Торайғыров университетінің
ҒЫЛЫМИ ЖУРНАЛЫ

НАУЧНЫЙ ЖУРНАЛ
Торайгыров университета

ТОРАЙҒЫРОВ УНИВЕРСИТЕТІНІҢ ХАБАРШЫСЫ

Химия-биологиялық сериясы

1997 жылдан бастап шығады

TORAIGHYROV UNIVERSITY

ВЕСТНИК ТОРАЙГЫРОВ УНИВЕРСИТЕТА

Химико-биологическая серия

Издается с 1997 года

ISSN 2710-3544

№ 1 (2024)

Павлодар

НАУЧНЫЙ ЖУРНАЛ
Торайгыров университета

Химико-биологическая серия
выходит 4 раза в год

СВИДЕТЕЛЬСТВО
о постановке на переучет периодического печатного издания,
информационного агентства и сетевого издания
№ KZ84VPY00029266

выдано
Министерством информации и коммуникаций Республики Казахстан

Тематическая направленность
публикация материалов в области химии, биологии, экологии,
сельскохозяйственных наук, медицины

Подписной индекс – 76134

https://doi.org/10.48081/AFVW5822

SRSTI 31.19

https://doi.org/10.48081/PTMQ2993

***R. Joia[1], M. Atamanov[2]**
[1]Nimruz University, Nimruz, Afghanistan;
[2]Institute of Combustion Problems,
Republic of Kazakhstan, Almaty.
e-mail: joia.reza@yahoo.com

N-DOPED ACTIVATED CARBON OBTAINED FROM PLANT WASTE BY DIFFERENT PRODUCTION METHODS FOR ADSORPTION OF CO_2

The pressing need to reduce CO_2 emissions and combat climate change has spurred a global commitment towards achieving carbon neutrality. While transitioning to renewable energy is pivotal, the limitations in renewable energy production highlight the necessity for alternative approaches. The focus on capturing and sequestering CO_2 has led to the exploration of porous solids, including zeolites, metal-organic frameworks (MOFs), porous organic polymers (POPs), and porous carbons. Porous carbons, with their low cost, widespread availability, large surface area, and ease of design, have garnered attention. However, their reported CO_2 adsorption capacities are currently limited. Addressing this constraint, nitrogen doping (N-doping) has proven effective in augmenting surface adsorption sites on porous carbon structures. Various production methods, such as chemical activation with nitrogen-containing compounds, physical methods utilizing nitrogen-containing gases, and hydrothermal methods, have been implemented. Particularly noteworthy is the application of nitrogen-doped activated carbon derived from plant waste, showcasing high surface areas, suitable structures, and significant CO_2 adsorption capacities. This positions them as promising candidates for large-scale CO_2 capture initiatives, contributing to global efforts in mitigating climate change.

Keyword: N-doped Activated carbon, CO_2 adsorption, chemical activation, physical activation, nitrogen-containing compounds, Hydrothermal activation.

Introduction

The imperative to curtail CO_2 emissions globally has fostered a commitment to reducing global warming, with many nations pledging carbon neutrality and proposing timelines. Shifting from fossil fuels to renewable energy is a primary strategy, although the production of renewable energy remains insufficient [1]. Another crucial avenue for achieving carbon neutrality involves capturing and sequestering CO_2 while preserving fossil fuel energy [2]. Porous solids, encompassing zeolites, metal-organic frameworks (MOFs), porous organic polymers (POPs), and porous carbons, are touted as promising adsorbents for CO_2 absorption due to their lower regeneration energy requirements and reduced environmental impact. Porous carbons, particularly valued for their cost-effectiveness, availability, large surface area, and versatile design, receive heightened attention for regeneration [3] a series of licorice residue-derived porous carbons were prepared with nitrogen-doped hydrothermal carbonization and KOH activation. The N-doped porous carbon activated at 600 °C exhibited excellent CO_2 adsorption capacity (6.43 mmol/g at 0 °C and 1 bar, 3.89 mmol/g at 25 °C and 1 bar. However, despite these advantages, reported porous carbons often exhibit limited CO_2 adsorption capacity, ranging from 0.5 to 3.2 mmol/g under standard conditions. N-doping of carbon structures emerges as an effective approach to augment surface adsorption sites [4]. The International Union of Pure and Applied Chemistry (IUPAC) classifies porous materials based on pore size into micro-pores (<2 nm), mesoporous (2–50 nm), and macro-pores (>50 nm). Tailoring the pore size of activated carbon is crucial for optimizing CO_2 absorption [5]. Microporous activated carbon, with a higher surface area and more adsorption sites, excels in adsorbing CO_2, while larger pore sizes in mesoporous or macro porous activated carbon prove more effective in high-flow or high-concentration CO_2 applications [6]. Various methods, including two-stage physical, one-stage chemical [7], direct pyrolysis, pyrolysis in gas and steam environments, and one-stage hydrothermal carbonization, are employed to produce activated carbon [3]a series of licorice residue-derived porous carbons were prepared with nitrogen-doped hydrothermal carbonization and KOH activation. The N-doped porous carbon activated at 600 °C exhibited excellent CO_2 adsorption capacity (6.43 mmol/g at 0 °C and 1 bar, 3.89 mmol/g at 25 °C and 1 bar. Simultaneously, nitrogen sources like urea [8], ammonia, and melamine contribute to the nitrogen-doping process [4].

Methodology and material

In this comprehensive review article, an in-depth exploration of nitrogen-doped activated carbon derived from plant waste for CO_2 adsorption is undertaken. Rigorous scrutiny of contemporary and trustworthy articles, alongside reputable

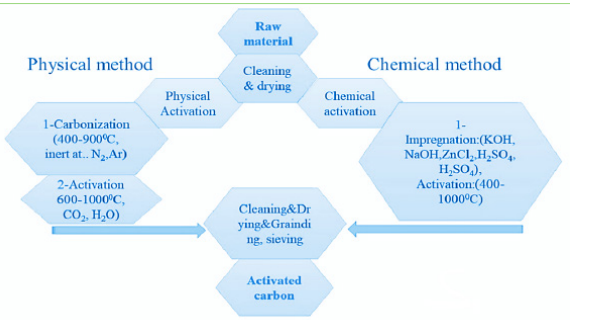
websites, forms the foundation of this review, ensuring the inclusion of the latest advancements and reliable information. The primary focus revolves around understanding the intricate aspects of synthesis methods, elucidating the properties, and deciphering the CO_2 adsorption capacities exhibited by nitrogen-doped activated carbon sourced from plant waste.

A significant emphasis is placed on the influence of different nitrogen sources, delineating their impact on the characteristics of nitrogen-doped activated carbon specifically tailored for CO_2 adsorption. Additionally, there is a notable focus on comparing the production methods employed by scientists in the creation of these carbon materials. This scrutiny encompasses a myriad of nitrogen sources, encompassing diverse plant waste precursors, to ascertain their nuanced effects on the final adsorption performance. The synthesis pathways, properties, and CO_2 adsorption capacities are meticulously dissected to provide a holistic overview. By delving into the intricacies of nitrogen-doped activated carbon, this review aims to contribute valuable insights into the advancement of sustainable and effective solutions for CO_2 capture, aligning with contemporary environmental challenges and sustainable practices.

Result and discussion

Principle

The synthesis of nitrogen-doped activated carbon from plant waste for CO_2 adsorption is a meticulously defined process, as illustrated in (Scheme 1). In the initial step, plant waste such as walnut shells [9]we report for the first time the fabrication of walnut shell-derived nanoporous carbon with chemical adsorption sites for CO_2 adsorption at mediate (1 bar, sugarcane bagasse, or bamboo charcoal [10] is carefully chosen for its appropriateness as a carbon precursor. Concurrently, nitrogen sources like urea, ammonia, or melamine are selected to introduce nitrogen functionality. Subsequently, diverse synthesis methods, encompassing chemical activation, physical activation [7], or hydrothermal approaches [3] a series of licorice residue-derived porous carbons were prepared with nitrogen-doped hydrothermal carbonization and KOH activation. The N-doped porous carbon activated at 600 °C exhibited excellent CO_2 adsorption capacity (6.43 mmol/g at 0 °C and 1 bar, 3.89 mmol/g at 25 °C and 1 bar, are chosen, and applied. Each method involves subjecting the selected precursors to carbonization and activation processes, resulting in the formation of nitrogen-doped activated carbon. This material, enriched with nitrogen functionalities, exhibits enhanced CO_2 adsorption capabilities [7]. The final stage involves a comprehensive characterization process to assess and evaluate specific characteristics such as surface area, porosity, and nitrogen content, ensuring the production of tailored nitrogen-doped activated carbon optimized for CO_2 capture applications [11].

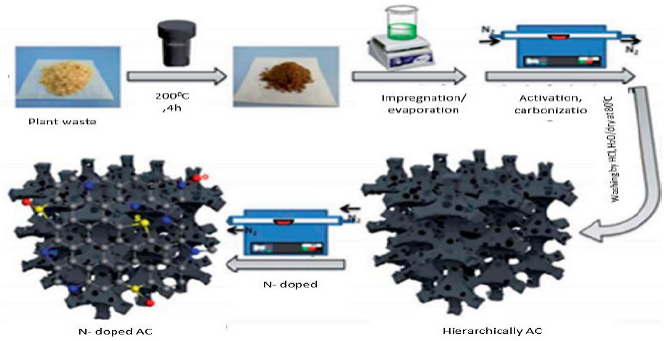


Scheme (1) principle of synthesizing of N-doped activated carbon in different methods.

Production methods of N-doped AC

Nitrogen doped activated carbon (AC) is already produced by scientists from different types of plant waste by various activation methods and they obtained N-doped AC with high surface area, suitable structure and pore size and huge adsorption capacity for uptake CO_2.

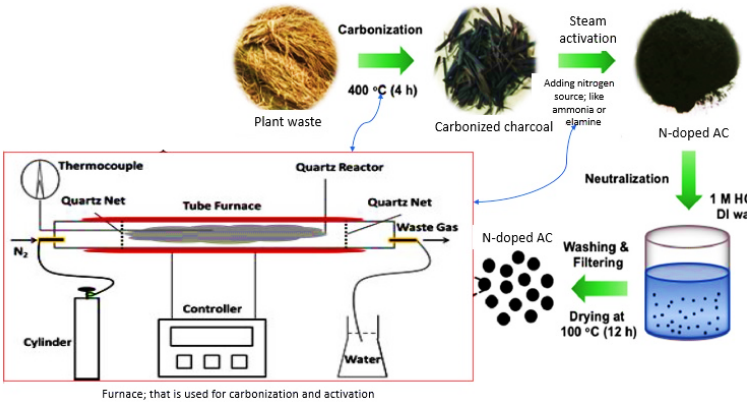
1- Chemical Activation with Nitrogen-Containing Compounds: In this method, the precursor material is impregnated with a nitrogen-containing compound, such as urea or melamine, before carbonization and activation [5]. The activation process is carried out at high temperatures, typically between 700–900 °C and adding some activation agent like KOH, ZnCl [12] ... This method results in the incorporation of nitrogen atoms into the activated carbon structure [13].



Scheme (2) process of chemical activation method for production of N-doped AC.

A very high-quality nitrogen doped activated carbon has been synthesized from sustainable biomass by chemical activation method(direct) with the assistance of melamine. The obtained N-doped AC with 2.1wt % N dopants possesses a high surface area (2477.27 m^2/g) and pore volume (1.93 cm^3/g). The N doped AC displayed enhanced 0.83wt % at 298 K, 100 bar) and adequate CO_2 uptake capacity (2.85 mmol/g at 298 K, 1 bar and 4.49 mmol/g at 273 K, 1 bar). activation mechanism with the assistance of melamine was proposed in accordance with the experimental data. The facile method of preparing N doped AC has potential for large-scaled production [14]

2- Physical Methods: Physical activation is a widely used method for producing activated carbon. The process involves the carbonization of a precursor material and followed by activation using a physical agent, such as steam or carbon dioxide. Nitrogen doping can be achieved during the physical activation process by introducing nitrogen-containing gases, such as ammonia or nitrogen gas [7]. Several studies have investigated the physical method of producing N-doped AC.



Scheme (3) process of physical activation method for production of N-doped AC.

As instance the production of N-doped AC by physical activation with carbon dioxide and nitrogen gas was conducted. The precursor material was carbonized at 800 °C and activated with carbon dioxide and nitrogen gas at 800 °C for 2 hours. The resulting N-doped AC had a high nitrogen content and a well-controlled pore size distribution, making it suitable for use in catalysis applications [15].

Another study investigated the effect of activation temperature on the properties of N-doped AC produced by physical activation with steam and

ammonia. The precursor material was carbonized at 900 °C and activated with steam and ammonia at temperatures ranging from 750 to 950 °C for 2 hours. The study found that the activation temperature had a significant effect on the pore size distribution and nitrogen content of the N-doped AC [16].

3- Hydrothermal method: this is a promising technique for producing nitrogen-doped activated carbon due to its ability to incorporate nitrogen into the carbon structure and control the pore size distribution. In this method the precursor is mixed with a nitrogen-containing compound, such as urea or ammonia, and placed in furnace tube for several hours and 400–800 °C according to the type of precursor. And after passing hydrothermal treatment, applied carbonization and activation steps the same as physical method on threated material [17].

As instance synthesized nitrogen-doped activated carbon from peanut shells using a hydrothermal method, used solution of urea as source of nitrogen and followed by chemical activation with potassium hydroxide (KOH). The synthesized activated carbon had a high surface area of 2700 m^2/g and a nitrogen content of 4.9 %. The adsorption isotherm showed that the activated carbon had a high CO_2 adsorption capacity of 7.6 mmol/g at 298 K and 1 bar [3] a series of licorice residue-derived porous carbons were prepared with nitrogen-doped hydrothermal carbonization and KOH activation. The N-doped porous carbon activated at 600 °C exhibited excellent CO2 adsorption capacity (6.43 mmol/g at 0 °C and 1 bar, 3.89 mmol/g at 25 °C and 1 bar.

Similarly, synthesized nitrogen-doped activated carbon from bamboo shoots using a hydrothermal method followed by activation with KOH. The synthesized activated carbon had a high surface area of 2494 m2/g and a nitrogen content of 4.63 %. The CO_2 adsorption capacity of the activated carbon was found to be 4.46 mmol/g at 298 K and 1 bar [18].

However, the selection of raw materials with excellent carbon content and no inorganic components, suitable production method and high nitrogen content doping agents are all important to obtain N-doped activated carbon with high quality (high surface area, high adsorption capacity, and suitable pore size and pore structure).

Characterization of N-Doped Activated Carbon:

The characterization of nitrogen-doped activated carbon is essential to understand its properties and performance for CO^2 adsorption. Several techniques have been used in recent studies, such as scanning electron microscopy (SEM) [19], transmission electron microscopy, X-ray diffraction (XRD) [7], Fourier transform infrared spectroscopy (FTIR) spectroscopy, and Brunauer-Emmett-Teller (BET) surface area analysis [19].

For instance, characterized nitrogen-doped activated carbon obtained from corn cob by the hydrothermal method using SEM, TEM, XRD, FTIR, and Raman spectroscopy. The SEM images showed that the activated carbon had a highly porous structure with a large surface area. The TEM images showed that the activated carbon had a graphitic structure with a large number of edge planes. The XRD and Raman spectra confirmed the presence of graphitic carbon and nitrogen-containing functional groups. The FTIR spectra showed the presence of various functional groups, such as C=O, C-N, and N-H, which can contribute to CO_2 adsorption [9].

Conclusion

The imperative to combat climate change has driven a global commitment to achieving carbon neutrality, necessitating innovative approaches for CO_2 capture. Porous carbons, including nitrogen-doped activated carbon derived from plant waste, have emerged as promising candidates for large-scale CO_2 capture initiatives. These materials exhibit high surface areas, suitable structures, and significant CO_2 adsorption capacities, addressing the limitations of reported porous carbons. The synthesis of nitrogen-doped activated carbon involves a well-defined process, emphasizing the selection of plant waste and nitrogen sources, such as urea, ammonia, or melamine. Various production methods, including chemical activation, physical activation, and hydrothermal methods, result in N-doped activated carbon with diverse properties. Chemical activation with nitrogen-containing compounds, such as melamine, urea, or ammonia, has proven effective, yielding high-quality N-doped activated carbon with enhanced CO_2 uptake capacity. Physical activation methods, utilizing nitrogen-containing gases like ammonia, demonstrate control over pore size distribution and nitrogen content. Hydrothermal methods, leveraging nitrogen-containing compounds, offer promise for incorporating nitrogen into the carbon structure. Characterization techniques, such as SEM, TEM, XRD, FTIR, and BET analysis, are crucial for understanding the properties and performance of nitrogen-doped activated carbon. These techniques reveal the highly porous structure, graphitic nature, and presence of nitrogen-containing functional groups, contributing to CO_2 adsorption. In conclusion, nitrogen-doped activated carbon derived from plant waste presents a sustainable and effective solution for CO_2 capture, aligning with global environmental challenges and sustainable practices.

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Received 30.11.23.
Received in revised form 24.04.24.
Accepted for publication 26.08.24.

**Р. Джоя[1], М.Атаманов[2]*
[1]Нимруз университеті, Нимруз, Ауғанстан;
[2]Жану мәселелері институты,
Қазақстан Республикасы, Алматы.
30.11.23 ж. баспаға түсті.
24.04.24 ж. түзетулерімен түсті.
26.08.24 ж. басып шығаруға қабылданды.

ӨСІМДІК ҚАЛДЫҚТАРЫНАН CO_2 АДСОРБЦИЯЛАУ ҮШІН ТҮРЛІ ӨНДІРІС ӘДІСТЕРІМЕН АЛЫНҒАН N-ҚОСЫЛҒАН БЕЛСЕНДЕН КӨМІР

CO_2 шығарындыларын азайту және климаттың өзгеруімен күресудің өзекті қажеттілігі көміртегі бейтараптығына қол жеткізуге жаһандық міндеттемені ынталандырды. Жаңартылатын энергияға көшу маңызды болғанымен, жаңартылатын энергияны өндірудегі шектеулер балама тәсілдердің қажеттілігін көрсетеді. CO_2-ні ұстауға және секвестрлеуге назар аудару кеуекті қатты заттарды, соның ішінде цеолиттерді, металл-органикалық қаңқаларды (MOF), кеуекті органикалық полимерлерді (ПОП) және кеуекті көміртектерді зерттеуге әкелді. Кеуекті көміртектер, олардың төмен құнымен, кең таралғандығымен, үлкен бетінің ауданымен және дизайнның қарапайымдылығымен назар аударды. Дегенмен, олардың CO_2 адсорбциялық мүмкіндіктері қазіргі уақытта шектеулі. Осы шектеуді шеше отырып, азотты қоспалау (N-допинг) кеуекті көміртекті құрылымдардағы беттік адсорбция учаскелерін ұлғайту үшін тиімді екенін дәлелдеді. Құрамында азот бар қосылыстармен химиялық белсендіру, құрамында азот бар газдарды пайдаланатын физикалық әдістер және гидротермиялық әдістер сияқты әртүрлі өндіріс әдістері жүзеге асырылды. Өсімдік қалдықтарынан алынатын азот қосылған белсендірілген көмірді қолдану ерекше назар аудартады, оның бетінің жоғары аудандары, қолайлы құрылымдары және маңызды CO_2 адсорбциялық қабілеті. Бұл оларды климаттың өзгеруін жеңілдетудегі жаһандық күш-жігерге үлес қосатын ауқымды CO_2 алу бастамалары үшін перспективалы үміткерлер ретінде көрсетеді.

Кілтті сөздер: N-қоспаланған белсендірілген көмір, CO_2 адсорбциясы, химиялық активтену, физикалық белсендіру, құрамында азот бар қосылыстар, Гидротермиялық активация.

*Р. Джоя[1], М. Атаманов[2]
[1]Университет Нимруза,
Афганистан, Нимруз;
[2]Институт проблем горения,
Республика Казахстан, г. Алматы.
Поступило в редакцию 30.11.23.
Поступило с исправлениями 24.04.24.
Принято в печать 26.08.24.

АКТИВИРОВАННЫЙ УГОЛЬ N-ДОПИРОВАННЫЙ, ПОЛУЧЕННЫЙ ИЗ ОТХОДОВ ЗАВОДОВ РАЗЛИЧНЫМИ МЕТОДАМИ ПРОИЗВОДСТВА, ДЛЯ АДСОРБЦИИ CO_2

Острая необходимость сокращения выбросов CO_2 и борьбы с изменением климата стимулировала глобальную приверженность достижению углеродной нейтральности. Хотя переход на возобновляемые источники энергии имеет решающее значение, ограничения в производстве возобновляемой энергии подчеркивают необходимость альтернативных подходов. Акцент на улавливании и секвестрации CO_2 привел к исследованию пористых твердых тел, включая цеолиты, металлоорганические каркасы (MOF), пористые органические полимеры (СОЗ) и пористый углерод. Пористый углерод благодаря своей низкой стоимости, широкой доступности, большой площади поверхности и простоте конструкции привлек внимание. Однако их заявленная способность к адсорбции CO_2 в настоящее время ограничена. Для решения этого ограничения легирование азотом (N-легирование) оказалось эффективным в увеличении мест поверхностной адсорбции на пористых углеродных структурах. Реализованы различные методы производства, такие как химическая активация азотсодержащими соединениями, физические методы с использованием азотсодержащих газов, гидротермальные методы. Особого внимания заслуживает применение активированного угля, легированного азотом, полученного из растительных отходов, демонстрирующего большую площадь поверхности, подходящие структуры и значительную способность к адсорбции CO_2. Это делает их многообещающими кандидатами на крупномасштабные инициативы по улавливанию CO_2, способствуя глобальным усилиям по смягчению последствий изменения климата.

Ключевые слова: N-легированный активированный уголь, адсорбция CO_2, химическая активация, физическая активация, азотсодержащие соединения, гидротермальная активация.

Теруге 04.03.2024 ж. жіберілді. Басуға 29.03.2024 ж. қол қойылды.
Электронды баспа
2,56 МБ RAM
Шартты баспа табағы 7,94.
Таралымы 300 дана. Бағасы келісім бойынша.
Компьютерде беттеген А. К. Темиргалинова
Корректорлар: А. Р. Омарова, Д. А. Кожас
Тапсырыс № 4292

Сдано в набор 04.03.2024 г. Подписано в печать 29.03.2024 г.
Электронное издание
2,56 МБ RAM
Усл. п. л. 7,94. Тираж 300 экз. Цена договорная.
Компьютерная верстка А. К. Темиргалинова
Корректоры: А. Р. Омарова, Д. А. Кожас
Заказ № 4292

«Toraighyrov University» баспасынан басылып шығарылған
Торайғыров университеті
Павлодар мемлекеттік университеті
140008, Павлодар қ., Ломов к., 64, 137 каб.

«Toraighyrov University» баспасы
Торайғыров университеті
140008, Павлодар қ., Ломов к., 64, 137 каб.
8 (7182) 67-36-69
e-mail: kereku@tou.edu.kz
www.vestnik-cb.tou.edu.kz