowed for the reduction of color, turbidity, and COD values (Eletta et al., 2018; Mohammad Razi et al., 2018; Zhang et al., 2025).

Adsorption Experiment Results

In this study, a total of five different activated carbon samples produced using chemical activation methods and commercially available were comparatively evaluated in terms of Chemical Oxygen Demand (COD), turbidity, and color removal parameters in wastewater treatment. Adsorption experiments were conducted with our activated carbon samples. The adsorption test results are shown in Table 2.

Table 3

Adsorption experiment results

Sample Name	p H	EC _m	COD	TURBIDITY	COLOR (RES)
	PH Reading	EC Reading $\mu\text{S/cm}$	mg/L	NTU	620 nm m^{-1}
Sample	7,38	2893	725	105	1,09
Commercial Activated Carbon	7,54	2885	597	46,2	0,96
AKT	7,67	2914	682	45,5	1,42
AKA	7,64	2901	639	55,2	1,03
OT	7,64	2893	587	40,6	0,95
OA	7,64	2928	595	54,7	1,03

In the study, the OT sample stood out with the highest adsorption capacity, with 19% COD removal, 61% turbidity removal, and 13% color removal. It was reported that the improved BET surface area and porosity resulted in more efficient removal of contaminants from wastewater (Mojoudi et al., 2019). The success of the OT sample in our study supports these results. The OT sample had the highest surface area and microporosity, demonstrating the best adsorption performance. The OA and AKA samples exhibited lower microporosity and surface area due to the use of phosphoric acid. It was emphasized that phosphate residues caused pore blockage, limiting adsorption capacity (Lua and Yang, 2004)

Commercial activated carbon (HAC) performed moderately compared to laboratory-

prepared samples. This is consistent with the view that commercial carbons may not always be suitable for specific applications (Baccar et al., 2009).

It has been stated that activated carbons, especially those produced from agricultural wastes, are more effective in the adsorption of small molecules and that micropores play a dominant role here. This is true for both OT and AKT (Kalderis et al., 2008). They emphasized that surface chemistry and pore size distribution affect adsorption performance. This balance was maintained at a moderate level in the AKT and HAK samples (Rajabi et al., 2017). It has been stated that carbons with high pore volume provide faster adsorption kinetics and these structures offer advantages especially in dynamic systems (Yahya et al., 2015). It was stated that larger mesopores may also be necessary for the adsorption of colored compounds, so the commercial activated carbon sample showed similar performance in color compared to AKT (Li et al., 2008). It has been emphasized that the performance of activated carbon depends not only on the surface area but also on the functional group distribution and internal diffusion capacity (Bansal and Goyal, 2005).

As a result of this comprehensive evaluation, the OT sample activated with ZnCl_2 achieved the highest adsorption capacity in wastewater treatment thanks to its high microporosity, large surface area, and low density. The AKT sample, with a more stable structure, demonstrated superior results compared to HAK in COD, turbidity, and color removal. While HAK remains at the average level in terms of performance, it has advantages in terms of stability and accessibility. The OA and AKA samples exhibited limited adsorption capacity due to pore blockage caused by phosphoric acid. These findings once again demonstrate that activated carbon selection should be based on the activation method, microporosity ratio, surface area, and molecular properties of the target pollutant.

Conclusion

In this study, the densities, porosity, surface properties, morphological characteristics, and wastewater treatment performance of activated carbon samples produced using different production methods were comparatively evaluated. The following findings were obtained from the experiments:

- According to these results, the OT sample had the highest surface area. These were followed by OA, AKA, AKT, and Commercial Activated Carbon, respectively. If we sort by micropore structure, the order is $\text{OT} > \text{OA} > \text{AKT} > \text{AKA} > \text{Commercial Activated Carbon}$. This indicates that micropore structure is a factor affecting surface area.
- The abundance of micropores indicates that a large portion of the total pore structure occurs in the interior of the samples.

- Zinc chloride was found to be more effective in micro- and mesopore development than phosphoric acid, and its pore distribution was more homogeneous.
- FE-SEM images revealed that some samples had distinct pore structures, while others had more pronounced macropores. Specifically, the presence of fewer macropores in the AKT sample indicated that micropores were concentrated more in the interior regions of the sample. The surface morphology revealed a rough and irregular surface morphology.
- Density analyses revealed the lowest density in the OT sample. The other samples were OA, AKA, AKT, and commercial activated carbon, respectively. The results indicate an inverse relationship between porosity and density, with density decreasing as porosity increases.
- Among the samples, the OT sample achieved high removal rates, with COD (19%), turbidity (61%), and color (13%). There were no significant changes in electrical conductivity or pH across all samples.
- In activated carbons produced with phosphoric acid, samples with lower porosity and higher density were obtained due to the blockage of pores by phosphate bonds. This limited adsorption capacity.
- When comparing the OA-OT and AKT-AKA samples, it is thought that the porosity in the OA and AKA samples negatively affects the adsorption capacity. On the other hand, activated carbons activated with zinc chloride had more developed micro- and mesoporous structures. As a result, they exhibited better adsorption performance.
- Once again, it was observed that micropores play a decisive role in the adsorption process and therefore the best adsorption occurred in the OT sample..
- The high hydrophobicity of the OT sample, unlike the others, is thought to have increased adsorption efficiency. These results are consistent with previous studies. Furthermore, the presence of cellulose in the sample suggests a positive effect on adsorption performance.

The OT sample exhibited better performance compared to the other samples. Its large pore structure, low density, and high adsorption performance make it a preferred material for wastewater treatment and other industrial applications. This study demonstrated that zinc chloride is more effective than phosphoric acid.

The results of this study indicate that activated carbons produced from waste paper and wood shavings are more effective in removing COD, color, and turbidity when compared to coconut-based activated carbons commonly used in the market. Furthermore, this approach allows for the production of environmentally friendly and economically valuable products by repurposing waste materials. Future research using different activation agents could explore their effects more comprehensively.

It can be expanded by conducting different studies; optimizing the parameters such as the amount of activation agent, temperature and time used in activation, evaluating different waste materials in activated carbon production, investigating their performance in long-term use and examining the adsorption isotherms and kinetics separately.

References

- Adinata, Donni, Wan Mohd Ashri Wan Daud, and Mohd Kheireddine Aroua. 2007. "Preparation and Characterization of Activated Carbon from Palm Shell by Chemical Activation with K_2CO_3 ." *Bioresource Technology* 98(1):145–49.
- Ahmedpour, Ali, and Duong Do. 1996. "The Preparation of Active Carbons from Coal by Chemical and Physical Activation." 471–79.
- Amine, Aziz, Hasna Mohammadi, Ilhame Bourais, and Giuseppe Palleschi. 2006. "Enzyme Inhibition-Based Biosensors for Food Safety and Environmental Monitoring." *Biosensors and Bioelectronics* 21(8).
- Baccar, R., J. Bouzid, M. Feki, and A. Montiel. 2009. "Preparation of Activated Carbon from Tunisian Olive-Waste Cakes and Its Application for Adsorption of Heavy Metal Ions." *Journal of Hazardous Materials* 162(2–3):1522–29. doi:10.1016/J.JHAZMAT.2008.06.041.
- Balçık, Eda Ülkeryıldız, Mehmet Torun, and Hilal Şahin Nadeem. 2020. "Gıda Atıklarından Aktif Karbon Üretimi ve Aktif Karbonun Gıda Endüstrisinde Uygulamaları." *Gıda* 45:217–29.
- Bansal, Roop Chand, and Meenakshi Goyal. 2005. *Activated Carbon Adsorption*.
- Bülbül, Şaban, and Halime Ergün. 2024. "Investigation of the Usability of Activated Carbon as a Filling Material in Nitrile Butadiene Rubber/Natural Rubber Components and Modeling by Regression Analysis." *Journal of Elastomers and Plastics* 56(1).
- Eletta, O. A. A., S. I. Mustapha, O. A. Ajayi, and A. T. Ahmed. 2018. "Optimization of Dye Removal from Textile Wastewater Using Activated Carbon from Sawdust." *Nigerian Journal of Technological Development* 15(1).
- Ergün, Mehmet Emin, and Saban Bülbül. 2022. "Production and Characterization of Activated Carbon from Black Poplar (*Populus Nigra*) Wood Waste with Different Chemical Activation Methods." *International Advanced Researches and Engineering Journal* 6.
- Ergün, Mehmet Emin, Abdullah İstek, İsmail Özlüsoylu, Filiz Koyuncu, and Şaban Bülbül. 2024. "Low Formaldehyde-Emission Particleboards with the Addition of Scots Pine Wood Waste Derived Activated Carbon." *Wood Material Science and Engineering*.

- Gomez-Serrano, V., E. M. Cuerda-Correa, M. C. Fernandez-Gonzalez, M. F. Alexandre-Franco, and Macias-Garcia. 2005. "Preparation of Activated Carbons from Chestnut Wood by Phosphoric Acid-Chemical Activation Study of Microporosity and Fractal Dimension." *Study of Microporosity and Fractal Dimension*. 846–53.
- González-García, P. 2018. "Activated Carbon from Lignocellulosics Precursors: A Review of the Synthesis Methods, Characterization Techniques and Applications." *Renewable and Sustainable Energy Reviews* 82.
- Gündoğdu, Ali. 2010. "Fabrika Çay Atıklarından Aktif Karbon Üretimi, Karakterizasyonu ve Adsorpsiyon Özelliklerinin İncelenmesi." *Doktora Tezi, Karadeniz Teknik Üniversitesi, Fen Bilimleri Enstitüsü*.
- Güneş, Sinem. 2016. *Portakal (Citrus Sinensis L.) Küspesinden Üretilen Aktif Karbonun Sulu Çözeltilerden Reaktif Boyar Madde Adsorpsiyonunda Kullanımı*.
- Guritno, M. Anom, Riwardi Sihombing, and Yuni K. Krisnandi. 2016. "Synthesis of Porous Activated Carbon from Petroleum Sludge Using Mesoporous Silica Template." in *AIP Conference Proceedings*. Vol. 1729.
- Gurten, I. Isil, Meryem Ozmak, Emine Yagmur, and Zeki Aktas. 2012. "Preparation and Characterisation of Activated Carbon from Waste Tea Using K_2CO_3 ." *Biomass and Bioenergy* 37:73–81.
- Hashemian, Saeedeh, Khatereh Salari, and Zahra Atashi Yazdi. 2014. "Preparation of Activated Carbon from Agricultural Wastes (Almond Shell and Orange Peel) for Adsorption of 2-Pic from Aqueous Solution." *Journal of Industrial and Engineering Chemistry* 20(4).
- Hayashi, Jun'ichi, Toshihide Horikawa, Isao Takeda, Katsuhiko Muroyama, and Farid Nasir Ani. 2002. "Preparing Activated Carbon from Various Nutshells by Chemical Activation with K_2CO_3 ." *Carbon* 40(13):2381–86.
- Heidarinejad, Zoha, Mohammad Hadi Dehghani, Mohsen Heidari, Gholamali Javedan, Imran Ali, and Mika Sillanpää. 2020. "Methods for Preparation and Activation of Activated Carbon: A Review." *Environmental Chemistry Letters* 18(2).
- Helvacı, Naciye Olcay, and Yasemin Korkmaz. 2024. "Çevre Dostu Hammaddelerden Üretilen Aktif Karbonlar ve Uygulama Alanları." *Kahramanmaraş Sütçü İmam Üniversitesi Mühendislik Bilimleri Dergisi*.
- <https://unitechlink.com/ftir-analysis/>. n.d. "https://Unitechlink.Com/Ftir-Analysis/."
- İlçi, Ayşe. 2017. *Sulu Çözeltilerden Pestisit Adorpsiyonunda Zeytinyağı Katı Atığından (Pirina) Elde Edilen Aktif Karbonun Kullanılabilirliğinin*.
- Jiang, Yuting, Jing Li, Zimu Jiang, Mengjiao Shi, Rui Sheng, Zheng Liu, Su Zhang, Yali Cao, Tong Wei, and Zhuangjun Fan. 2021. "Large-Surface-Area Activated

- Carbon with High Density by Electrostatic Densification for Supercapacitor Electrodes.” *Carbon* 175.
- Kalderis, Dimitrios, Sophia Bethanis, Panagiota Paraskeva, and Evan Diamadopoulos. 2008. “Production of Activated Carbon from Bagasse and Rice Husk by a Single-Stage Chemical Activation Method at Low Retention Times.” *Bioresource Technology* 99(15):6809–16. doi:10.1016/J.BIORTECH.2008.01.041.
- Kingsresearch. n.d. “Activated-Carbon-Market-531.” <https://www.kingsresearch.com/tr/activated-carbon-market-531>.
- Kirubakaran, C. John, K. Krishnaiah, and S. K. Seshadri. 1991. “Experimental Study of the Production of Activated Carbon from Coconut Shells in a Fluidized Bed Reactor.” *Industrial and Engineering Chemistry Research* 30(11):2411–16.
- Kopac, Turkan, and Fatma Oğuz Erdogan. 2009. “Temperature and Alkaline Hydroxide Treatment Effects on Hydrogen Sorption Characteristics of Multi-Walled Carbon Nanotube-Graphite Mixture.” *Journal of Industrial and Engineering Chemistry* 15(5):730–35.
- Kopac, Turkan, and Yigit Kırca. 2020. “Effect of Ammonia and Boron Modifications on the Surface and Hydrogen Sorption Characteristics of Activated Carbons from Coal.” *International Journal of Hydrogen Energy* 45(17):10494–506.
- Küçükgül, Enver Yaser. 2004. *Ticari Aktif Karbon Üretimi ve Özelliklerinin Belirlenmesi*.
- Liou, Tzong Horng. 2010. “Development of Mesoporous Structure and High Adsorption Capacity of Biomass-Based Activated Carbon by Phosphoric Acid and Zinc Chloride Activation.” *Chemical Engineering Journal* 158(2).
- Li, Wei, Libo Zhang, Jinhui Peng, Ning Li, Shimin Zhang, and Shenghui Guo. 2008. “Tobacco Stems as a Low Cost Adsorbent for the Removal of Pb(II) from Wastewater: Equilibrium and Kinetic Studies.” *Industrial Crops and Products* 28(3):294–302. doi:10.1016/J.INDCROP.2008.03.007.
- Lua, Aik Chong, and Ting Yang. 2004. “Effect of Activation Temperature on the Textural and Chemical Properties of Potassium Hydroxide Activated Carbon Prepared from Pistachio-Nut Shell.” *Journal of Colloid and Interface Science* 274(2):594–601. doi:10.1016/J.JCIS.2003.10.001.
- Mahapatra, Kalyani, D. S. Ramteke, and L. J. Paliwal. 2012. “Production of Activated Carbon from Sludge of Food Processing Industry under Controlled Pyrolysis and Its Application for Methylene Blue Removal.” *Journal of Analytical and Applied Pyrolysis* 95.
- Mehmet Emin Ergün, Filiz Koyuncu, Abdullah İstek, İsmail Özlüsoylu, Şaban Bülbül, and Ayben Kılıç-Pekgözlü. 2025. “Utilization of Orange Peel Waste for Activated

- Carbon Production and Its Application in Particleboard for Formaldehyde Emission Reduction.” *Biofuels, Bioproducts and Biorefining (Biofpr)* 690–704.
- Mohammad Razi, Mohd Adib, Adel Al-Gheethi, Mohammed Al-Qaini, and Anwar Yousef. 2018. “Efficiency of Activated Carbon from Palm Kernel Shell for Treatment of Greywater.” *Arab Journal of Basic and Applied Sciences* 25(3). doi:10.1080/25765299.2018.1514142.
- Mohd Radhuwan, Siti Nasuha, Ahmed Saud Abdulhameed, Ali H. Jawad, Zeid A. ALOthman, Lee D. Wilson, and Sameer Algburi. 2024. “Production of Activated Carbon from Food Wastes (Chicken Bones and Rice Waste) by Microwave Assisted ZnCl_2 Activation: An Optimized Process for Crystal Violet Dye Removal.” *International Journal of Phytoremediation* 26(5).
- Mojoudi, N., N. Mirghaffari, M. Soleimani, H. Shariatmadari, C. Belder, and J. Bedia. 2019. “Phenol Adsorption on High Microporous Activated Carbons Prepared from Oily Sludge: Equilibrium, Kinetic and Thermodynamic Studies.” *Scientific Reports* 9(1). doi:10.1038/s41598-019-55794-4.
- mordorintelligence. n.d. “Mordorintelligence Reports Activated-Carbon-Market.” <https://www.mordorintelligence.com/industry-reports/activated-carbon-market>.
- Mozammel, Hoque M., Ota Masahiro, and S. C. Bhattacharya. 2002. “Activated Charcoal from Coconut Shell Using ZnCl_2 Activation.” *Biomass and Bioenergy* 22(5):397–400.
- Namane, A., A. Mekarzia, K. Benrachedi, N. Belhaneche-Bensemra, and A. Hellal. 2005. “Determination of the Adsorption Capacity of Activated Carbon Made from Coffee Grounds by Chemical Activation with ZnCl_2 and H_3PO_4 .” *Journal of Hazardous Materials* 119(1–3):189–94. doi:10.1016/J.JHAZMAT.2004.12.006.
- Orta Anadolu Kalkınma Ajansı. 2021. *Sivas İli Aktif Karbon Üretimi Ön Fizibilite Raporu*.
- Özdemir Derya. 2023. “Atık Kâğıttan Üretilen Aktif Karbonun Kauçuk Matrisli Bileşiklerde Kullanımı ve Karakterizasyonu .” *Necmettin Erbakan Üniversitesi, Fen Bilimleri Enstitüsü, Yüksek Lisans Tezi*.
- Özdemir, Derya, Saban Bülbül, and Mehmet Emin Ergün. 2023. “Production of Activated Carbon from the Waste Paper by Chemical Activation Method.” *International Advanced Researches and Engineering Journal* 7(1). doi:10.35860/iaiej.1222591.
- Rajabi, M., K. Mahanpoor, and O. Moradi. 2017. “Removal of Dye Molecules from Aqueous Solution by Carbon Nanotubes and Carbon Nanotube Functional Groups: Critical Review.” *RSC Advances* 7(74). doi:10.1039/c7ra09377b.

- Rouquerol J., and Sing K. 1999. "Adsorption by Powders and Porous Solids Academic Press, San Diego." *Vakuum in Forschung Und Praxis* 404–404.
- Roy, Glenn M. 2023. *Activated Carbon Applications in the Food and Pharmaceutical Industries*. Routledge. New York.
- Ruofei, C., L. Liqing, L. Zheng, L. Mingming, W. Chunhao, L. Hailong, M. Weiwu, and W. Shaobin. 2017. "Preparation and Characterization of Activated Carbons from Tobacco Stem by Chemical Activation." *Journal of the Air and Waste Management Association* 67(6):713–24.
- Şaban BÜLBÜL. 2021. "Portakal Kabuğu ve Odun Atıklardan Üretilen Aktif Karbonun Ayakkabı Tabanı Üretiminde Değerlendirilmesi." *Necmettin Erbakan Üniversitesi, Fen Bilimleri Enstitüsü, BAP Projesi*.
- Savova, D., E. Apak, E. Ekinci, F. Yardim, N. Petrov, T. Budinova, M. Razvigorova, and V. Minkova. 2001. "Biomass Conversion to Carbon Adsorbents and Gas." *Biomass and Bioenergy* 21(2):133–42. doi:10.1016/S0961-9534(01)00027-7.
- Toles, C., S. Rimmer, and J. C. Hower. 1996. "Production of Activated Carbons from a Washington Lignite Using Phosphoric Acid Activation." *Carbon* 34(11).
- Trade Map. n.d. "Trade Map." <https://www.Trademap.Org/Index.aspx>.
- Tsai, W. T., C. Y. Chang, S. Y. Wang, C. F. Chang, S. F. Chien, and H. F. Sun. 2001. "Preparation of Activated Carbons from Corn Cob Catalyzed by Potassium Salts and Subsequent Gasification with CO₂." *Bioresource Technology* 78(2):203–8. <https://www.sciencedirect.com/science/article/abs/pii/S0960852400001115>.
- Wigmans, T. 1989. "Industrial Aspects of Production and Use of Activated Carbons." *Carbon* 27(1).
- Xia, Hongying, Song Cheng, Libo Zhang, and Jinhui Peng. 2016. "Utilization of Walnut Shell as a Feedstock for Preparing High Surface Area Activated Carbon by Microwave Induced Activation: Effect of Activation Agents." *Green Processing and Synthesis* 5(1):7–14.
- Yagmur, Emine, Meryem Ozmak, and Zeki Aktas. 2008. "A Novel Method for Production of Activated Carbon from Waste Tea by Chemical Activation with Microwave Energy." *Fuel* 87.
- Yahya, Mohd Adib, Z. Al-Qodah, and C. W. Zanariah Ngah. 2015. "Agricultural Bio-Waste Materials as Potential Sustainable Precursors Used for Activated Carbon Production: A Review." *Renewable and Sustainable Energy Reviews* 46:218–35. doi:10.1016/J.RSER.2015.02.051.
- Yavuz, Reha, Hanife Akyildiz, Nilgün Karatepe, and Eda Çetinkaya. 2010. "Influence of Preparation Conditions on Porous Structures of Olive Stone Activated by

H₃PO₄.” *Fuel Processing Technology* 91(1).

Yunus, Zalilah Murni, G. Yashni, Adel Al-Gheethi, Norzila Othman, Rafidah Hamdan, and Nurun Najwa Ruslan. 2022. “Advanced Methods for Activated Carbon from Agriculture Wastes; a Comprehensive Review.” *International Journal of Environmental Analytical Chemistry* 102(1).

Zhang, Huirong, Lijun Zhu, Zihe Pan, Jinglei Cui, Baofeng Wang, Dongke Zhang, Yanxia Guo, and Fangqin Cheng. 2025. “Exploring the Mechanisms of Enhanced Activated Carbon’s Toluene Adsorption and Regeneration by Utilizing Inherent Pyrite in Coal.” *Fuel* 386:134224.

About The Authors

Uzeyir YALMAN, PhD is a Machine Manufacturing Manager at the 41st Branch Directorate of the 4th Regional Directorate of the State Hydraulic Works. I have a Master’s degree in Mechanical Engineering from Necmettin Erbakan University. His main areas of interest are dams, reservoirs, and irrigation facilities.

Email: uzeyir.yalman52@hotmail.com, **ORCID:** 0000-0002-1221-5661

Saban BULBUL, PhD is an Associate Professor of Mechanical Engineering at Necmettin Erbakan University in Konya. I have a master’s degree in metallurgy education from Karabük University. His main areas of interest are casting technology, powder metallurgy, polymer materials and polymer applications.

Email: sabanbulbul42@hotmail.com, **ORCID:** 0000-0002-9268-1469

Hakan GOKMESE, PhD is a Professor of Mechanical Engineering at Necmettin Erbakan University in Konya. I have a master’s degree in metallurgy education from Gazi University. His main areas of interest are casting technology, powder metallurgy, heat treatments and composites-nanocomposites applications.

Email: hakan1440@gmail.com, **ORCID:** 0000-0003-0053-8444

Similarity Index

The similarity index obtained from the plagiarism software for his book chapter is 7 %.