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Effect of NaCl Activator Concentration on Iodine Adsorption of PET- based Activated Carbon

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ABSTRAK

Penelitian ini mengkaji penggunaan NaCl sebagai aktivator dalam produksi karbon aktif dari limbah Polyethylene terephthalate (PET) untuk mengatasi permasalahan lingkungan akibat penumpukan sampah plastik yang sulit terurai. Penelitian ini bertujuan untuk mengkaji pengaruh konsentrasi NaCl terhadap kapasitas adsorpsi iodin dari karbon aktif. Jenis penelitian ini adalah penelitian eksperimen. Sampel yang digunakan sebanyak 15 sampel karbon aktif. Metode pengumpulan data melalui proses eksperimen laboratorium. Analisis data dilakukan dengan analisis regresi linier sederhana. Hasil analisis menunjukkan bahwa variasi konsentrasi NaCl berpengaruh secara signifikan terhadap kapasitas adsorpsi iodin, dengan nilai R^2 sebesar 0,868 yang mengindikasikan 86,8% variasi kapasitas adsorpsi dapat dijelaskan oleh konsentrasi NaCl. Konsentrasi 1M dianggap optimal dalam menyeimbangkan efektivitas, biaya produksi, dan dampak lingkungan, meskipun konsentrasi yang lebih tinggi menghasilkan kapasitas adsorpsi yang lebih baik. Penelitian ini menyimpulkan bahwa pemanfaatan limbah PET untuk produksi karbon aktif memberikan solusi berkelanjutan untuk polusi plastik, mengurangi limbah sekaligus menghasilkan produk bernilai tinggi untuk aplikasi industri, dan berkontribusi pada pengembangan metode produksi karbon aktif yang lebih ramah lingkungan dan ekonomis.

ABSTRACT

This study examines the use of NaCl as an activator in the production of activated carbon from Polyethylene terephthalate (PET) waste to overcome environmental problems due to the accumulation of plastic waste that is difficult to decompose. This study aims to examine the effect of NaCl concentration on the iodine adsorption capacity of activated carbon. This type of research is experimental research. The samples used were 15 samples of activated carbon. Data collection methods through laboratory experiments. Data analysis was performed by simple linear regression analysis. The results of the analysis showed that variations in NaCl concentration had a significant effect on iodine adsorption capacity, with an R^2 value of 0.868 indicating 86.8% of variations in adsorption capacity could be explained by NaCl concentration. A concentration of 1M was considered optimal in balancing effectiveness, production cost, and environmental impact, although higher concentrations resulted in better adsorption capacity. This study concludes that the utilization of PET waste for activated carbon production provides a sustainable solution to plastic pollution, reduces waste while producing high-value products for industrial applications, and contributes to the development of more environmentally friendly and economical activated carbon production methods.

1. INTRODUCTION

Plastic is an important material in modern life because it is light, strong, transparent, flexible and cheap. However, the increasing use of plastic causes the accumulation of non-degradable waste, giving rise to serious environmental and human healthy problems (Aulia et al., 2023; Pilapitiya & Ratnayake, 2024). Data from the Ministry of Environment and Forestry (KLHK) shows that the composition of plastic waste in Indonesia in 2023 will reach 18.78, second only to food waste. The existence and danger of plastic in human health, particularly at the cellular level where it can potentially trigger cancer, necessitate crucial efforts toreduce and control plastic use through the application of the 3R principle (Reduce, Reuse, Recycle) and the substitution of plastic raw materials with more environmentally friendly alternatives (Cahyono et al., 2021; Firmansyah, Y W, Fuadi, 2021). However, these technical efforts must be balanced with increasing public awareness and education regarding the importance of plastic recycling and recovery. This education, especially for younger generation, is a strategic step to ensure the active participation of the younger generation in protecting the environment (Maerani et al., 2023; Manik et al., 2023). In the context of a circular economy, the conversion of plastic waste into activated carbon is one of the important innovations that offers a sustainable solution to reduce plastic waste and maximize resource reuse (Babaremu et al., 2022; Zhao et al., 2022). By applying

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circular economy principles, which aim to retain, recover and redistribute materials in the system as long as possible, we can mitigate the impact of plastic waste on the environment, this comprehensive strategy involves redesigning products and processes to facilitate recycling, reduce waste, and extend product life cycles, ultimately leading to a more sustainable future (Schwarz et al., 2021; Subekti, 2023). Plastic is a type of macromolecularly formed from the polymerization process, polymerization is the incorporation of several simple molecules (monomers) into large molecules (polymers) (Aulia et al., 2023; Utomo & Susi Arfiana, 2023). Plastic is a material that can be formed into the desired shape with the help of heat or pressure, most plastics come from organic base materials such as oil, cotton, sugarcane, coal, and corn. Polyethylene terephthalate (PET) is a type of plastic that is widely used in various industries. PET has a high carbon content, so it has the potential to be used as activated carbon (Ilyas et al., 2021; Smeaton, 2021). Activated carbon is a carbon amorph compound that can be produced from materials that contain carbon, both organic and non-organic and activated carbon is used to remove odors, tastes, colors and other organic contaminants, activated carbon itself can be in the form of granules or powders. Activated carbon has small pores that are able to adsorb other substances and is usually made through dehydration, carbonization and activation processes (Ganjoo et al., 2023; Heidarinejad et al., 2020).

Various chemicals such as KOH, HCl, and H3PO4 have been used as activators in making active carbon from PET waste, but their use has negative impacts on health and the environment (Falkenberg et al., 2020; Wilson et al., 2020). Therefore, this research developed activated carbon from PET plastic waste using NaCl as an activator. NaCl was chosen because it is pH neutral, cheap, and does not require a pH neutralization process after soaking, making it easier to make active carbon and in previous research with different raw materials, namely coconut shells and several other raw materials with a variety of activators, the best quality activated carbon can be obtained from the NaCl activator (Tarmidzi et al., 2021; Ukanwa et al., 2019). NaCl also acts as an effective dehydration agent in removing tar deposits that are still attached to the carbon pores, this process helps in opening the activated carbon pores, increasing the surface area available for adsorption (Dzigbor & Chimphango, 2019; Tarmidzi et al., 2021). To determine the characteristics of the activated carbon produced, it is necessary to test the carbon's adsorption capacity for iodine. The iodine adsorption capacity test is important to measure the adsorption capacity and surface area of activated carbon, as well as ensuring its quality and effectiveness in adsorbing other substances (Ganjoo et al., 2023; He et al., 2023) This research emphasizes the importance of providing innovative solutions to two problems at once, namely, the management of PET plastic waste which is an environmental problem, and increasing the efficiency of activated carbon as an adsorbent material. With the increasing demand for effective and environmentally friendly water treatment technologies, it is important to understand the effect of NaCl concentration as an activator on the iodine adsorption capacity of PET-based activated carbon. This is a matter of great importance (Falkenberg et al., 2020; Novia, 2021).

This research is supported by previous studies showing that activated carbon from organic materials, including plastic waste, has great potential as an adsorbent in various applications (Gunawan et al., 2020; Yaqoob et al., 2022). Some studies have also tested the use of various activators, such as NaCl, to enhance the adsorption ability of activated carbon (Ahangar et al., 2021; Oko et al., 2021). However, this research provides novelty in the specific context of using NaCl as an activator for PET-based activated carbon, and its impact on iodine adsorption. The uniqueness of this research is the use of a holistic approach combining PET waste management and adsorbent material optimization, which has not been widely studied before. The aim of this study was to examine how NaCl concentration affects the ability of activated carbon to adsorb iodine. Through this research, it is hoped that it can serve as a foundation for further development in the plastic recycling industry and adsorption technology, as well as make a positive contribution in reducing the environmental impact of PET plastic waste.

2. METHOD

This type of research is experimental research. The experiments was carried out in the environmental chemistry laboratory at President University. This experiment involved a series of laboratory tests to explore the effect of different NaCl concentrations on the adsorption capacity of activated carbon produced. This results was then compared to the Indonesian National Standard (SNI) for the activated carbon adsorption thresholds, namely SNI 06- 3730-1995. A total of 15 activated carbon samples (3 samples for each NaCl concentration) were analyzed in this study and these samples were generated from PET plastic waste collected from the local environment. All samples of carbon was obtained through carbonization of PET plastic waste in a lab scale. PET type plastic is washed clean then dried and cut into smaller sizes about 2 – 4 cm. Pieces of dried plastic waste are put into porcelain cups and in the oven for 1 hour at a temperature of 105^{0}C so that the plastic waste dries more and the size is smaller. After that, the sample of plastic is put into the furnace and carbonized for 1 hour and 30 minutes with a temperature of 480^{0}C, During the carbonization process, make sure to open the furnace lid to reduce the amount of oxygen during the combustion process. After the plastic waste is carbonized and produces black carbon, it is crushed with pestle mortar and then sifted with a 200mesh sieve to make it smoother and become powder. The crushed carbon is soaked with acetone for 24 hours to remove the remaining combustion residues, then filter the carbon with vacuum and whatman 42, after the acetone and carbon are separated, dry the carbon in an oven for 3 hours at a temperature of 110^{0}C and do physical activation by heating in the furnace for 2 hours at a temperature of 750^{0}C. Weigh the dried carbon as much as 25 grams and soak it withNaCl with a variety of activators 1M, 1.5M, 2M, 2.5 M, 3M in 250 ml and let it sit for 2 hours, dry the carbon again with a vacuum and whatman 42 and oven for 3 hours at a temperature of 110^{0}C, after feeling the temperature just put it in the desicator for 30 minutes, carbon ready to use. Iodine solution is made by dissolving 25 g of KI (Potassium Iodide) in 30 ml of water in a 1000 ml volumetric flask. After that, 13 g of I2 (iodine) was added to the solution and shaken until completely dissolved. Then, distilled water is added until it reaches the limit mark on the measuring flask. This solution should be stored in a dark place and should only be used for up to 10 days. For the sodium thiosulfate solution, 26 g of sodium thiosulfate (5 hydrate) was dissolved and 0.2 g of Na2CO3 (sodium carbonate) was added with 1 L of distilled water. Meanwhile, a 1% starch solution was made by mixing 10 ml of distilled water with 1 g of starch and stirring until evenly mixed, then adding 100 ml of hot water and leaving it for a few moments. Activated carbon was heated in an oven at 115°C for 1 hour, then 0.5 g of activated carbon was putinto an Erlenmeyer and 50 ml of 0.1 N iodine solution was added. The sample was shaken for 15 minutes, left to sit until the carbon settled, and the supernatant 10 ml titrated with 0.1 N sodium thiosulfate solution until the color of the solution becomes pale yellow. Add 1% starch solution as an indicator and titrate again until the blue color disappears. Experimental data were analyzed using simple linear regression to determine the effect of NaCl concentration on the iodine adsorption capacity of activated carbon. The analysis results are expected to provide insight into the optimal concentration of NaCl as an activator in making active carbon from PET plastic waste.

3. RESULT AND DISCUSSION

Result

The creation of activated carbon from PET plastic is an innovative step that is expected to make a significant contribution to reducing plastic waste which has a negative impact. This process not only helps solve the plastic waste problem, but also offers a cost-effective method for producing carbon-based materials that have many industrial applications. In this research, 10 grams of PET plastic (A) were weighed and then heated at 450°C in a furnace. This heating process produces 1.9 grams of carbon (B), which represents an 81% mass reduction, presented in Figure 1.

Figure 1. (A) PET Plastic Cut Into Small Pieces (B) Carbon Resulting from the Carbonization Stage of PET Plastic

The carbon produced from PET plastic is dark black and in the form of a fine powder. This process involves grinding or crushing the activated carbon until it reaches a very small size and then filtering it using a 200 mesh sieve. The carbon particles that pass through are about 0.074 mm or smaller, which are very fine and ideal for a variety of industrial applications. After grinding, the carbon produced from PET plastic is activated using NaCl with varying concentrations ranging from 1M to 3M in a volume of 250 ml (a) . This mixture is stirred briefly until it forms a paste, then left for 2 hours for the activation process. After that, the activated carbon is vacuumed and dried to remove the water content in the carbon (b), presented in Figure 2.

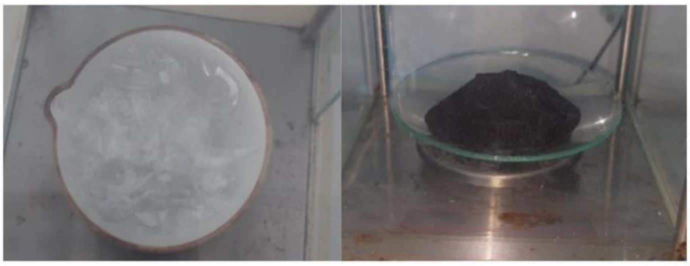

Figure 2. (a) Activated Carbon in NaCl Soak (b) Activated Carbon in Vacuum (c) Activated Carbon in Oven (d) Activated Carbon Results

The use of sodium chloride (NaCl) as an activator in the carbon soaking process has proven to be effective in improving the quality of activated carbon. NaCl's ability to clean activated carbon from remaining tar without forming new functional groups, so that the surface of the activated carbon pores becomes more open and actived carbon becomes highly adsorbent. After activated carbon is successfully produced, activated carbon must be tested for iodine adsorption as a standardization of activated carbon. The activated carbon was first heated in an oven at 115°C for 1 hour, then 0.5 g of activated carbon (1M, 1.5M, 2M, 2.5M, 3M) was put into an Erlenmeyer and 50 ml of 0.1 N iodine solution was added. The sample was shaken for 15 minutes with a stirrer, allowed to settle, and 10 ml of supernatant was titrated with 0.1 N sodium thiosulfate solution until the color of the solution became pale yellow. Add 1% starch solution as an indicator and titrate again until the blue color disappears. **Table 1.** Presents data on the amount of NaCl concentration and iodine adsorption capacity by PET- based activated carbon. Activated carbon, known for its large surface area and high porosity, is a good adsorbent for various substances, including iodine.

Table 1. Descriptive Statistics of Iodine Adsorption Based on NaCl Concentration

Stat. Descriptive	[NaCl]	Adsoption
Mean	2.00	1022.67
Std. Dev	0.73	53.01
Min.	1	969
Max	3	1116
Skewness	000	0.971
kurtosis	-1.328	-0.430
No. Of Data	15	15

After carrying out three experiments for each PET activated carbon, the average results of iodine uptake were obtained as seen in the data above which was calculated according to the formula. The data shows that in all variations of NaCl concentration it has exceeded the SNI minimum standard for activated charcoal with Iodine uptake characteristics.

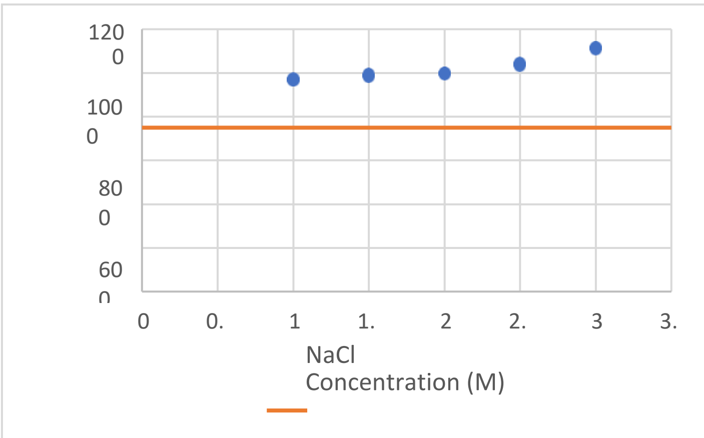

Figure 3. Iodine Adsorption with Variations in Concentration and SNI 06-3730-1995

Figure 3. provides a clear picture of the increase in iodine abdsorption with each increase in concentration. Initially, iodine adsorption is at a lower level, but as the concentration increases, there is a significant increase in iodine adsorption.

Table 2. Data Analysis

Model summary						
Model		**R**		**R square**	**AdjustedR square**	
1		0.931		0.868	0.857	
Anova						
Model		**Sum of square**	**df**	**Mean square**	**F**	**Sig.**
1	Regression	34138.133	1	34138.133	85.162	0.01
	Residual	5211.200	13	400.862		
	Total	39349.333	14			
Coefficients						
Model		**Unstandardized**	**Coefficients std.error**	**Standardized coefficients Beta**	**t**	**sig**
1	Constant	887.733	15.509	931	57.241	0.01
	concentration	67.467	7.311		9.228	0.01

Based on a simple linear regression analysis carried out on data on the active carbon uptake capacity for iodine which was tested three times per activator, it was found that the NaCl concentration had a significant influence on the iodine uptake rate. The results of the analysis show that the p-value obtained is 0.01, which is smaller than the alpha level of 0.05. This shows that there is a significant relationship between the concentration of NaCl as an activator and the level of iodine uptake. Simple linear regression analysis produces an R square value of 0.868. This R square value shows that around 86.8% of the variation in iodine uptake rate can be explained by the concentration of NaCl as an activator. Thus it can be concluded that the concentration of NaCl has a significant influence on the level of iodine uptake in activated carbon.

Discussion

The process of making activated carbon from PET plastic can significantly reduce the mass of PET plastic waste.In the carbonization process, which involves high temperatures, the plastic material is decomposed into carbon and the volatile organic components are removed (Ganjoo et al., 2023; Zepka, 2019). This process causes the decomposition of organic material and the release of impurities, so that most non-carbon elements are lost. These carbonization results are in line with previous research which shows that carbonization of PET plastic results in a significant mass reduction and produces carbon with a high surface area (Ahangar et al., 2021; Sharifian & Asasian-Kolur, 2022). This process also helps open the pores in the carbon structure, increasing the area where the molecules can interact, thereby increasing the adsorption capacity of activated carbon (Devi & Rawat, 2021; Dhahak et al., 2019). The increase in adsorbancy on each activated carbon can be explained through the mechanism NaCl as an activator can increase the surface area and porosity of activated carbon, the activation process with NaCl opens up more pores in the carbon structure, allowing more area for iodine molecules to interact, and as the concentration of NaCl increases, more pores are exposed, further expanding the surface area available for adsorption (Dzigbor & Chimphango, 2019; Utomo & Susi Arfiana, 2023).

In this study, the use of a 1 M NaCl concentration in the activated carbon activation process from PET plastic was considered more optimal by considering the effectiveness of adsorption capacity, production costs and environmental impacts in the optimal sense for carbon affordability. At a NaCl concentration of 1 M, activated carbon is able to adsorb 971 mg/g of iodine, meeting the Indonesian national standard (SNI) which sets a minimum of 750 mg/g. Although this value does not reach the adsorption capacity at concentrations of 2.5 M (1040 mg/g) or 3 M (1114 mg/g), a concentration of 1 M is quite effective for applications that require adequate adsorption capacity. In terms of cost, increasing the NaCl concentration will increase the cost of producing activated carbon. A concentration of 1 M is more economical than higher concentrations, such as 2.5 M or 3 M, providing significant economic advantages, especially in large-scale production. In addition, the use of large amounts of NaCl can increase the salinity of waste which can damage aquatic ecosystems if not managed properly, disrupt aquatic life, and reduce water quality, Increased salinity can also cause soil degradation, reducing soil fertility and agricultural productivity (Karolinoerita & Annisa, 2020; Utomo & Susi Arfiana, 2023). A concentration of 1 M with a lower amount of NaCl will produce waste with lower salinity, so that negative impacts on the environment can be minimized. This study shows that the use of PET plastic waste for activated carbon production with NaCl as activator offers an efficient and environmentally friendly solution. The carbonization process significantly reduced the waste mass and produced carbon with high surface area. NaCl, especially at a concentration of 1 M, proved optimal in increasing the adsorption capacity of activated carbon while keeping production costs low and minimizing environmental impact (Ahangar et al., 2021; Devi & Rawat, 2021). Although higher concentrations of NaCl can increase the adsorption capacity, they also carry greater environmental risks, such as increased salinity of the effluent.

Therefore, a concentration of 1 M is seen as a balanced choice, making this method a sustainable approachthat can be applied on an industrial scale to address the problem of plastic waste. The findings of this study are similar to previous research showing that the type and concentration of activator has a significant influence on the pore structure and surface area of activated carbon, which in turn has a direct impact on the ability of activated carbon to absorb iodine or other substances (Heidarinejad et al., 2020; Radika & Astuti, 2020). In addition, it is also in line with research showing that the use of NaCl as an activator can increase the efficiency of activated carbon in absorbing iodine (Ilyas et al., 2021; Manik et al., 2023). Based on this, the overall results showed that variations in NaCl concentration significantly affected the quality of the activated carbon produced, with all tested concentrations exceeding the minimum standard set by the Indonesian National Standard (SNI). This research has advantages in terms of innovation in the use of plastic waste (PET) to create activated carbon that has potential in adsorption applications (Ahangar et al., 2021; Oko et al., 2021). The implications of this research show that changing the concentration of NaCl as an activator has an impact on the ability of activated carbon to adsorb iodine, which has an important role in improving the effectiveness of sewage and water treatment. However, this research has limitations in terms of the limited testing scale which may not fully reflect the actual industrial application conditions. As a recommendation, future research could expand the experimental scale and explore the use of other activators to improve the performance of activated carbon, as well as test its application in various environmental conditions.

4. CONCLUSION

This study highlights the effectiveness of using NaCl as an activator in producing activated carbon from Polyethylene terephthalate (PET) waste. The study showed that variations in NaCl concentration significantly affected the quality of activated carbon produced, with all tested concentrations exceeding the minimum standard set by the Indonesian National Standard (SNI). NaCl effectively increased the surface area and porosity of the carbon, leading to an increase in adsorption capacity. A strong positive correlation was observed between NaCl concentration and adsorption capacity, indicating that higher NaCl concentration increases the ability of carbon to adsorb substances. However, this study identified 1M NaCl as the optimal concentration, which balances between effectiveness, production cost, and environmental impact. This approach not only provides a cost-effective solution but also minimizes environmental risks, offering a sustainable method to manage plastic waste while producing valuable industrial materials..

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