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Adsorption Dye in Batik Wastewater using Biomass Adsorbent : a State of the Art Review

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ABSTRACT

In this article, we study several research about optimizing the adsorption of harmful compounds contained in batik dye liquid waste using activated carbon. The employment of naphthalene as a chromogenic agent in the batik industry introduces a significant quandary by contributing to water pollution through effluent discharge. Noteworthy efforts have been made by certain industries, employing activated carbon to mitigate the presence of Pb and Cr attributable to naphthalene. The principal objective of this exposition is to consolidate insights into the sequestration of perilous dyes within batik industry effluents, leveraging various forms of natural activated carbon. The kinetics of the adsorption process will be quantified utilizing the appropriate kinetic order formula, while equilibrium data will be scrutinized through reaction isotherms employing diverse models.

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INTRODUCTION

Batik was designated as a world cultural heritage in 2009 by UNESCO, the Batik textile industry experienced a steady increase following fashion trends with trendy batik modifications (Kusworo et al., 2022). This increase, in line with the value of batik exports in Indonesia, which from time to time will increase, this actually has a very positive impact, because it can introduce Indonesian culture to the wider community. But along with the increasing demand, more and more industries are producing batik. This will also cause by-products in the form of liquid waste from batik production. This batik liquid waste will greatly disturb the aquatic ecosystem of the surrounding population. Waters contaminated with batik liquid waste will cause toxic substances and harmful to humans. The batik industry reportedly contributes 17-20% of global water pollution(Jegatheesan et al., 2016).

Generally, the batik industry produces liquid waste from the process of dyeing, soaking, washing and removing wax used during the batik making process(Yanto et al., 2023). Of course, Batik wastewater contains typical pollutants, such as dyes, starch, aluminum sulfate, and wax with extreme PH, COD, BOD, TSS high and concentrated colors that exceed wastewater disposal quality standards (Tangahu et al., 2019)the dyeing process is one of the processes that contribute the most liquid waste to the batik industry. Based on its chemical content, dyes are divided into natural and synthetic dyes. However, in the batik industry, more synthetic dyes are found which are classified into several types, such as dispersion dyes, vat dyes, sulfur dyes, acid dyes, and alkaline dyes(Putri et al., 2022). The use of synthetic reactive dyes is what can worsen water quality with their high toxicity and cannot be biodegraded (Rahmayanti et al., 2020)

Therefore, the right solution is needed to overcome these problems. The adsorption process is the most familiar process among the public in absorbing a waste, one of which is batik industry liquid waste. Considering that the liquid waste of the batik industry is still not responded to properly. Therefore, in this journal review, it focuses on knowing what types of natural materials can be used as adsobsion for the absorption of batik industry liquid waste, what is the efficiency of the trapper and what types of content can be absorbed including adsorption kinetics and also the most potential and most useful natural materials in the process of absorbing batik industry liquid waste.

LITERATURE REVIEW

Batik Industry

The batik industry, known for its vibrant and intricate textile designs, generates a substantial amount of wastewater during the dyeing and coloring processes. This wastewater, often referred to as batik effluent, is characterized by a complex composition of dyes, mordants, and other chemicals used in the textile treatment (Yanto et al., 2023). Batik industry waste exhibits a diverse composition, encompassing various organic and inorganic pollutants. Heavy metals, including lead (Pb), chromium (Cr), and cadmium (Cd), are common components of batik effluent. These heavy metals often originate from the dyes, mordants, and fixatives used in the dyeing processes. For example, mordants containing chromium are frequently employed to enhance color fastness in batik textiles, contributing to the presence of Cr in the wastewater. Lead-based pigments in certain dyes also contribute to elevated levels of Pb. The discharge of batik effluent containing these heavy metals can have severe ecological consequences, as these elements are known to be persistent, toxic, and bioaccumulative .

Adsorption

Adsorption isotherms play a pivotal role in understanding the interaction between adsorbate molecules and the adsorbent surface, providing insights into the equilibrium conditions of the adsorption process. One of the fundamental models extensively used in the study of adsorption isotherms is the Langmuir model. Langmuir proposed that adsorption occurs on a homogeneous surface with a finite number of identical sites, and the model assumes monolayer adsorption without any lateral interaction between adsorbed molecules. The Langmuir isotherm equation has been widely applied in various fields, including environmental science and catalysis, to quantify the adsorption capacity and understand the surface characteristics of adsorbents (Daud et al., 2022).

Another commonly employed model is the Freundlich isotherm, which allows for multilayer adsorption and considers heterogeneous surfaces. The Freundlich model expresses a non-ideal relationship between adsorbate concentration and adsorption, with a power-law dependence. This model is particularly valuable when the adsorption process does not strictly adhere to monolayer coverage. The Freundlich isotherm has been applied in studies related to soil science, wastewater treatment, and the characterization of porous materials.(Zhang et al., 2023)

Type of Activated Carbon

Utilizing agricultural waste materials for the production of activated carbon has garnered significant attention due to its potential as a sustainable and cost-effective approach. Various agricultural by-products, such as corn husk, coconut shell, orange peel, and cocoa shell, have been explored as precursors for activated carbon (Handayani et al., 2024; Lam et al., 2017; Tiegam et al., 2021; Wu et al., 2022)The activation of these materials typically involves a series of processes, including carbonization and activation, to enhance their porosity and surface area. Corn husk, coconut shell, and orange peel, in particular, have been studied for their adsorption capacities and suitability for environmental remediation, such as in water treatment and air purification.

Moreover, Cocoa shell, a by-product of the cocoa industry, has emerged as a notable precursor for the production of activated carbon. Studies have shown that cocoa shell possesses unique structural and chemical properties, making it an attractive candidate for activated carbon synthesis. The carbonization and activation of cocoa shell have been investigated to create adsorbents with high porosity and a well-developed surface area. Activated carbon derived from cocoa shell has demonstrated effectiveness in adsorbing various pollutants, including heavy metals and organic contaminants, showcasing its potential for environmental applications. The utilization of cocoa shell not only addresses the issue of agricultural waste management but also contributes to the development of sustainable materials for water and air purification processes (Tiegam et al., 2021)

Parameters (Kinetics, Isotherms, Regeneration) that Affect the Adsorption

Adsorption kinetics describe the rate at which adsorption occurs, providing essential insights into the mechanism and efficiency of the process. The pseudo-first-order and pseudo-second-order models are commonly used to analyze adsorption kinetics. For instance, in a study by (Wang et al., 2019), the adsorption kinetics of methylene blue onto activated carbon derived from coconut shells were investigated. The pseudo-second-order kinetic model demonstrated a better fit to the experimental data, indicating that chemisorption was the rate-limiting step in the adsorption process. The study highlighted the significance of understanding the kinetic behavior for designing efficient adsorption systems.(Zhang et al., 2023)

Adsorption isotherms establish the relationship between the amount of adsorbate adsorbed at equilibrium and its concentration in the solution. The Langmuir and Freundlich isotherm models are widely utilized to interpret adsorption isotherm data. The Langmuir isotherm model fitting revealed a maximum adsorption capacity of 45.87 mg/g for cadmium ions. This data indicated the monolayer adsorption behavior of cadmium ions on the biochar surface. Understanding such isotherm characteristics is crucial for predicting the adsorption capacity of the material and optimizing its application in water treatment and environmental remediation.(Widiyastuti et al., 2020)

The regeneration of adsorbents is a vital aspect of sustainable adsorption processes. Practical examples in the literature illustrate the impact of regeneration parameters(Vievard et al., 2023). In a study by (Chen et al., 2018), the regeneration of activated carbon from sewage sludge after adsorption of antibiotics was investigated. Thermal regeneration at 500°C was found to be effective, achieving a regeneration efficiency of 92.5%. The study emphasized the importance of temperature as a key parameter in the regeneration process. Such insights are crucial for developing adsorption systems that not only effectively capture pollutants but also allow for the repeated use of adsorbents, reducing overall costs and environmental impact.

METHODOLOGY

The methodology in this research is a literature review with several approaches in a journal review. Several researchers this time focus on finding out what types of natural materials can be used for adsorption in the absorption of liquid waste from the batik industry, what the trapping efficiency is and what types of content can be absorbed including the adsorption kinetics. and also the most potential and useful natural ingredients in the process of absorbing liquid waste from the batik industry.

RESEARCH RESULT AND DISCUSSION

Types of Adsorbent and Efficiency of Adsorption

Researchers do a lot of handling using natural materials that are used as adsorbents with the help of chemical and physical processes.

Table 1. Types of Adsorbents and absorbency

Adsorbent Ingredients	Adsorbat Materials	Absorbent Force	Isoterm	Reference
Corn husk	Methylene blue	99,79%	Langmuir	(Handayani et al., 2024)
Coconut shell	Methylene blue	96%	Langmuir	(Widiyastuti et al., 2020b)
Orange peel	Methylene blue	96%	Langmuir	(Ramutshatsha-Makhwedzha et al., 2022)
Cacao shell	Pb2+ give Cr+	87% and 71%	-	(Njoku et al., 2011)

The data above is the data from research that has been carried out by previous researchers using several adsopsial kinetic formulas to determine the kinetic order, isotherms and also using several tools to determine the remaining adsorbate concentration. The types of kinetics that are mostly used are determination of reaction order, isotherm and thermodynamics. The following formulas are commonly used in the adsorption process.

Kinetics

Pseudo-one-order

$$q_t = q_e(1 - e^{-k_1 t})$$

Pseudo-second-order

$$\frac{t}{q_t} = \frac{1}{k_2 q_c^2} + \frac{t}{q_c}$$

Elovich

$$q_t = \frac{ln\, a_e b_e}{b_e} + \frac{1}{b_e}\ln t$$

Intraparticle diffusion

$$q_t = k_{ip} t^{0,5} + c$$

Information:

q_t= adsorbate adsorption capacity by adsorbent at time t (mg/g)
q_e= adsorption capacity at equilibrium (mg/g),
k 1 is the kinetic constant of the pseudo-first-order model (1/h)
k2 = kinetic constant of pseudo-second-order model g/(mg·h)
k_{ip}= in particles (mg/g·min0.5) ,
C = constant corresponding to boundary layer thickness
(Hung et al., 2023)

Isotherm

Langmuir

$$q_e = \frac{q_m K_L C_e}{1+K_L C_e}$$

Keterangan:

q_m = Maximum adsorption capacity of adsorbate(mg/g)
K_L = is Langmuir's constant (L/mg)
C_e = is the adsorbate equilibrium concentration (mg/L)
q_e = Adsorption capacity at equilibrium(mg/g)

Freundlich

$$q_e = K_F C_e^{1/n}$$

K_F = konstanta Freundlich (mg/g) $\left(\frac{L}{mg}\right)^{1/n}$,
n = strength factor

Temkin

$$q_e = \frac{R\ t}{b} \ln k + \frac{R\ T}{b} lnC_e$$

C_e = Adsorbate Equilibrium Concentration (Mg/L)
B = Relationship of Surface Coverage Area with Activation Energy

(Norfaizah M. Noor et al., 2023)

Termodynamics

$$K_d = \frac{q_e}{c_e}$$

$$\Delta G = -RT \ln K_d$$

$$lnK_d = \frac{\Delta S}{R} - \frac{\Delta H}{RT}$$

(Chakraborty et al., 2023)

The relationship between adsorption, kinetics, and isotherm is integral in understanding the efficiency and mechanisms of adsorption processes. In the case of corn husks, these agricultural by-products showcase exceptional adsorption efficiency, with a remarkable 99.79% adsorption of methylene blue. The kinetics are well-described by the second-order pseudo model, indicating a chemisorption process where the rate-limiting step involves the formation of a monolayer on the surface. The Langmuir isotherm model fitting further suggests that adsorption occurs on a homogeneous surface with a finite number of identical sites. Similarly, coconut shell emerges as a promising adsorbent with a significant 96% adsorption capacity for methylene blue. The kinetics, characterized by intraparticle diffusion, reveal that intraparticle diffusion is the rate-controlling step. The Langmuir isotherm model fitting underscores that adsorption takes place on a surface with a finite number of identical sites, forming a monolayer.

Orange peel, a versatile adsorbent, exhibits substantial adsorption capacities for both methylene orange (96%) and methylene blue (98%). The second-order pseudo model for kinetics indicates a chemisorption process, with the Langmuir isotherm model fitting supporting adsorption on a surface with a finite number of identical sites. In contrast, cocoa shell demonstrates good adsorption capabilities for heavy metals Pb2+ (87%) and Cr2+ (71%). While specific kinetic data is not provided, the absence of such information suggests a need for further investigation into the kinetics of the adsorption process. Similarly, isotherm information is not available, emphasizing the need for a comprehensive understanding of cocoa shell's surface characteristics and adsorption capacities for heavy metals.

The data regarding cocoa shell's adsorption capabilities for heavy metals, specifically Pb2+ and Cr2+, presents intriguing possibilities for its application in treating wastewater from the batik industry, which often contains these pollutants. Cocoa shell demonstrates a commendable adsorption efficiency of 87% for Pb2+ and 71% for Cr2+, indicating its potential as a natural and sustainable adsorbent for heavy metal removal. The utilization of cocoa shell for treating batik industry waste could offer several advantages. Firstly, cocoa shell is an agricultural by-product, making it an environmentally friendly and cost-effective option, aligning with the principles of sustainability. Its availability as a waste material from the cocoa industry contributes to the utilization of resources that would otherwise be discarded. The demonstrated adsorption efficiency for Pb2+ and Cr2+ suggests that cocoa shell could be integrated into wastewater treatment processes for batik industry effluents. Its capacity to selectively remove heavy metals aligns with the need to address environmental concerns associated with textile dyeing processes. Moreover, the use of natural adsorbents like cocoa shell can contribute to minimizing the environmental impact of industrial activities, promoting a more sustainable approach.

CONCLUSIONS AND RECOMMENDATIONS

The data on various agricultural by-products, including corn husks, coconut shell, orange peel, and cocoa shell, showcase their diverse adsorption capacities for different adsorbates. Understanding the kinetics and isotherms of these materials is essential for designing effective adsorption systems. Corn husks and orange peel exhibited high adsorption efficiencies, with cocoa shell showing promise for heavy metal removal. For the batik industry, cocoa shell's potential for adsorbing Pb2+ and Cr2+ suggests its applicability in treating wastewater. However, practical implementation requires further investigation into scalability, regeneration capabilities, and economic feasibility. Considering the potential application of cocoa shell in the batik industry wastetreatment, it is recommended to conduct further research to explore its performance under realistic conditions. Detailed studies on the regeneration of cocoa shell, scalability assessments, and economic analyses should be prioritized to evaluate its practical viability. Additionally, broader investigations into the potential impact of coexisting pollutants in batik industry wastewater on the adsorption efficiency of cocoa shell are essential for a comprehensive understanding.

ADVANCED RESEARCH

Over time, the evolution of technology brings advancements toward more sophisticated and efficient methods. These changes are expected to serve as benchmarks or refinements for adsorption methods in absorbing heavy metals. The emergence of new methods is anticipated to be more economical and effective for application, both on a laboratory and industrial scale.

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