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THE INFLUENCE OF $CaCl_2$, $ZnCl_2$, AND Na_2CO_3 ACTIVATORS ON THE IODINE ADSORPTION CAPACITY OF ACTIVATED CARBON FROM CAESALPINIA SAPPAN WOOD

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ABSTRACT

This study aims to evaluate the influence of three chemical activators, namely $CaCl_2$, $ZnCl_2$, and Na_2CO_3, on the iodine adsorption capacity of activated carbon derived from Caesalpinia sappan wood. This wood was chosen for its high lignocellulosic content and antioxidant-rich brazilin, which may facilitate the production of highly porous activated carbon. The activation process was carried out using a reactor with varying concentrations of activators, and iodine adsorption capacity was tested according to ASTM-D4607-14 standards. The results revealed that $ZnCl_2$ exhibited the highest iodine adsorption capacity compared to $CaCl_2$ and Na_2CO_3, with a maximum adsorption capacity of 1123 mg/g at a 1-gram ratio. This study demonstrates that the choice of activator significantly influences the characteristics and adsorption capacity of activated carbon, which has potential applications in water and gas purification.

Keywords Activated carbon; Iodine adsorption; Caesalpinia sappan; $ZnCl_2$; $CaCl_2$; Na_2CO_3;
Paper type Research paper

INTRODUCTION

Activated carbon is a porous material known for its high adsorption capacity, characterized by its large surface area and high porosity. Its microporous and mesoporous structure allows it to adsorb small to medium-sized molecules, making it highly effective in various industrial applications. For example, activated carbon is used in water purification to remove organic and inorganic contaminants, as well as harmful chemicals. In gas purification, it plays a role in adsorbing toxic or unwanted gases. In the chemical industry, activated carbon is often employed as an adsorbent to separate specific components from complex chemical mixtures [1].

As industries such as pharmaceuticals, food, and beverages continue to rely on adsorption processes, the demand for activated carbon is increasing [2]. Modern industries also face growing environmental challenges, driving the need for more efficient and eco-friendly adsorption technologies, where activated carbon plays a critical role. The raw materials for activated carbon production typically come from organic carbon-based sources such as coconut shells, wood, or other biomass waste. Utilizing these materials not only contributes to waste reduction but also offers the potential to produce high-quality activated carbon at lower costs. Innovations in activated carbon production, such as optimizing pyrolysis and activation processes, continue to be developed to enhance adsorption capacity and efficiency in various industrial applications [3]. Therefore, activated carbon is emerging as a key solution to modern industrial and environmental challenges.

One potential source of activated carbon that has been underexplored is Caesalpinia sappan wood, which is known for its rich lignocellulosic content and chemical structure that supports activated carbon formation. Caesalpinia sappan wood contains brazilin, a chemical compound with antioxidant properties [4]. Brazilin's antioxidant properties may also contribute to the chemical activation process of activated carbon, supporting pore formation and enhancing the material's quality and adsorption capacity. Brazilin is generally used for its coloring properties and has a chemical formula of $C_{16}H_{14}O_5$, which imparts a red hue. Brazilin is an antioxidant compound with a catechol structure, which may play a role in the activation process.

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To enhance the effectiveness and efficiency of activated carbon, chemical activation is often performed using activators such as $ZnCl_2$, $CaCl_2$, and Na_2CO_3. These activators can open up pores and increase the surface area of the activated carbon [5]–[7]. Each activator has a different mechanism for pore formation and reactivity with raw materials, making it important to compare the effectiveness of these three activators in producing activated carbon from Caesalpinia sappan wood. This research is important as it explores the use of alternative raw materials like Caesalpinia sappan wood, which contains brazilin. Additionally, this study aims to understand the influence of various activators on the characteristics of the activated carbon produced.

METHOD

Preparation of Activated Carbon

Caesalpinia sappan wood used in this study was sourced from Ngawi Regency, East Java, Indonesia. The wood was cut into pieces measuring 10 cm in length and 2 cm in thickness before undergoing carbonization. The carbonization process was conducted in a reactor at 400°C for 8 hours. The resulting charcoal was then sieved to a 40-mesh size.

Figure 1. (a) Sappan wood charcoal, (b) Activator solution mixing process and (c) Sappan wood activated charcoal.

The 40-mesh Caesalpinia sappan charcoal was activated using $CaCl_2$, Na_2CO_3, and $ZnCl_2$ at ratios of 1, 2, 3, and 4 grams of activator to 25 ml of water. The activation process began by preparing the activator solution and allowing it to sit for 30 minutes. The $CaCl_2$ solution was then added to 20 grams of Caesalpinia sappan charcoal and left for 30 minutes before being heated in a reactor at 200°C for 3 hours under a nitrogen atmosphere.

Iodine Absorbency

The iodine adsorption test followed ASTM-D4607-14 standards. The titration test procedure began by preparing 0.1 N sodium thiosulfate and iodine solutions. Then, 0.5 grams of activated carbon sample was mixed with 50 ml of iodine solution, stirred for 30 minutes, and left to stand for another 30 minutes. The mixture was filtered using filter paper, and 25 ml of the filtrate was titrated with 0.1 N sodium thiosulfate using starch solution as an indicator. The iodine adsorption capacity was then calculated using equation 1.

$$I = \frac{(V_1\, N_1 - V_2\, N_2) \times 126{,}9 \times f_p}{w} \tag{1}$$

The iodine number (I), expressed in mg/g, indicates the iodine adsorption capacity of activated carbon. To determine this, the volume of sodium thiosulfate solution used in the blank titration (V1) and its normality (N1) are measured, as well as the volume of sodium thiosulfate solution used in the titration of the activated carbon samples (V2) and its corresponding normality (N2). The dilution factor (fp) and the weight of the activated carbon used in the test (w) also play critical roles in the calculation. These factors collectively determine the iodine adsorption capacity of the activated carbon.

DISCUSSION

Brazilin, as a homoisoflavonoid, shares structural similarities with flavonoids but with minor differences in carbon chain length. Flavonoids vary in size depending on their subgroups. Brazilin is known to be water-soluble and has good adsorption capabilities, particularly due to its polyphenolic properties. However, flavonoids are also recognized for their strong adsorptive properties when interacting with porous materials like activated carbon [8]. Below is an illustration of brazilin in

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Figure 2, generated using Avogadro software, showing the two aromatic rings connected by a three-carbon chain containing hydroxyl (-OH) and carbonyl (-C=O) groups.

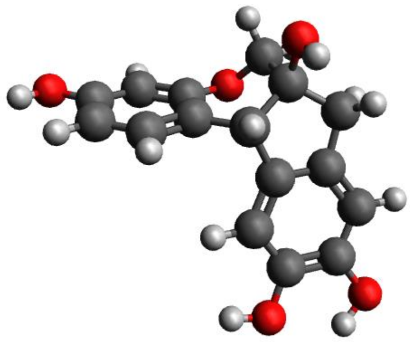

Figure 2. Atomic Structure of Brazilin.

Effect of $CaCl_2$ (Calcium Chloride) Activator

Calcium chloride ($CaCl_2$) is a commonly used activator in activated carbon production because it enhances surface area and pore formation through various mechanisms. $CaCl_2$ works by drawing water out of the carbon material during heating, causing further dehydration [9]. This process results in the formation of micropores within the carbon structure, increasing its specific surface area [10]. $CaCl_2$ typically produces activated carbon with a relatively higher surface area compared to other activators, due to its dominant micropore formation [11]. This makes it suitable for applications such as gas or water vapor adsorption. $CaCl_2$ produces activated carbon with good physical stability, although its pore sizes tend to be narrower and limited to micropores.

Effect of $ZnCl_2$ (Zinc Chloride)

$ZnCl_2$ is one of the most frequently used chemical activators in the industry for producing activated carbon due to its ability to generate a large surface area and enhance the formation of both micropores and mesopores. $ZnCl_2$ dehydrates carbon materials at lower temperatures, preventing excessive carbonization and maintaining an open pore structure [12]. This makes it highly effective at opening and enlarging pores during activation. Activated carbon produced with $ZnCl_2$ has a very large surface area, with a well-distributed network of micropores and mesopores, making it highly effective at adsorbing small to medium-sized molecules, such as gases or organic vapors [13]. However, $ZnCl_2$ can produce slightly acidic activated carbon, which may affect the adsorption of certain substances [14]. Activated carbon activated with $ZnCl_2$ is often used in water purification and wastewater treatment applications due to its ability to adsorb organic compounds and heavy metals [15].

Effect of Na_2CO_3 (Sodium Carbonate)

Na_2CO_3, or sodium carbonate, is known as a milder chemical activator compared to $CaCl_2$ and $ZnCl_2$. The use of sodium carbonate tends to result in activated carbon with a different pore distribution and a more moderate surface area. Na_2CO_3 promotes the thermal decomposition of carbon materials more slowly and moderately than $ZnCl_2$ or $CaCl_2$, leading to the formation of more mesopores and a more open pore structure. Na_2CO_3 tends to produce activated carbon with a dominant mesoporous structure, larger than micropores but smaller than macropores [9]. This makes the resulting activated carbon more suitable for adsorbing larger molecules such as proteins, dyes, and other organic substances [16]. The surface area produced by Na_2CO_3 is typically lower than that of $ZnCl_2$, but Na_2CO_3 produces activated carbon that is more suitable for applications requiring larger pores, such as liquid filtration and the purification of liquids containing large particles.

TABLE I. COMPARISON OF THE THREE ACTIVATORS

Activator	Activation Mechanism	Surface Area	Pore Distribution	Suitable Application
$CaCl_2$	Rapid dehydration, micropore formation	High	Micropore dominance	Adsorption of gas, vapor, water, light organic compounds
$ZnCl_2$	Fast dehydration, limited carbonization	Very High	Combination of micropores & mesopores	Water purification, heavy metal adsorption, gas, steam
Na_2CO_3	Moderate activation, mesopore formation	moderate	Predominantly mesoporous	Large molecule adsorption, liquid purification

The use of $CaCl_2$, $ZnCl_2$, and Na_2CO_3 as chemical activators in the production of activated carbon results in distinct effects on the properties of the resulting material. $ZnCl_2$ tends to produce activated carbon with the largest surface area and a well-balanced distribution of micropores and mesopores, making it suitable for applications such as gas purification, water treatment, and waste management. In contrast, $CaCl_2$ generates activated carbon predominantly characterized by micropores, which is ideal for adsorbing gases and small organic compounds. Na_2CO_3, on the other hand, promotes the formation of mesopores, making it more appropriate for adsorbing larger molecules like proteins and dyes.

(a) (b) (c)

Figure 3. Activated carbon with various activator (a) $ZnCl_2$, (b) $CaCl_2$, and (c) Na_2CO_3.

Iodine number serves as a critical parameter to assess the adsorption capacity of activated carbon, indicating the amount of iodine adsorbed per gram of carbon. A higher iodine number signifies greater adsorption capacity. Activated carbon derived from Caesalpinia sappan wood exhibits an iodine adsorption capacity of 1078.9 mg/g, which can be enhanced for applications such as water purification and air filtration [17].

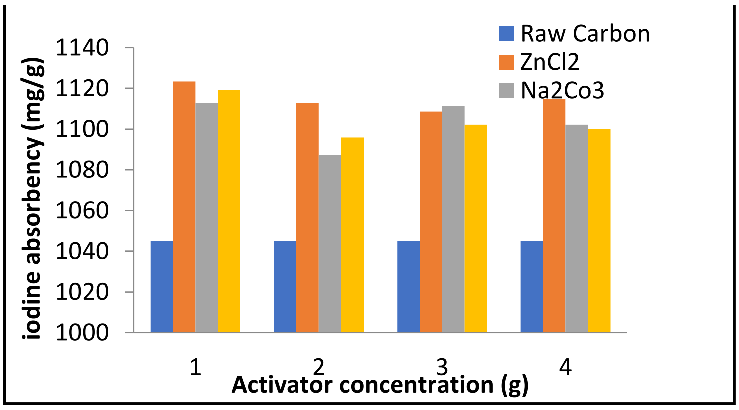

Figure 4. Graph of the relationship between iodine absorbance and activator solution concentration.

Figure 4 illustrates the iodine adsorption capacity of activated carbon at various concentrations of the activators. The graph reveals that $ZnCl_2$ consistently achieves the highest iodine adsorption across all concentrations, peaking at a concentration of 4 grams with an adsorption capacity of approximately 1123 mg/g. $ZnCl_2$ tends to outperform the other two activators, with a significant dip at concentrations of 2 and 3 grams before rising again at 4 grams.

$ZnCl_2$ as an activator results in the highest iodine adsorption value, reaching 1123 mg/g at 1 gram of activator, aligning with previous studies that demonstrate its optimal performance compared to other activators [5]. This is attributed to the structural characteristics of activated carbon, including pore size distribution and surface functional groups, which directly correlate with its iodine adsorption capacity [18]. The mechanism behind the formation of activated carbon using $CaCl_2$ involves the development of a more porous structure, thereby increasing the surface area available for iodine adsorption. The chemical activation process entails heating the precursor material in the presence of a chemical agent, which facilitates the development of microporous and mesoporous networks, enhancing the material's overall adsorption capacity [19].

CONCLUSION

The use of different chemical activators $CaCl_2$, $ZnCl_2$, and Na_2CO_3 significantly affects the iodine adsorption capacity of activated carbon derived from Caesalpinia sappan wood. Among these, $ZnCl_2$ proves to be the most effective, yielding the highest iodine adsorption capacity of 1123 mg/g due to its ability to produce a well-distributed microporous and mesoporous structure. $CaCl_2$ primarily forms microporous activated carbon, making it suitable for adsorbing smaller molecules, while Na_2CO_3 promotes the development of mesopores, making it more effective for adsorbing larger molecules. Each activator offers distinct advantages depending on the targeted application, highlighting the importance of selecting the appropriate activator to optimize the adsorption properties of activated carbon for specific industrial uses.

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