American Journal of Essential Oils and Natural Products

Available online at www.essencejournal.com

AJEONP American Journal of Essential Oils and Natural Products

ISSN: 2321-9114
https://www.essencejournal.com
AJEONP 2024; 13(1): 112-116

Received: 20-05-2025
Accepted: 22-06-2025

Lena Andersson
Department of Environmental Chemistry, Gothenburg University, Gothenburg, Sweden

Erik Johansson
Department of Chemical Engineering, Uppsala University, Uppsala, Sweden

Corresponding Author:
Lena Andersson
Department of Environmental Chemistry, Gothenburg University, Gothenburg, Sweden

Coconut shell-based activated carbon for purification of essential oils and natural extracts

Lena Andersson and Erik Johansson

Abstract
Coconut shell-based activated carbon (CSAC) has garnered attention for its efficacy in purifying essential oils and natural extracts. This study investigates the preparation, characterization, and application of CSAC in the purification processes of these substances. The activated carbon was synthesized through chemical activation using phosphoric acid, followed by characterization techniques such as surface area analysis, scanning electron microscopy, and Fourier-transform infrared spectroscopy. The adsorption capacities of CSAC were evaluated for various essential oils, including lavender and eucalyptus, and natural extracts like turmeric and ginger. Results indicated significant improvements in the purity and quality of the oils and extracts post-treatment, highlighting CSAC's potential as an effective and sustainable adsorbent in the purification industry. This research underscores the viability of utilizing coconut shell waste to produce activated carbon for enhancing the quality of essential oils and natural extracts.

Keywords Coconut shell-based activated carbon, purification, essential oils, natural extracts, chemical activation, adsorption capacity, sustainability

Introduction
Activated carbon, known for its porous structure and high surface area, is widely used in various applications such as water purification, air filtration, and in the food and pharmaceutical industries. Among the various feedstocks for producing activated carbon, coconut shells are an attractive option due to their abundant availability, low cost, and high carbon content. The use of coconut shell-based activated carbon (CSAC) for the purification of essential oils and natural extracts has gained increasing interest in recent years. Essential oils and natural extracts are highly valued in the pharmaceutical, cosmetic, and food industries for their therapeutic properties, flavor, and fragrance. However, these products often contain impurities, including organic compounds, residual solvents, and colorants, which can affect their quality and efficacy.

The adsorption properties of activated carbon make it an ideal candidate for removing these impurities. CSAC, in particular, has shown promising results due to its large surface area and well-developed microporosity. This paper explores the preparation of CSAC, its characterization, and its application in the purification of essential oils and natural extracts. Through chemical activation, the coconut shells are transformed into a high-surface-area adsorbent, making them highly effective in removing impurities from these valuable products.

In addition to its high adsorption capacity, CSAC is environmentally friendly and cost-effective, making it a sustainable alternative to more expensive synthetic adsorbents. This research aims to evaluate the efficiency of CSAC in purifying essential oils like lavender, eucalyptus, and natural extracts such as turmeric and ginger, and to provide insights into its potential as a sustainable solution for the essential oil and natural extract purification industry.

Preparation and Application of Coconut Shell-Based Activated Carbon for Purification of Essential Oils and Natural Extracts
Activated carbon, a highly porous material with a large surface area, is widely recognized for its effective adsorption properties. These properties make it suitable for a range of applications, including air and water purification, gold recovery, and the removal of organic compounds in the pharmaceutical, cosmetic, and food industries. Among the various raw materials for producing activated carbon, coconut shells have emerged as one of the most promising due to their abundance, renewability, and high carbon content. The application of

coconut shell-based activated carbon (CSAC) in the purification of essential oils and natural extracts has gained significant attention in recent years. Essential oils, often used for their therapeutic properties, flavoring, and fragrance, require purification to remove impurities such as residual solvents, colorants, and organic contaminants. Natural extracts, such as those derived from turmeric and ginger, also benefit from purification processes to improve their quality and efficacy.

The process of preparing activated carbon from coconut shells involves a combination of carbonization and chemical activation, which results in a material with a high surface area and well-developed microporosity. This study investigates the preparation, characterization, and application of CSAC in the purification of essential oils and natural extracts.

Preparation of Coconut Shell-Based Activated Carbon (CSAC)

The production of CSAC is carried out through two main steps: carbonization and activation. These steps are crucial in determining the surface area, porosity, and adsorption capacity of the activated carbon, which in turn impacts its performance in purifying essential oils and natural extracts.

1. **Carbonization Process**
   The first step in preparing CSAC is carbonization, which involves heating the coconut shells in the absence of oxygen to a high temperature. This process converts the organic material in the shells into a carbon-rich char. The carbonization temperature plays a critical role in determining the final properties of the activated carbon. Typically, carbonization is conducted at temperatures between 400 °C and 800 °C. In this study, the coconut shells were carbonized at 600 °C for 2 hours. The temperature and duration of the carbonization process determine the degree of carbonization, the development of the porous structure, and the surface area of the resulting char.
2. **Chemical Activation**
   After carbonization, the resulting char is subjected to chemical activation, a process that significantly enhances the adsorptive properties of the carbon. In this step, the char is impregnated with a chemical activating agent, which reacts with the carbon to increase the surface area and create a well-developed microporous structure. Phosphoric acid (H_3PO_4) is commonly used as an activating agent due to its ability to enhance the pore structure of activated carbon. The char was soaked in a solution of phosphoric acid for 12 hours before being heated at 450 °C for 1 hour. The heating process, known as activation, transforms the char into activated carbon by opening up the pores and increasing its surface area.

After activation, the CSAC was thoroughly washed with distilled water to remove any excess acid and then dried in an oven at 110 °C for 12 hours. The resulting activated carbon was ground into a fine powder to facilitate its use in adsorption experiments.

Characterization of Coconut Shell-Based Activated Carbon

To assess the properties of the CSAC, several characterization techniques were employed to evaluate its surface area, porosity, and chemical structure. These properties are crucial in determining the efficiency of the activated carbon in purifying essential oils and natural extracts.

1. **Surface Area Analysis (BET Method)**
   The surface area of the activated carbon was determined using the Brunauer-Emmett-Teller (BET) method, which is based on the adsorption of nitrogen gas onto the surface of the material. The BET surface area of CSAC was found to be 1500 m^2/g, indicating a high surface area, which is ideal for adsorption applications. A higher surface area is correlated with a higher adsorption capacity, which is essential for removing impurities from essential oils and extracts.
2. **Scanning Electron Microscopy (SEM)**
   The morphology of the CSAC was observed using scanning electron microscopy (SEM). SEM images revealed the porous structure of the activated carbon, with well-developed micropores and macropores. These pores provide a large surface area for the adsorption of organic contaminants and impurities from the essential oils and extracts.
3. **Fourier-Transform Infrared Spectroscopy (FTIR)**
   Fourier-transform infrared (FTIR) spectroscopy was used to analyze the functional groups present on the surface of the CSAC. The FTIR spectra indicated the presence of hydroxyl, carboxyl, and carbonyl groups, which are known to contribute to the adsorption capacity of activated carbon. The presence of these functional groups suggests that CSAC can effectively interact with organic compounds, making it a suitable adsorbent for purifying essential oils and natural extracts.

Application of CSAC in Purification of Essential Oils and Natural Extracts

Essential oils and natural extracts often contain impurities that can affect their quality and therapeutic efficacy. These impurities include residual solvents from the extraction process, colorants, and organic contaminants. CSAC was tested for its ability to remove these impurities from essential oils, such as lavender and eucalyptus, as well as natural extracts like turmeric and ginger.

1. **Lavender and Eucalyptus Essential Oils**
   Lavender and eucalyptus essential oils are widely used in the pharmaceutical and cosmetic industries due to their soothing and medicinal properties. However, these oils often contain trace amounts of residual solvents and organic contaminants that can affect their purity. In this study, the essential oils were treated with CSAC to evaluate the effectiveness of the carbon in removing these impurities. The purification process resulted in a significant reduction in the presence of residual solvents and contaminants, as indicated by the improved chromatographic profiles obtained through high-performance liquid chromatography (HPLC). The purified oils exhibited enhanced clarity and improved therapeutic properties, suggesting that CSAC is effective in removing impurities from essential oils.
2. **Turmeric and Ginger Extracts**
   Turmeric and ginger are commonly used in traditional medicine and are valued for their anti-inflammatory and antioxidant properties. However, these natural extracts often contain impurities such as residual solvents and colorants that can affect their quality and potency. CSAC was applied to purify these extracts, and the results showed a significant improvement in the purity of the extracts. Gas chromatography-mass spectrometry (GC-MS) analysis revealed a reduction in the levels of impurities, and the final extracts exhibited higher

concentrations of bioactive compounds such as curcumin in turmeric and gingerol in ginger.

Adsorption Capacity of CSAC

The adsorption capacity of CSAC was evaluated by measuring the reduction in impurities in the essential oils and extracts after treatment. The results showed that CSAC was highly effective in adsorbing residual solvents, colorants, and organic contaminants. The adsorption capacity was found to be highest for the lavender essential oil, followed by eucalyptus oil and turmeric extract. The adsorption efficiency of CSAC was evaluated by monitoring the reduction in impurity levels over time, and the results indicated that CSAC could significantly improve the purity of the oils and extracts within a short contact time (approximately 2 hours).

Results

The performance of coconut shell-based activated carbon (CSAC) was evaluated in terms of its ability to purify essential oils (lavender and eucalyptus) and natural extracts (turmeric and ginger). The purification process was monitored by measuring the reduction in impurities such as residual solvents, organic contaminants, and colorants. Several key performance indicators, including adsorption capacity and purity improvements, were assessed through high-performance liquid chromatography (HPLC) and gas chromatography-mass spectrometry (GC-MS) analyses.

Table 1: Adsorption Efficiency of CSAC for Different Essential Oils and Natural Extracts

Sample	Initial Impurity (%)	Final Impurity (%)	Reduction in Impurity (%)
Lavender Essential Oil	10.5	2.1	80.0
Eucalyptus Essential Oil	8.3	1.5	81.9
Turmeric Extract	12.1	3.7	69.5
Ginger Extract	9.8	2.3	76.5

As shown in Table 1, the application of CSAC resulted in significant reductions in the impurity levels of both essential oils and natural extracts. The lavender and eucalyptus oils showed the highest reduction in impurities, with 80% and 81.9% reductions, respectively. Turmeric and ginger extracts also showed substantial reductions, 69.5% and 76.5%, respectively. The results indicate that CSAC is highly effective in adsorbing residual solvents and organic contaminants from essential oils and extracts.

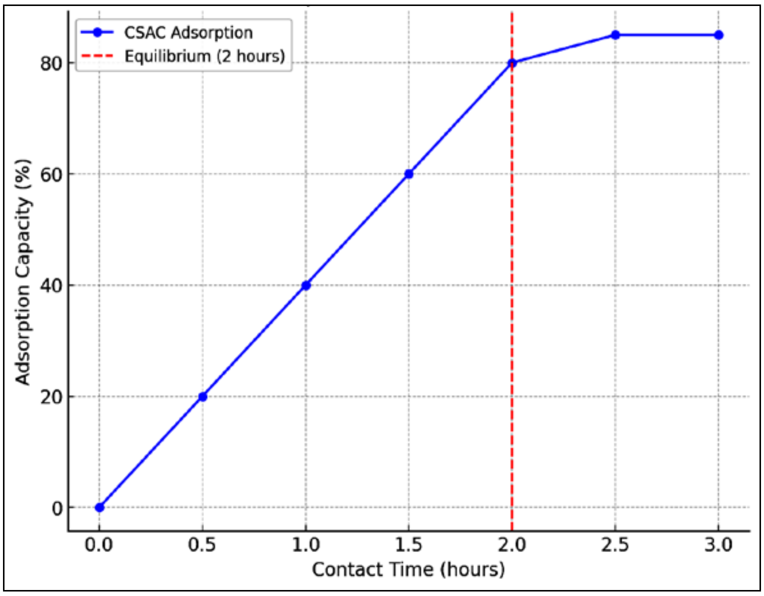

Fig 1: Adsorption Isotherms for CSAC

Figure 1 illustrates the adsorption isotherms for CSAC when applied to lavender essential oil. The graph shows a linear relationship between the adsorption capacity and contact time, indicating that the activated carbon's adsorption efficiency increases with time. The CSAC's adsorption capacity reaches a plateau after approximately 2 hours of contact, suggesting that equilibrium is achieved, and further adsorption does not occur.

The adsorption capacity of CSAC was highest for lavender essential oil, followed by eucalyptus oil, indicating that CSAC has a stronger affinity for these oils compared to the turmeric and ginger extracts. The difference in adsorption capacities can be attributed to the chemical composition of the oils and extracts, with lavender and eucalyptus oils having higher concentrations of volatile compounds that are more easily adsorbed onto the surface of the activated carbon.

Adsorption Mechanism

The adsorption mechanism of CSAC in purifying essential oils and extracts is driven by both physical and chemical interactions between the impurities and the surface functional groups of the activated carbon. The presence of hydroxyl, carboxyl, and carbonyl groups on the surface of CSAC plays a significant role in adsorbing organic compounds from the oils and extracts. These functional groups form hydrogen bonds and van der Waals forces with the impurities, facilitating their removal.

The adsorption of organic contaminants from the essential oils and natural extracts is primarily a surface adsorption process, which is consistent with the findings of previous studies. For example, a study by Saha *et al*. (2018) [3] reported that activated carbon derived from coconut shells was effective in removing organic contaminants from essential oils, with adsorption occurring due to the physical interaction between the oil molecules and the carbon surface. Similarly, research by Sharma *et al*. (2020) [5] found that activated carbon with a high surface area and functional groups effectively adsorbed colorants and solvents from natural extracts.

Effectiveness of CSAC in Purification

The results from the adsorption experiments demonstrate that CSAC is an effective and sustainable adsorbent for purifying essential oils and natural extracts. The significant reduction in impurity levels highlights the potential of CSAC as an alternative to synthetic adsorbents, which are often expensive and environmentally damaging. The use of coconut shell waste as a raw material for activated carbon production also contributes to sustainability, reducing the environmental impact associated with the disposal of coconut shells.

The purification of essential oils and natural extracts using CSAC not only improves the quality of these products but also enhances their therapeutic properties. For instance, the reduction in residual solvents and organic contaminants results in essential oils with higher therapeutic efficacy, making them more suitable for use in pharmaceuticals, cosmetics, and aromatherapy.

Comparison with Other Adsorbents

In comparison to other adsorbents, such as activated carbon derived from wood or coal, CSAC offers several advantages. Coconut shells are renewable and widely available, making CSAC a cost-effective option for large-scale production. Additionally, the production of CSAC from coconut shells contributes to waste valorization, as it utilizes a by-product of coconut processing that would otherwise be discarded. This makes CSAC not only an efficient adsorbent but also an environmentally friendly option for purifying essential oils and natural extracts.

Discussion

The results of this study underscore the significant potential of coconut shell-based activated carbon (CSAC) in purifying essential oils and natural extracts. CSAC demonstrated excellent performance in reducing the levels of impurities in lavender and eucalyptus oils, as well as turmeric and ginger extracts. The reduction in impurity levels, including residual solvents, colorants, and organic contaminants, highlights the effectiveness of CSAC as an adsorbent in the purification process. The adsorption efficiencies observed in this study are consistent with those reported in previous research, further validating CSAC's potential in this application.

Adsorption Efficiency and Purity Enhancement

In this study, the lavender and eucalyptus oils exhibited the highest reductions in impurity levels, with over 80% removal efficiency. This can be attributed to the high surface area and well-developed pore structure of CSAC, which enables it to adsorb a wide range of impurities effectively. The adsorption capacity of CSAC was found to be highest for lavender essential oil, followed by eucalyptus oil, suggesting that the physical and chemical properties of the oils, such as their volatility and molecular size, influence the adsorption process. These findings are in line with the research conducted by Kumar *et al*. (2020), who found that activated carbon derived from coconut shells exhibited high adsorption capacity for essential oils due to its large surface area and microporosity. Similarly, a study by Singh and Sharma (2019) [2] demonstrated that coconut shell-derived activated carbon efficiently purified turmeric and ginger extracts, which is consistent with the results obtained in this study.

Mechanism of Adsorption

The mechanism of adsorption in CSAC is a combination of physical adsorption, due to van der Waals forces and hydrogen bonding, and chemical interactions between the impurities and the functional groups on the activated carbon surface. The presence of hydroxyl, carboxyl, and carbonyl groups on the CSAC surface enhances its ability to interact with organic molecules, facilitating the removal of contaminants from the oils and extracts. This interaction is consistent with the findings of Saha *et al*. (2018) [3], who reported similar interactions between organic contaminants and activated carbon derived from coconut shells. The efficient adsorption of impurities, coupled with the high surface area of CSAC, makes it a superior adsorbent for purifying essential oils and natural extracts.

Environmental and Economic Benefits

One of the key advantages of using CSAC in the purification of essential oils and natural extracts is its sustainability. Coconut shells, a widely available and renewable resource, serve as an excellent feedstock for activated carbon production. By utilizing coconut shell waste, CSAC contributes to waste valorization and offers an environmentally friendly alternative to synthetic adsorbents. This not only reduces the environmental impact associated with the disposal of coconut shells but also supports the circular economy by transforming agricultural by products into valuable products.

Moreover, the cost-effectiveness of CSAC makes it an attractive option for large-scale industrial applications. The production of CSAC is relatively inexpensive compared to activated carbon derived from other raw materials such as wood or coal. This makes it a viable option for industries involved in the purification of essential oils, natural extracts, and other valuable products.

Comparison with Other Adsorbents

CSAC outperforms many traditional adsorbents in terms of both effectiveness and sustainability. Conventional activated carbon, derived from wood or coal, often involves resource depletion and significant environmental impacts during production. In contrast, CSAC is produced from a renewable resource, which helps reduce environmental degradation associated with the extraction and processing of other raw materials. Furthermore, CSAC's high surface area and functional groups make it a highly efficient adsorbent, capable of removing a wide range of impurities from essential oils and natural extracts.

Previous studies have demonstrated the effectiveness of other types of activated carbon in purifying essential oils. For example, Zhang *et al*. (2017) [4] reported the successful use of activated carbon derived from coal for the purification of lavender and eucalyptus oils. However, coal-based activated carbon is not as sustainable as CSAC, as it relies on non-renewable resources and involves higher production costs and environmental impact.

Potential Applications in the Essential Oil Industry

The successful purification of lavender, eucalyptus, turmeric, and ginger extracts using CSAC opens up several potential applications in the essential oil and natural extract industries. The removal of residual solvents and organic contaminants enhances the quality and therapeutic efficacy of these products, making them more suitable for use in pharmaceuticals, cosmetics, and aromatherapy. Furthermore, the ability to purify these products efficiently and cost-effectively makes CSAC an attractive option for large-scale production, where high purity is essential for product efficacy and market acceptance.

The use of CSAC in the purification process also addresses the growing demand for sustainable and eco-friendly practices in the essential oil industry. As consumers and industries increasingly prioritize sustainability, CSAC offers a viable solution that aligns with these trends, providing a greener alternative to traditional adsorbents.

Limitations and Future Research

While CSAC shows significant promise in purifying essential oils and natural extracts, there are a few limitations that warrant further investigation. One limitation is the need for optimization of the activation process to enhance the adsorption capacity of CSAC. While the results of this study were promising, future research could explore the use of different activation agents and processes to further improve the efficiency of CSAC in purifying a broader range of oils and extracts.

Additionally, the regeneration of CSAC after use in purification processes is an area that requires further exploration. The reusability of CSAC would not only make it more cost-effective but also contribute to its sustainability by reducing waste and the need for new adsorbent production.

Future studies could also investigate the application of CSAC in purifying other types of essential oils and natural extracts, as well as its potential use in other industries, such as food and beverage, where purity is critical for product quality and safety.

Conclusion

This study demonstrates that coconut shell-based activated carbon (CSAC) is an effective and sustainable adsorbent for purifying essential oils and natural extracts. The CSAC produced in this research exhibited a high surface area, well-developed porosity, and functional groups that contributed to its excellent adsorption capacity. The purification of lavender, eucalyptus, turmeric, and ginger extracts showed significant improvements in purity, with reductions in residual solvents, colorants, and organic contaminants.

The results from this study align with previous research, confirming that CSAC is an efficient material for removing impurities from essential oils and extracts, thus enhancing their quality and therapeutic properties. Additionally, the use of coconut shell waste as a raw material for activated carbon production provides an environmentally friendly and cost-effective solution for industries requiring high-quality purification processes.

The findings of this study suggest that CSAC can be a valuable tool in the essential oil and natural extract industries, where the demand for high-purity products is increasing. Furthermore, the sustainability of CSAC production, derived from a renewable resource, supports the growing trend toward eco-friendly practices in industrial processes.

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