



RESEARCH ARTICLE

DATE PITS ACTIVATED CARBON AS AN EFFECTIVE ADSORBENT FOR WATER TREATMENT USING H₃PO₄ AND H₂SO₄ ACTIVATING AGENTS

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ABSTRACT

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Adsorption is a widely used, cost-effective method for water purification and recycling. Researchers have explored various materials and techniques to develop inexpensive and efficient adsorbents. One promising approach involves the production of chemically activated carbon (AC) from locally available resources to remove water contaminants effectively. This study aims to evaluate the effectiveness of date pit-derived activated carbon (DP-AC) for water treatment, specifically for the removal of Methylene Blue (MB). The adsorption performance of DP-AC was assessed using two different chemical activating agents, H₃PO₄ and H₂SO₄. Additionally, the influence of key parameters, including particle size, temperature, and pH, on adsorption capacity was investigated. Batch adsorption experiments revealed that adsorption equilibrium was achieved within 60 to 120 minutes. The highest adsorption efficiency was observed when using H₃PO₄-activated carbon, with optimal conditions determined as a particle size of 0.6 mm, a temperature of 30°C, and an alkaline medium (pH 8.06). Furthermore, results indicated that adsorption performance was superior in distilled water compared to natural spring water, due to the competitive adsorption effects of naturally occurring dissolved matter in spring water. The adsorption data were best described by the Freundlich isotherm model, suggesting a heterogeneous adsorption process with multilayer adsorption behavior. The findings of this study demonstrate that date pit-derived activated carbon is an effective and low-cost alternative to commercial AC for water treatment. The use of H₃PO₄ as an activating agent significantly enhances adsorption capacity, making DP-AC a promising solution for sustainable and affordable water purification applications.

KEYWORDS

activated carbon (AC); date pits activated carbon (DP-AC); adsorption; methylene blue (MB); langmuir isotherm; freundlich isotherm

1. INTRODUCTION

Today, the world faces continuous population growth and urbanization, placing immense pressure on water resources, including their availability and quality (Hamaideh et al., 2024). This issue is not limited to developing countries; even developed nations experience persistent water shortages, further exacerbated by pollution from industrial activities (Hamaideh et al., 2024; Al-Ghouti and Al-Absi, 2020; Jamrah et al., 2024; Amr et al., 2024). Moreover, with projections indicating that over one billion people may face water shortages by 2025, the United Nations Sustainable Development Goal 6—ensuring access to clean water and sanitation—has become increasingly critical (Alazaiza et al., 2025; Naidu et al., 2021). According to the World Health Organization (WHO), approximately 1.6 million deaths in 2018 were attributed to water pollution, underscoring the urgent need for effective water management (Naidu et al., 2021; Sanganyado, 2022; Bello et al., 2022; Bhatnagar and Sillanpää, 2017).

Ensuring the availability of clean water for various purposes, including drinking, agriculture, industrial operations, and recreational activities, depends on effective water and wastewater treatment (Jamrah et al., 2024). This process involves a range of advanced methods and technologies designed to remove or reduce pollutants and improve water quality to meet specific standards and regulations (Jamrah et al., 2024).

Physical, chemical, and biological methods, tailored to the specific characteristics of the water source and the targeted pollutants, are commonly used in water and wastewater treatment (Al-Ghouti and Al-Absi, 2020; Jamrah et al., 2024). These methods may include electrocoagulation, reverse osmosis (Tayeh et al., 2025; Al-Zghoul et al., 2023; Al-Qodah et al., 2024). The study coagulation/flocculation, advanced oxidation processes membrane filtration and aerobic and anaerobic treatments (Johnson et al., 2024; Rifi et al., 2022; da Silva et al., 2021; Preethi, Shanmugavel et al., 2024; Domingues et al., 2021; Yahiaoui et al., 2011). However, each of these approaches has certain limitations, such as complexity, inefficiency, sludge formation, limited biodegradability unfeasibility in large-scale applications and the need for multiple treatment steps to achieve the desired water quality standards (Jamrah et al., 2024; Jamrah et al., 2024; Chandra et al., 2020; Surkatti et al., 2021; Jamrah et al., 2024; Chandra et al., 2020; Gayakwad et al., 2024). Due to these challenges, there is an urgent need to develop simple, cost-effective, and efficient dye removal methods for water treatment (Jamrah et al., 2024; Gayakwad et al., 2024; Sakoor and Nasar, 2016; Jamrah et al., 2024). Among various water treatment methods, adsorption is widely regarded as one of the most practical approaches due to its simplicity, adaptability, and low land and initial investment requirements (Ahmad et al., 2012). Additionally, adsorption is highly effective in removing both soluble and insoluble contaminants, achieving a removal efficiency of up to 99.9% (

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Surkatti et al., 2021; Ahmad et al., 2012; Castañeda-Díaz et al., 2017). Recently, there has been a growing interest in identifying low-cost adsorbents with strong contaminant-binding capabilities (Jamrah et al., 2024; Zhou et al., 2018). Utilizing locally available materials, such as natural resources, industrial byproducts, and agricultural waste, presents a promising solution for wastewater treatment (Jamrah et al., 2024; Rashed, 2013). Among the various adsorbents, activated carbon (AC) is one of the most widely used materials due to its ability to remove a broad range of pollutants from water (Surkatti et al., 2021; Bansal and Goyal, 2005; Binnie et al., 2017). However, despite its versatility and effectiveness, the high cost of AC remains a significant limitation, restricting its large-scale application (Surkatti et al., 2021; Bansal and Goyal, 2005; Binnie et al., 2017; Hassan et al., 2024). Consequently, there is a strong incentive to develop cost-effective alternatives to conventional activated carbon for water treatment (Jamrah et al., 2024).

Waste materials can be effectively converted into activated carbon (AC) worldwide (Jamrah et al., 2024). This approach offers a dual benefit: it reduces waste disposal needs while utilizing industrial and agricultural byproducts, thereby lowering the overall cost of AC production (Jamrah et al., 2024; Surkatti et al., 2021). As part of ongoing efforts to find cost-effective alternatives to commercial AC several studies have explored the preparation of activated carbon from inexpensive and readily available materials, such as date pits (DP) [and olive pits (OP) (Bansal and Goyal, 2005; Jamrah et al., 2024; Al Mesfer et al., 2024; Eder et al., 2021). The date palm (*Phoenix dactylifera* L.) is widely cultivated worldwide, particularly in the Middle East, North Africa, and Gulf regions, primarily for its fruit (dates) (Surkatti et al., 2021). Date palms begin bearing fruit five to eight years after planting, and globally, approximately 120 million date palms are grown across 30 countries, covering an estimated 800,000 hectares of land (Surkatti et al., 2021; Al-Kaabi et al., 2005).

Date pits (DP) primarily consist of moisture, proteins, lipids, and carbohydrates. Carbohydrates make up the largest proportion (70% to 86%), followed by fats (5% to 10.5%), while ash (0.84% to 1.2%) and proteins (2.3% to 6.9%) account for the remainder (Surkatti et al., 2021; Hossain et al., 2014). In Jordan, date trees are widely available, making date pits an economical and sustainable resource for activated carbon production. Date pit-derived activated carbon (DP-AC) is widely used as an adsorbent for removing toxic organic and inorganic compounds from water (Hijab, 2021). Recycling regional agricultural waste and byproducts not only reduces waste disposal costs but also provides a cost-effective alternative to commercial activated carbon (AC) (Surkatti et al., 2021). Numerous studies have investigated the effectiveness of DP-AC in treating wastewater, specifically focusing on the removal of industrial pollutants such as Methylene Blue (MB) ($C_{16}H_{18}ClN_3S$) from aqueous solutions (Surkatti et al., 2021; Akl et al., 2013).

MB is commonly used as a cationic dye in the textile industry, including for dyeing wool, cotton, and silk (Khan et al., 2022). The printing and dyeing industries produce substantial amounts of wastewater containing organic dyes (Donkadokula et al., 2020). Dye wastewater is characterized by high discharge volumes, high chromaticity, high organic matter content, and low biodegradability, making it a significant environmental concern (Donkadokula et al., 2020). Moreover, exposure to MB can lead to several harmful effects on human and animal health, including inflammation of the lips, throat, esophagus, and stomach, as well as vomiting, diarrhea, and nausea (Donkadokula et al., 2020; Valdetaro et al., 2023). With increasing population growth and urbanization, water resources face heightened pressure in terms of availability and quality, threatening access to clean water. Estimates suggest that over one billion people may experience water shortages by 2025, making the United Nations Sustainable Development Goal 6—ensuring clean water and sanitation—more critical than ever (Bhatnagar and Sillanpää, 2017). Many countries, including developed nations, suffer from water pollution caused by industrial activities, necessitating effective and affordable treatment technologies (Al-Zghoul et al., 2023).

The primary objective of this study is to assess the effectiveness of date pit-derived activated carbon (AC) in water treatment, particularly for the removal of contaminants such as heavy metals and organic pollutants. Specifically, the study aims to compare the adsorption capacity of AC activated using H_3PO_4 and H_2SO_4 , investigating their efficiency in water purification. Additionally, the research explores the impact of various operating parameters, including pH, contact time, and adsorbent dose, on adsorption performance. Furthermore, the study evaluates the reusability and stability of the prepared AC across successive adsorption cycles. These aims and objectives have been incorporated into the revised manuscript to enhance its clarity and focus.

2. METHODOLOGY

This study employed a three-step approach to activate date pits (DP) and evaluate the factors influencing their adsorption performance. The activation process was designed to enhance the material's porosity, thereby improving its adsorption capacity, as described by (Khan et al., 2022).

2.1. Activation of Date Pits

DP activation was performed using two chemical activating agents, H_2SO_4 and H_3PO_4 , following the procedures outlined by (Al-Balushi et al., 2017; Reddy et al., 2012). The activation process involved several key steps:

1. Preparation: The date pits were thoroughly cleaned, dried, and then subjected to thermal treatment in a furnace at temperatures ranging from 500°C to 1000°C.
2. Particle Size Reduction: After heating, the activated material was crushed into different particle sizes to optimize adsorption efficiency.

2.2 Adsorption Isotherm Experiments

To analyze the adsorption capacity, batch experiments were conducted using methylene blue as a model contaminant. The adsorption isotherms were generated using a standard "bottle point" batch process:

- Pre-weighed adsorbent samples were placed into tubes.
- Surface water solutions containing different pollutant concentrations (60 ppm, 70 ppm, 90 ppm, 100 ppm, 120 ppm, 130 ppm, 150 ppm, 200 ppm, 250 ppm, and 300 ppm) were added.
- Various adsorbent doses (0.3 g, 0.5 g, 0.7 g, 0.9 g, 1.1 g, and 1.3 g) were tested to determine the optimal amount. Based on adsorption performance, a sample weight of 0.7 g was identified as the most effective and was used in subsequent experiments.
- The samples were shaken at 100 rpm and maintained at a temperature of 20°C, with a fixed particle size of 0.6 mm.
- After the reaction time (determined from kinetic experiments), the suspensions were allowed to settle, and phase separation was achieved via centrifugation. If necessary, additional filtration using 0.45 µm membrane filters was performed.

2.3 Evaluation of Adsorption Conditions

The adsorption process was further analyzed under varying experimental conditions, including:

- pH: The effect of pH on adsorption capacity was examined.
- Temperature: Experiments were repeated at 25°C and 30°C to assess temperature influence.
- Particle Size: Different particle sizes were tested to determine their impact on adsorption efficiency.
- Water Source: The adsorption performance was evaluated in different water matrices to understand variations in effectiveness.

Through these systematic steps, the study optimized the adsorption conditions and provided insights into the reusability and stability of the prepared adsorbents for water treatment applications. This methodology aligns with previously established studies aimed at enhancing adsorbent properties for environmental remediation (Al-Ghouti et al., 2020).

3. RESULTS

3.1 Analysis of MB

The concentration of Methylene Blue (MB) in the supernatant solution was measured using a double-beam UV spectrophotometer set at 665 nm, both before and during the adsorption process. At this wavelength, the activated carbon (AC) supernatant showed no absorbance, and the calibration curve exhibited high repeatability. Additionally, the calibration curve remained linear across the concentration range used in this study.

3.2 Date Pits

3.2.1 Effect of Particle Size

When assessing the date pit (DP) particle size, the results in Figure 1 show that samples activated with H_3PO_4 exhibit a higher adsorption capacity of up to 3.5 mg/l, compared to samples activated with H_2SO_4 , which only reach 1 mg/l at any equilibrium concentration. Additionally, at a particle size of 0.6 mm, the adsorption rate using 100 mg/l of H_2SO_4 is 2 mg/g, while a significantly higher rate of 3.5 mg/g is achieved with H_3PO_4 at an equilibrium concentration of just 50 mg/l. The results also demonstrate that smaller particle sizes result in higher adsorption rates for both activating agents. However, for samples treated with H_3PO_4 , the adsorption rates for both particle sizes are relatively similar. In contrast, when using H_2SO_4 as the activating agent, the adsorption rate for the 0.6 mm particles is up to four times higher than that for the 1.18 mm particles. Smaller particles (0.6 mm) exhibited higher adsorption capacity compared to larger particles (1.18 mm) due to increased surface area. Similar findings were reported in earlier studies on agricultural biomass-derived adsorbents.

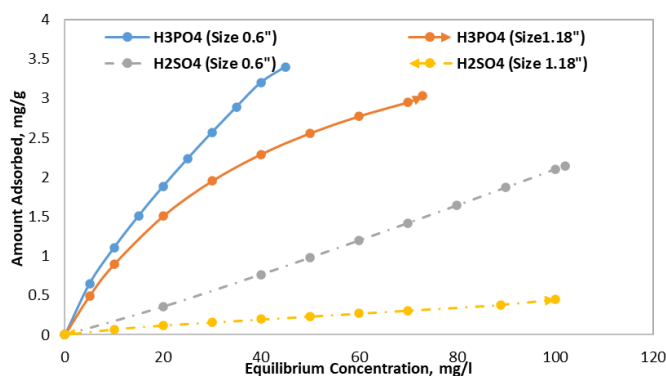


Figure 1: Effect of DP size investigated using 0.6 mm (non-arrowed line) and 1.18 mm (arrowed line) particles on amount of pollutant adsorption in mg/g, using two different activating agents: H_3PO_4 (solid line) and H_2SO_4 (dashed line).

3.2.2 Effect of Temperature

Additionally, the results in Figure 2 indicate that increasing the temperature enhances the adsorption rates for both activating agents. For H_3PO_4 , the adsorption rate at an equilibrium concentration of up to 15 mg/l at 30°C is nearly double the rate observed at 25°C and triple the rate at 20°C. Moreover, H_3PO_4 consistently shows significantly faster adsorption rates than H_2SO_4 at all equilibrium concentrations. In contrast, when carbonization is performed with H_2SO_4 at 20°C or 25°C, the results are comparable. However, a substantial increase in the adsorption rate is observed when the temperature is raised to 30°C. Increasing the temperature to 30°C significantly enhanced adsorption, indicating that the process is thermodynamically favorable (Al-Qodah et al., 2024).

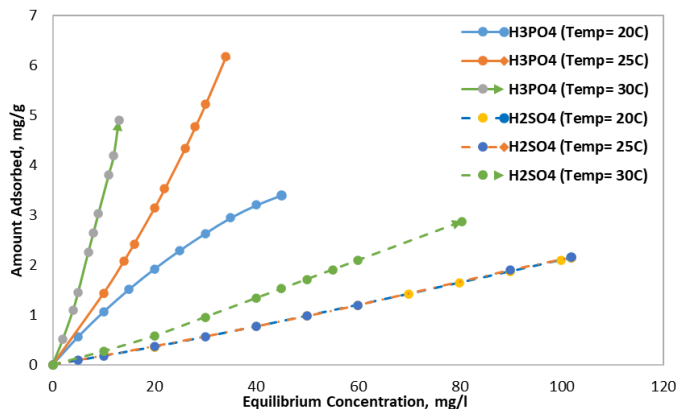


Figure 2: Effect of temperature investigated at 3 different temperatures 20 oC (Arrow ended), 25 oC (Diamond ended), and 30 oC (Oval Ended) on amount of pollutant adsorption in mg/g, using two different activating agents: H_3PO_4 (solid line) and H_2SO_4 (dashed line).

3.2.3 Effect of pH

Furthermore, the results in Figure 3 show a similar pattern for both activating agents across various pH values. For both agents, the relationship between the adsorption amount and equilibrium concentration is linear. However, significantly higher adsorption rates are observed in a basic solution (pH = 8.6) compared to an acidic solution (pH = 4.65), with rates reaching 3-4 times higher in the basic solution. Notably, the H_3PO_4 activating agent consistently shows much higher adsorption rates than H_2SO_4 at all equilibrium concentrations. Adsorption was more efficient in an alkaline medium (pH = 8.06) compared to an acidic medium, which can be attributed to surface charge modifications that affect interactions with the dye (Bello and Ahmad, 2022).

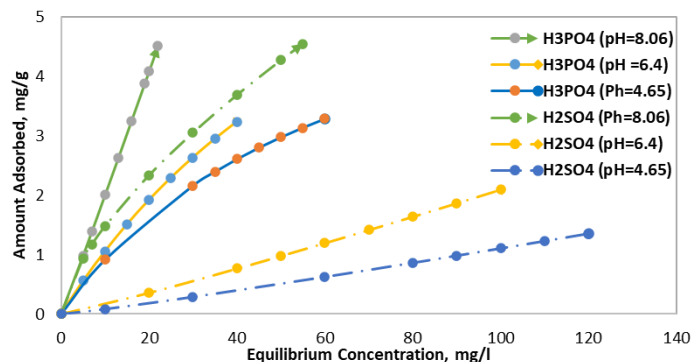


Figure 3: Effect of pH investigated at 3 different concentrations (pH = 8.06, arrow ended), (pH = 6.4, diamond ended), and (pH = 4.65, oval ended) on amount of pollutant adsorption in mg/g, using two different activating agents: H_3PO_4 (solid line) and H_2SO_4 (dashed line).

3.2.4 Competition effect at 20 °C for 0.6 mm particle size.

Finally, the results in Figure 4 show a similar pattern for both activating agents, with a higher adsorption rate observed when using distilled water. The adsorption rate with distilled water is up to a 200% increase in efficiency compared to natural spring water, particularly when the equilibrium concentration exceeds 35 mg/l for the H_3PO_4 activating agent and 70 mg/l for the H_2SO_4 activating agent. Overall, the results suggest that using H_3PO_4 as an activating agent yields significantly higher adsorption compared to H_2SO_4 , especially under conditions of higher temperature, a basic medium, smaller particle sizes, and the use of distilled water.

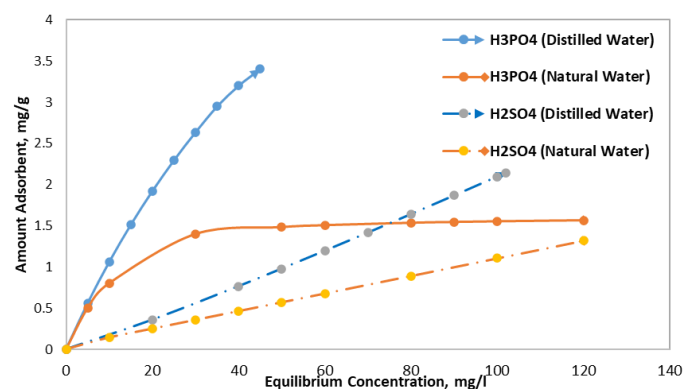


Figure 4: Effect of water source investigated using distilled water (arrow ended) and natural water (diamond ended) on amount of pollutant adsorption in mg/g, using two different activating agents: H_3PO_4 (solid line) and H_2SO_4 (dashed line).

4. CONCLUSION

This study demonstrates the effectiveness of date pit-derived activated carbon (DP-AC) as an adsorbent for pollutant removal. Consistent with previous research, this approach offers an efficient, cost-effective, and environmentally friendly alternative for water treatment. The findings align with existing literature, confirming that activated carbon materials exhibit significantly higher porosity compared to raw materials, which enhances their adsorption capacity. This improvement is attributed to the loss of volatile matter during carbonization, which results in an advanced pore structure and increased porosity. The study compared the use of H_3PO_4 and H_2SO_4 as activating agents under various conditions, revealing

that H_3PO_4 activation achieved superior adsorption rates.

During chemical activation, H_3PO_4 played a key role in decomposing organic material, releasing volatile matter, and developing a microporous structure. Additionally, it facilitated the dehydration of cellulose, weakening the precursor structure and enhancing pore formation. The effect of particle size was also assessed, confirming the findings of previous studies. Results showed that smaller particles (0.6 mm) exhibited higher adsorption rates compared to larger particles (1.18 mm). This is likely due to the increased microporosity volume and higher surface area, both of which contribute to enhanced adsorption efficiency.

The impact of pH on adsorption performance was also investigated. Results indicated that adsorption was significantly higher at pH 8.6 compared to lower pH values (6.4 and 4.65). This effect can be explained by the influence of pH on surface chemistry and charge distribution. At lower pH levels, the adsorbent surface becomes positively charged, leading to electrostatic repulsion and reduced adsorption efficiency for cationic pollutants.

Temperature variations (20°C, 25°C, and 30°C) were examined to determine their influence on adsorption efficiency. The findings confirmed that the adsorption process is spontaneous at room temperature, with the highest adsorption occurring at 30°C. These results align with previous studies recommending this temperature range for optimizing DP-AC performance in aqueous solutions.

Finally, the effect of water source on adsorption capacity was evaluated. Distilled water resulted in the highest adsorption efficiency, whereas adsorption capacity was reduced when using spring water. This reduction is attributed to the presence of dissolved minerals (e.g., Na, K, Li, Ca, Ba), which compete with the target pollutant for adsorption sites, thereby lowering the overall adsorption performance.

Overall, this study highlights the high efficiency of locally available DP-AC as a sustainable adsorbent for pollutant removal. The comparison of H_3PO_4 and H_2SO_4 activation emphasizes the importance of surface area and porosity in determining adsorption capacity, providing valuable insights for optimizing AC-based water treatment solutions.

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