Effectiveness of Corn Cob Activated Carbon In Removing Total Suspended Solids And Total Chromium In Batik Waste

Canda Diwratna Wulandari[1*], Anis Artiyani[2], Maria Roslyn Dwiputri[3], Hery Setyobudisudarso[4]

[1,2,3,4] Environmental Engineering Study Program, Institut Teknologi Nasional, Malang, East Java, Indonesia.
[*] Corresponding author:
Email: candra_wulandari@lecturer.itn.ac.id

Abstract.
The batik production process involves several stages that generate liquid, gaseous, and solid waste. Furthermore, the process requires significant amounts of water. Without proper treatment, this can degrade water quality. Certain waste parameters, specifically Total Suspended Solids (TSS) and Total Chromium, exceed established quality standards. Given the limitations batik artisans face regarding infrastructure, resources, and access to technology, there is a need for a waste treatment model that is simple, modular, and easy to maintain. Adsorption is a widely used method for wastewater treatment, with corn cobs serving as an adsorbent. The purpose of this study is to test the ability of activated carbon from corn cobs to reduce TSS and total chromium in batik wastewater. The adsorbent dosage was 1.5 grams and 3 grams, with stirring times of 30, 60, and 90 minutes, at a stirring speed of 200 rpm. The results indicate that activated carbon derived from corn cobs effectively adsorbed TSS and Total Chromium from batik wastewater. The highest effectiveness of the percentage of TSS and Chromium content allowance at the variation of activated carbon dose of 3 grams and at the contact time of 90 minutes with the percentage of TSS elimination of 80% and Total Chromium of 97%, but it has not met the quality standards in accordance with the Ministry of Environment and Foresty Regulation No. 16 of 2019, namely TSS of 50 mg/L and total Chromium of 1 mg/L.
Keywords: *Adsorption, Activated Carbon, Batik and Corn Cob.*

I. INTRODUCTION

Batik production consists of several stages, the process begins with waxing, coloring, and the process concludes with de-waxing, or the wax removal process [1]. During the batik making process, waste will be produced, according to the process carried out, the waxing process produces gas waste from heating smoke and wax vapor, the coloring process produces liquid waste containing natural dyes and synthetic dyes, whereas the de-waxing process produces gas waste from heating smoke, solid waste from wax residue, and liquid waste containing starch, soda, dye residue and fabric fiber residue [2], [3].

Batik production requires a lot of water during the production process, resulting in high batik waste discharge [2]. Each meter of batik cloth requires 25-20 m3 of clean water, and 80% of the water will become waste [4]. Improperly treated batik waste can contribute to environmental degradation and pollution, as has occurred in Pekalongan City, where the condition of the river is moderately to severely polluted, characterized by the presence of plankton types Nitzschia, Navicula, and Oscillatoria, which indicate the presence of organic and inorganic material pollution [5]. The abundance of plankton in the Maduri River, Pekalongan ranges from 1104-5393, while the diversity index (H') ranges from 1.011-1.885, which means the river is in a moderate to severely polluted condition [6].

The characteristics of batik waste exceed the industrial wastewater quality standards according to the Regulation of the Minister of Environment of the Republic of Indonesia Number 5 of 2014, the characteristics of batik waste are as follows: pH 8,31, TSS 2,40 mg/L, TDS 0,66 mg/l, TS 3,04 mg/L, COD 1070,16 mg/L, BOD 54,40 mg/L, and DO 1,20 mg/L [7]. The results of Belaon & Hendrasarie, 2023 obtained the following batik wastewater characteristics: TSS 160 mg/L, TDS 997 mg/L, COD 1120 mg/L, color 540,1 Pt-Co, temperature 27 0C, and pH 9,77 [8]. In addition to organic materials, batik waste can contain heavy metals such as Cadmium (Cd), Mercury (Hg), Lead (Pb), Chromium (Cr), and Copper (Cu) [9]. Heavy metals come from synthetic dyes such as Diazo salts or Diazonium salt, Caustic Soda, and Sodium Hydroxide, CrCl3 (Chromium Chloride), K2Cr2O7 (Kalium Dichromate), Cr (NO3) (Chromium

Nitrate), and $PbCrO_4$ (Lead II Chromate) [10], [11]. The concentration of Cr^{6+} in batik waste was 2,361 mg/L [12], while according to Widaryati & Laksmitasari, 2020, Cr^{6+} in batik waste was 0,153 mg/L, whereas the total Chromium concentration was around 10,0 mg/l [13], [14].

The concentration of chromium in batik wastewater is influenced by the type of dye used, the amount of solvent, and the frequency of washing [11]. Chromium in water can harm aquatic organisms by disrupting their metabolic system due to the inhibition of enzymes in physiological processes [15]. Chromium can irritate the eyes, nose, and lungs, as well as cause skin irritation. Continuous exposure at high doses can cause skin burns, cancer of the digestive tract, and lung cancer [16].

Most batik industries are developed on a household scale, with industrial areas located within the same premises as the artisans' homes [17]. The batik industry has the potential to pollute the environment because batik artisans do not have their own waste treatment facilities, while the capacity of existing integrated wastewater treatment facilities is insufficient to accommodate the total volume of waste produced [18]. Limited infrastructure, resources, and access to technology for batik industry players necessitate a simple, modular, and easy-to-maintain wastewater treatment system [19]. Under these circumstances, adsorption is an effective and easy-to-operate alternative wastewater treatment method [15].

Conventional wastewater treatment methods for separating ions from water include precipitation, ion exchange, biological absorption, membrane filtration, electrochemistry, and adsorption [20]. Adsorption is the process of mass transfer through the pore surface from the adsorbate to the adsorbent [21]. Adsorption is a widely chosen method for wastewater treatment. This method has the advantages of high absorption capacity, regeneration ability, lower cost, and abundant raw materials [22]. One adsorbent that can be used is corncobs.

Corn cob activated carbon has been tested to reduce Iron levels in well water. The results derived from the study indicate that corn cob activated carbon can reduce Iron levels by 56% [23]. Corn cob adsorbent can reduce Chromium (Cr IV) and Cadmium (Cd II) levels in artificial waste by 80% [24]. Meanwhile, the ability of corn cob adsorbent to reduce TSS, COD, and color in textile waste is 15.47%, 13.21%, and 67.5%, respectively [25]. Corncobs have advantages such as being readily available, inexpensive, and easy to manufacture, having a higher carbon content, and being environmentally safe because they are made from organic materials. The chemical content of corn cobs consists of cellulose, hemicellulose, lignin, and extractive substances. When in the form of activated carbon, the cellulose content is 40% and hemicellulose is 36% [26].

Based on the aforementioned problems, the objective of this study was to test the ability of corn cob activated carbon to reduce TSS and Total Chromium in batik wastewater by varying the adsorbent dosage and stirring time.

II. METHODS

Batik waste was collected from UMKM batik "X" in Malang City. Currently, the UMKM batik does not have a wastewater treatment plant (MMTP), and the remaining batik waste is disposed of directly into water bodies. This study used a descriptive qualitative approach. The study was conducted at the Environmental Engineering Laboratory of ITN Malang. Data collection through laboratory experiments involved several stages: initial research, including activated carbon preparation, carbonization, and activation. The next step was the main research, which involved the adsorption of batik wastewater using activated carbon derived from corn cobs.

The equipment used in this study was a jar test, an Atomic Absorption Spectrophotometer (AAS), an analytical balance, an oven, a furnace, Glassware, and filter paper. The materials used were batik waste, corn cob waste, NaOH 0,5 N, Distilled Water, concentrated Nitric Acid (HNO_3), Hydrogen Peroxide (H_2O_2), Chromium Stock Solution (Cr) 1000mg/L, Acetylene gas, and Diluting Solution.

The manufacture of corn cob-derived activated carbon begins with a preparation process. This preparation aims to reduce the moisture content of corn cobs through drying them until completely dry. This process facilitates a more complete carbonization stage. The next stage is the carbonization of corn cobs. In the carbonization stage, the dried corn cobs are heated in a furnace at a temperature of 400 0C for 1 hour to obtain carbon. Following the cooling process, the carbonized corn cob was ground to obtain the desired particle size and then sieved using a 100-mesh sieve. In the subsequent stage, the carbonized corn cob was activated by soaking it in a 0.5 N NaOH solution for 24 hours. The purpose of activation is to expand the surface of the activated carbon and release hydrocarbons and organic compounds that are still attached to the carbon. The next stage involved washing the activated carbon with distilled water until a neutral pH is obtained. Before use, the activated carbon was dried using an oven at a temperature of 100 0C for 3 hours, and cooled in a desiccator.

The main study used a batch adsorption method, using a jar test to aid stirring at a stirring speed of 200 rpm. The media weights varied between 1.5 grams and 3 grams, and stirring times were 30, 60, and 90 minutes. Each variation was repeated three times to ensure valid data.

TSS analysis was conducted using the gravimetric method. This method is a quantitative analytical technique based on measurement of the difference in sample weight before and after heating. The TSS concentration can be calculated using the following formula:

$$\text{TSS Reduction}= \frac{(\text{w1-w0})\text{x}1000}{\text{v}} \qquad (1)$$

Where W0 is the weight of the media containing the filter paper (mg), while W1 is the weight of the media containing the filter paper and the residue (mg), V is the Volume of the test sample (ml) and 1000 is the conversion factor.

Total chromium concentration was analyzed using ASS, a method that quantitatively analyzes elements by measuring the wavelengths of free metal atoms. The chromium concentration was calculated as follows:

$$\text{Metal content (mg/L)} = C \times fp \qquad (2)$$

Where C is the metal content obtained from the measurement result (mg/L), while Fp is the dilution factor.

III. RESULT AND DISCUSSION

The physical characteristics of batik wastewater include a dark red color, turbidity, absence of odor, and foam formation. Preliminary analysis was conducted to determine the initial characteristics of batik waste. The analysis results showed a TSS concentration of 480 mg/L, and the total chromium concentration was 1.71 mg/L. Both parameters exceeded the quality standards required by the Minister of Environment Regulation No. 16 of 2019. Where the TSS concentration was 50 mg/L and the total chromium was 1 mg/L for textile waste with a discharge of less than 100 m3/day.

This study compared adsorbent dosage and mixing time. The weight variations used were 1,5 grams and 3 grams, while the mixing times were 30,60, and 90 minutes. The best removal percentages for TSS and total Chromium were achieved at high dosages and longer stirring times. The complete analysis results can be seen in Table 1.

Table 1. Results of TSS concentration measurements

No	Dose Adsorbent (gr)	Time Stirring (minute)	Initial Concentration (mg/L)	Average Concentration (mg/L)	Percentage Elimination
1	1,5	30	480	390	19%
		60		310	35%
		90		233	51%
2	3	30		197	59%
		60		150	69%
		90		90	80%

Source: Processed primary data, 2026

The percentage of TSS removal increased with increasing adsorbent dosage and longer stirring time. The highest percentage of removal was at 3 grams of adsorbent weight with a stirring time of 90 minutes, with a percentage of 80%. The percentage of TSS removal in each variation can be seen in Fig. 1.

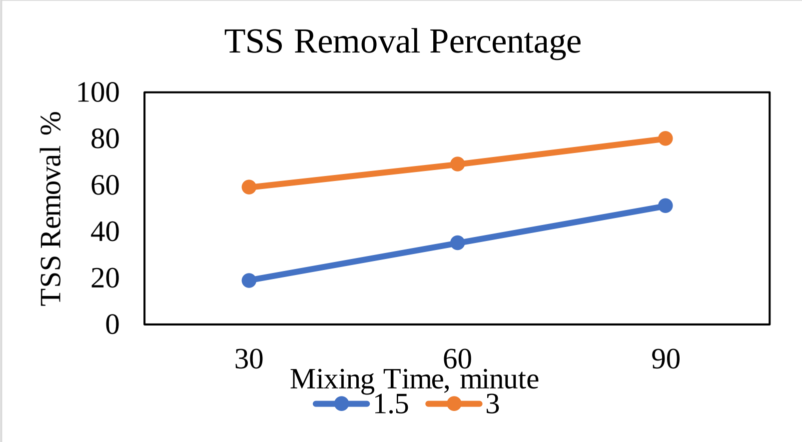

Fig. 1. TSS Removal Percentage

The decrease in TSS values is due to the large surface area and small pores of activated carbon derived from corn cobs, which are capable of binding and retaining suspended solid particles in liquid waste, thus reducing TSS levels [27]. Table 1 shows that the adsorbent dosage affects the decrease in TSS concentration. The amount of adsorbent itself will affect the surface area of the adsorbent, where the wider the surface area of the adsorbent, the more substances will be adsorbed.

Contact time can also affect the amount of adsorbate absorbed, as each adsorbent has its own specific adsorption capacity and rates. An increase in contact time between the adsorbent and the adsorbate leads to a higher amount of adsorbate being absorbed [28].

According to [29], the decrease in TSS can be caused by the binding of organic compounds by carbon and it can be said that activated carbon from corn cobs works effectively to reduce TSS levels in batik waste. The percentage of TSS removal increases with the increase in the weight of activated carbon. At a variation of 3 grams of adsorbent weight, the TSS removal efficiency is between 59-80%, while at 1.5 grams of adsorbent weight, the TSS removal efficiency is between 19-51%. This is because the heavier the mass of activated carbon, the greater the absorption capacity. An increase in activated carbon dosage results in a larger available surface area of the adsorbent, which enhances the interaction between the adsorbent and adsorbate. This allows more TSS molecules to attach to the surface of the adsorbent, thereby increasing absorption efficiency.

Adsorption is a reaction that occurs on the surface of a solid or adsorbent, whether in a gaseous or liquid state [30]. Adsorption is a mass transfer process involving the adsorbate is removed by the adsorbent. This separation process occurs due to electrostatic effects that create van der Waals forces [31].

Corn cobs contain carbon compounds, consisting of 41% cellulose and 36% hemicellulose, which are the main ingredients for making activated carbon [32]. Corn cobs have a low ash content of 0.91%, while their high carbon content compared to the ash content makes them a promising precursor for the production of activated carbon with potential adsorbent capabilities [33]. Activated carbon production can be carried out through physical and chemical activation. The purpose of activation is to open pores so that adsorption performance can be maximized [34]. With the activation process using NaOH, micropores will increase, thereby enlarging the adsorption area and increasing the absorption efficiency of suspended particles such as TSS [35]. NaOH activation can cause degradation of the lignocellulose structure, thereby breaking lignin and cellulose bonds and enlarging the micropores [36]. Activation of corn cob activated carbon with NaOH can form negatively charged functional groups on the surface of the activated carbon, thereby strengthening the electrostatic interaction with positive ions such as TSS [37].

Contact time plays an important role in the adsorption process. An increase in contact time between the adsorbent and adsorbate provides more opportunities for adsorbate molecules to interact with the active sites of the adsorbent, resulting in an increase in adsorption capacity [38]. The contact time variation of 90 minutes provides the highest efficiency of 80% at an adsorbent weight of 3 grams, while at a contact time of 30 minutes the efficiency is lower at 59%. During immersion, activated carbon comes into contact with the compound to be absorbed, so the longer the immersion contact time, the greater the resulting adsorption capacity. Adsorption using activated carbon is a type of physical adsorption that involves pores and attractive forces between adsorbent and adsorbate molecules. There are large pores in Activated carbon, which also affects the size of the adsorbate molecules absorbed [39]. Sufficient contact time is needed to achieve adsorption equilibrium. If the liquid phase containing the adsorbent is in a stationary state, then the diffusion of the adsorbate through the adsorbent surface will be slower, so stirring is needed to accelerate adsorption [40].

The study was conducted in batches with a stirring speed of 200 rpm. Stirring in the adsorption process can increase adsorption efficiency and capacity. Stirring enhances the kinetic energy, so that the frequency of collisions between the adsorbent and adsorbate increases, reducing boundary layer resistance and accelerating mass transfer from the solution to the adsorbent surface [41]. Stirring speed helps optimize adsorption. With stirring, the adsorption process will be faster, so that the formed film layer is thinner and a large adsorption constant is obtained [42].

The total chromium concentration in batik waste was 1,718 mg/l, exceeding the quality standards required by the Minister of Environment Regulation No. 16 of 2019. Based on Table 2, it was found that the adsorbent dosage and stirring time affected the percentage of total Chromium removal. The percentage of total Chromium removal increased with increasing adsorbent dosage and contact time.

Table 2. Results of Total Chromium Concentration Measurements

No	**Dosage Adsorbent (gr)**	**Time Stirring (minute)**	**Initial Concentration (mg/L)**	**Average**	**Percentage Elimination**
1	1,5	30	1,718	0,956	44
		60		0,677	61
		90		0,559	67
2	3	30		0,44	74
		60		0,304	82
		90		0,054	97

Source: Processed Primary Data, 2026

The largest Chromium removal was at 98% with an adsorbent weight variation of 3 grams and a stirring time of 90 minutes, while the smallest percentage was at 1,5 grams with an adsorbent weight of 30 minutes, with a percentage of 44%. The effect of weight variation and stirring time can be seen in Fig. 2 below.

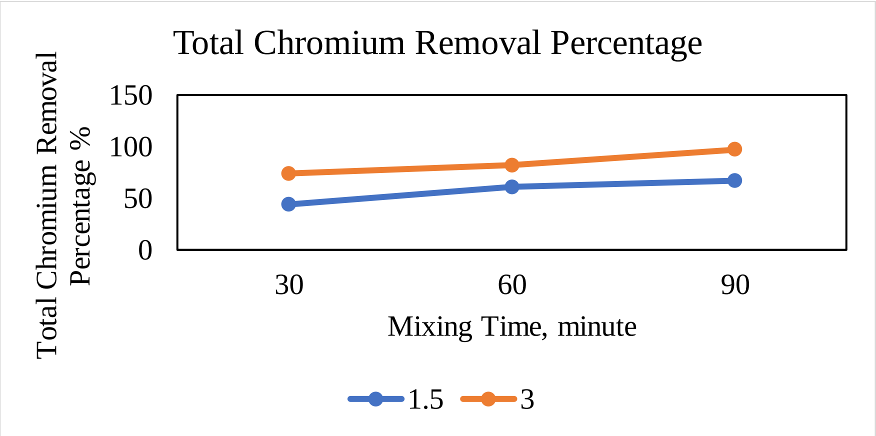

Fig. 2. Percentage of total Chromium Removal

The decrease in Cr value is due to the heavier activated carbon. The higher the efficiency of Cr ion reduction, the more activated carbon causes an increase in the surface area of the adsorbent. The larger the activated carbon, the more active groups are available, so that the exchange of H+ with the total Cr metal increases.

Activated carbon is a carbon that has the ability to absorb cations, anions, and compounds in the form of inorganic and organic compounds in the form of gas or solution [43]. The increase in Cr reduction occurs because the longer the contact time, the more Cr metal comes into contact with the activated carbon, so that more Cr metal is adsorbed in the pores of the activated carbon [44].

Adsorption on cellulose-based adsorbent is controlled by several factors such as van der Waals forces, hydrophobicity, hydrogen bonds, polarity, and steric interactions. Cellulose consists of repeating units of β-D-Glucopyranose covalently linked by acetal functions between the equatorial OH group on the carbon atom (C4) and the carbon atom (C1) therefore, it is called β-1,4-glucan. As a result, cellulose has a large linear chain polymer with a large number of hydroxyl groups (three groups per anhydrous glucose unit) [45]. In physical adsorption, adsorbates (heavy metals) accumulate on the surface of the adsorbent by interactions mentioned above [46]. The mechanism of decreasing chromium concentration is influenced by electrostatic attraction. Electrostatic attraction occurs between functional groups that have a negative charge on the surface of the adsorbent and chromium molecules that have a positive charge. This force binds the chromium to the carbon surface, allowing separation via adsorption [47]. The atomic arrangement on the surface of activated carbon is an unbalanced force compared to that of most solids [29]. This imbalance causes other molecules to attempt to penetrate the activated carbon surface. The difference in adsorbate concentration between the adsorbates with activated carbon, it will attract metal ions into the adsorbent to form a single layer (monolayer) and diffuse in the carbon pores [48].

Research data shows that a 3-gram adsorbent weight variation has a higher chromium removal percentage than a 1.5-gram weight variation. This indicates that adding more adsorbent will increase the efficiency of the Chromium removal process. Increasing the weight/dose of the adsorbent will increase the availability of particle contact surfaces, which means that the active groups for adsorption also increase, thus facilitating the penetration of chromium metal ions into the adsorbent groups [49].

The increase in adsorption efficiency may also be attributed to the formation of additional functional groups during NaOH-assisted thermochemical activation and the increased surface area, which can contribute to enhancing the metal absorption capacity of the corn cob-derived adsorbent [50]. This is also in accordance with research conducted by Jamshaid et al, 2017, which concluded that alkaline treatment has the highest adsorption capacity [51]. The alkaline conditions and high temperatures in the initial treatment will cause a more perfect degradation process, resulting in purer cellulose and achieving a more optimal adsorption process [24]. Activated carbon that has been activated when contacted with liquid waste containing heavy metals will absorb the heavy metals. This is due to the capillary phenomenon that causes the emergence of adsorption power on the surface of the activated carbon [52].

The hydroxyl groups in cellulose make the adsorbent polar. Therefore, cellulose is more effective at adsorbing polar substances than less polar ones [53]. During the adsorption process, heavy metal ions migrate from the solution to the surface of the corncob adsorbent, where they are adsorbed due to van der Waals forces. Thus, electrostatic interactions occur when chromium ions are close to the adsorbent side [54]. The interaction of hydroxyl groups with chromium ions can also occur through the formation of coordination complexes. The oxygen atom in the hydroxyl group has a lone electron pair that will occupy the empty orbital on the metal ion to form a compound or complex ion [53].

The longer the contact time between the adsorbate and the adsorbent, the percentage of total chromium removal increases. At a contact time of 90 minutes, a percentage of 97% was obtained at a variation of the adsorbent weight of 3 grams, while at a weight of 1.5 grams, a percentage of 67% was obtained. The longer the contact time between the adsorbent and the adsorbate, the greater the adsorption capacity is [55]. Each adsorbent has a different ability to absorb pollutants. This ability depends on the type of adsorbent and the surface area of the pores. The adsorption capacity is influenced by the contact time between the adsorbent and the adsorbate. If the contact time is too short, the metal contaminants cannot be bound properly. On the other hand, if the contact time is too long, the pores of the adsorbent are reduced, so that the adsorbent's ability to absorb metals decreases and the metal will be released back into the water [16].

One important factor that helps the adsorption process is stirring. Stirring helps the activated charcoal come into contact with the waste so that it becomes homogeneous and helps the collision process between heavy metals and the adsorbent. The stirring speed affects the contact area of the adsorbent; the faster the stirring speed, the better the expansion of the contact so that the absorbed metal molecules are larger [56]. Stirring helps ensure the constant movement of the adsorbate particles. This movement will accelerate the particles in the wastewater to diffuse more quickly into the pores [41]. During the stirring process, a bond is formed between the adsorbent and adsorbate. If the stirring speed is too high, it can result in the activated carbon being unable to form a strong bond, so that only a small amount of adsorbate can be absorbed [57].

IV. CONCLUSION

Based on the results of the study, it can be concluded that activated carbon from corn cobs has the potential as an adsorbent to reduce the concentration of TSS and total Chromium in batik industrial wastewater. The adsorbent dose and contact time affect the removal of TSS and total Chromium concentrations. The effectiveness of the highest TSS and Chromium removal percentage is at a variation of the activated carbon dose of 3 grams and at a contact time of 90 minutes, with a TSS removal percentage of 80% and a total Chromium of 97%, but it has not met the quality standards according to the Minister of Environment Regulation No 16 of 2019. It is necessary to test other parameters and combine them with other treatments so that batik wastewater can meet the quality standards.

V. ACKNOWLEDGMENTS

The authors express their gratitude to the Environmental Engineering Study Program at the National Institute of Technology Malang for their support and the facilities provided for this research. We appreciate all parties who have contributed, directly or indirectly, to this research.

REFERENCES

[1] A. Suzana, E. Adriansyah, P. Herawati, M. Marhadi, T. Silvina, and R. Sufra, "Pengolahan Air Limbah Batik Jambi Menggunakan Filtrasi dan Fotokatalisis TiO2 (Titanium Dioksida)," ***Jurnal Ilmiah Universitas Batanghari Jambi***, vol. 24, no. 1, p. 578, Feb. 2024, doi: 10.33087/jiubj.v24i1.4958.

[2] I. R. Anugrah, N. A. Nisa, F. Luthfiana, and A. M. F. Dani, "Penerapan Prinsip Interaksi Antar Molekul dalam Pengolahan Limbah Batik**,"** ***Jurnal Tadris Kimia IAIN Syekh Nurjati Cirebon***, vol. 02, no. 01, pp. 19–28, 2022.

[3] N. Diyah, T. Ratuannisa, E. Ekawati, E. Yulia, B. S. Purwasasmita, and A. B. Nugraha, "Studi Pengolahan Air Limbah Batik pada Skala Industri Rumah Tangga dan Usaha Kecil Menengah di Cirebon, Indonesia," Dampak, vol. 20, no. 1, pp. 8–15, Jan. 2023, doi: 10.25077/dampak.20.1.8-15.2023.

[4] D. C. Hakika, Z. Mufrodi, R. T. Evitasari, C. P. Bhakti, and B. Robi'in, "Peningkatan Pengetahuan Peserta Training of Trainer (ToT) 'Pelatihan Batik dengan Pewarnaan Alami' dengan Penyuluhan Mengenai Pengolahan Limbah Cair Industri Batik," ***Abdimas Jurnal Pengabdian kepada Masyarakat***, vol. 25, no. 2, pp. 233–238, 2021.

[5] A. W. Ragil, S. Abdul Ghofar, A. Gunawan, and D. N. Misidawati, "Analisis Strategi Pengelolaan Air Limbah Industri Batik Yang Berkelanjutan Di Kota Pekalongan**,"** ***Jurnal Sahmiyya***, vol. 2, no. 1, pp. 1–9, 2023.

[6] M. N. Permatasari, H. Ariadi, B. D. Madusari, and H. Soeprapto, "Kajian Kualitas Air Sungai Meduri Pekalongan Akibat Pembuangan Limbah Cair Batik Berdasarkan Indikator Biologi," ***Journal of Aquaculture Science***, vol. 6, no. 2, pp. 130–136, Oct. 2021, doi: 10.31093/joas.v6i2.198.

[7] C. Febrianti, M. Ulfah, and K. Kusumastuti, "Pemanfaatan Ampas Kopi sebagai Bahan Karbon Aktif untuk Pengolahan Air Limbah Industri Batik," agriTECH, vol. 43, no. 1, p. 1, Feb. 2023, doi: 10.22146/agritech.68014.

[8] B. T. Belaon and N. Hendrasarie, "Penurunan Beban Organik Limbah Batik Jetis Menggunakan Adsorben Serat Tebu, Kulit Kedelai dan Kulit Bawang," ***Jurnal Serambi Engineering***, vol. VIII, no. 3, pp. 6180–6190, 2023.

[9] E. P. Anggraeni, F. Khoirunnisa, and A. Aktawan, "Penjerapan Logam Cu dan Cd pada Limbah Cair Batik Menggunakan Adsorben dari Limbah Tulang Ayam," ***Jurnal Kimia Dan Rekayasa*** , vol. 4, no. 1, pp. 9–7, 2023, [Online]. Available: http://kireka.setiabudi,ac.id

[10] S. R. Pradipta, J. Triastuti, and N. N. Dewi, "Utilization of Green Mussel (Perna viridis) as A Lead Metal Pollutant Adorbent in Batik Dye Waste**,"** ***Journal of Marine and Coastal Science***, vol. 13, no. 3, pp. 144–151, Sep. 2024, doi: 10.20473/jmcs.v13i3.54598.

[11] M. Sitia And Juswardi, "Potensi Fitoremediasi Bambu Air (Equisetum Hyemale L.) Dalam Mereduksi Logam Berat Kromium Limbah Cair Kain Jumputan Dengan Sistem Lahan Basah Buatan," In Artikel Pemakalah Paralel Isu-Isu Strategis Sains, Lingkungan, Dan Inovasi Pembelajarannya, 2022, Pp. 346–354.

[12] H. R. Fidiastuti And A. S. Lathifah, "Uji Karakteristik Limbah Cair Industri Batik Tulungagung: Penelitian Pendahuluan," In Seminar Nasional Pendidikan Biologi Dan Saintek Iii, 2018, Pp. 296–300.

[13] B. Widaryanti And E. Laksmitasari, "Penurunan Kadar Kromium (Vi) Pada Limbah Batik Desa Giriloyo Imogiri Menggunakan Serbuk Eceng Gondok (Eichhornia Crassipes)," In Seminar Nasional Pendidikan Biologi Dan Saintek (Snpbs) Ke-V, 2020, Pp. 486–490.

[14] E. Kurnianingtyas, "Combination Of Trembesi (Samanea Saman) Adsorbents And Fitormediation Of Kiambang (Salvinia Molesta) Plants To Reduce Chrome Levels In Batik Waste," ***Sustainable Environmental And Optimizing Industry Journal***, Vol. 4, No. 2, Pp. 108–114, Oct. 2022, Doi: 10.36441/Seoi.V4i2.1185.

[15] I. Lestari, M. Mahraja, F. Farid, D. R. Gusti, And E. Permana, "Penyerapan Ion Pb(Ii) Menggunakan Adsorben Dari Limbah Padat Lumpur Aktif Pengolahan Air Minum," Chemistry Progress, Vol. 13, No. 2, Pp. 68–75, Nov. 2020, Doi: 10.35799/Cp.13.2.2020.31391.

[16] U. A`Yunina, A. D. Moelyaningrum, And E. Ellyke, "Pemanfaatan Arang Aktif Tempurung Kelapa (Cocos Nucifera) Untuk Mengikat Kromium (Cr) (Study Pada Limbah Cair Batik)," ***Jurnal Kesehatan Lingkungan Indonesia***, Vol. 21, No. 1, Pp. 93–98, Feb. 2022, Doi: 10.14710/Jkli.21.1.93-98.

[17] K. Oginawati, A. A. H. Anka, S. H. Susetyo, S. A. Febriana, I. Tanziha, And C. R. S. Prakoeswa, "Urinary Hippuric Acid Level As A Biological Indicator Of Toluene Exposure On Batik Workers," Heliyon, Vol. 7, No. 8, Pp. 1–7, Aug. 2021, Doi: 10.1016/J.Heliyon.2021.E07775.

[18] V. Rachmawati, R. Nurjayati, And M. D. Yuniati, "Penurunan Konsentrasi Cod Limbah Batik Pada Proses Seeding Dan Aklimatisasi Menggunakan Material Preservasi Mikroorganisme (Mpmo)," ***Jurnal Kesehatan Lingkungan Indonesia***, Vol. 21, No. 1, Pp. 73–82, Feb. 2022, Doi: 10.14710/Jkli.21.1.73-82.

[19] A. P. Farahdiansari, M. F. Perdana, W. T. Sasmi, A. R. Pratama, And F. M. Dewadi, "Studi Literatur Pengembangan Teknologi Pengolahan Limbah Cair Pewarna Batik: Pendekatan Desain Peralatan Ramah Lingkungan," ***Jadi (Jurnal Teknik Industri)***, Vol. 1, No. 2, Pp. 59–67, 2025, [Online]. Available: Https://Jadi.Indiepress.Id/Jadi/Index.Php/Jadi/Index

[20] M. J. Subarkah And H. S. Titah, "Remediasi Logam Berat Pb Dengan Menggunakan Biochar Sekam Padi Dan Tongkol Jagung," ***Jurnal Sains Dan Seni Its***, Vol. 12, No. 1, Pp. F48–F52, 2023.

[21] Paryanto, M. A. Fadilah, And M. F. I. Aji, "Penentuan Nilai Kesetimbangan Adsorbsi Zat Warna Alami Kulit Mahoni Ke Dalam Kain Dengan Proses Batch," Inovasi Teknik Kimia, Vol. 3, No. 2, Pp. 1–7, 2018.

[22] W. D. P. Rengga, Harianingsih, A. Erwanto, And B. Cahyono, "Kesetimbangan Adsorpsi Isotermal Logam Pb Dan Cr Pada Limbah Batik Menggunakan Adsorben Tongkol Jagung (Zea Mays)," ***Journal Of Chemical Process Engineering***, Vol. 4, No. 2, Pp. 56–63, 2019.

[23] Y. J. Simangunsong And Yusmidiarti, "Efektivitas Karbon Aktif Bonggol Jagung (Zea Mays) Untuk Menurunkan Kadar Besi (Fe) Air Sumur Gali Di Kelurahan Padang Serai Kota Bengkulu," ***Jurnal Sanitasi Profesional Indonesia***, Vol. 2, No. 1, 2021.

[24] N. Rokhati, A. Prasetyaningrum, N. 'Aini Hamada, A. L. C. Utomo, H. B. Kurniawan, And I. H. Nugroho, "Pemanfaatan Tongkol Jagung Sebagai Adsorben Limbah Logam Berat," ***Jurnal Inovasi Teknik Kimia***, Vol. 6, No. 2, P. 89, Oct. 2021, Doi: 10.31942/Inteka.V6i2.5508.

[25] L. M. Susanto, A. Rahmatulloh, And S. J. Endarto, "Pengolahan Limbah Cair Tekstil Dengan Memanfaatkan Tongkol Jagung Sebagai Karbon Aktif Menggunakan Aktivator Natrium Hidroksida (Naoh)," Distilat: ***Jurnal Teknologi Separasi,*** Vol. 11, No. 1, Pp. 01–09, Mar. 2025, Doi: 10.33795/Distilat.V11i1.6893.

[26] Suwantiningsih, Khambali, And Narwati, "Daya Serap Arang Aktif Tongkol Jagung Sebagai Media Filter Dalam Menurunkan Kadar Besi (Fe) Pada Air," ***Ruwa Jurai: Jurnal Kesehatan Lingkungan***, Vol. 14, No. 1, P. 33, Aug. 2020, Doi: 10.26630/Rj.V14i1.2170.

[27] I. Pratiwi And A. I. Setiorini, "Penurunan Nilai Ph, Cod, Tds, Tss Pada Air Sungai Menggunakan Limbah Kulit Jagung Melalui Adsorben," ***Jurnal Redoks***, Vol. 8, No. 1, Pp. 55–62, 2023.

[28] N. Herawati, R. Rifdah, And N. M. Muthiah, "Kajian Pengaruh Massa Dan Waktu Operasi Pada Pengolahan Limbah Cair Industri Tahu Dengan Menggunakan Residue Catalytic Cracking (Rcc) Sebagai Adsorben," Distilasi, Vol. 8, No. 1, Pp. 1–11, 2023.

[29] U. M. Anggriani, A. Hasan, And I. Purnamasari, "Kinetika Adsorpsi Karbon Aktif Dalam Penurunan Konsentrasi Logam Tembaga (Cu) Dan Timbal (Pb)," *Jurnal Kinetika*, Vol. 12, No. 02, Pp. 29–37, 2021, [Online]. Available: Https://Jurnal.Polsri.Ac.Id/Index.Php/Kimia/Index

[30] R. N. Wakid, H. Prasetyo, And A. Mulyaningtyas, "Prosiding Seminar Nasional Teknik Kimia 'Kejuangan' Pengaruh Konsentrasi Koh Dan Suhu Terhadap Adsorpsi Cu Pada Limbah Cair Batik Dengan Adsorben Bonggol Jagung," Jurusan Teknik Kimia, Pp. 14–15, 2020.

[31] N. M. Eka, G. A. Muluk, And T. R. Azis, "Pemanfaatan Limbah Tongkol Jagung Sebagai Bioabsorben Dalam Proses Adsorpsi Besi(Ii) Dan Metilen Biru," ***Jurnal Chemurgy***, Vol. 8, No. 1, Pp. 59–67, 2023, [Online]. Available: Http://E-Journals.Unmul.Ac.Id/Index.Php/Tk

[32] M. Jannah, F. Kriswandana, Marlik, And I. R. E. Wardojo, "Bioadsorben Campuran Kulit Dan Tongkol Jagung Untuk Menurunkan Kadar Bod Limbah Batik," ***Window Of Health :Jurnal Kesehatan,*** Vol. 5, No. 2, Pp. 511–518, 2022.

[33] Meilianti, "Pembuatan Karbon Aktif Dari Arang Tongkol Jagung Dengan Variasi Konsentrasi Aktivator Natrium Karbonat (Na2co3)," Distilasi, Vol. 5, No. 1, Pp. 14–20, 2020.

[34] A. Saban, Jasruddin, And Husain, "Pengaruh Konsentrasi Aktivator (Naoh Dan Hcl) Terhadap Karakteristik Karbon Aktif Dari Tongkol Jagung," Jurnal Sains Dan Pendidikan Fisika (Jspf) Jilid, Vol. 19, No. 2, Pp. 2548–6373, 2023.

[35] V. Hernández-Montoya, L. A. Ramírez-Montoya, A. Bonilla-Petriciolet, And M. A. Montes-Morán, "Optimizing The Removal Of Fluoride From Water Using New Carbons Obtained By Modification Of Nut Shell With A Calcium Solution From Egg Shell," Biochem. Eng. J., Vol. 62, Pp. 1–7, Mar. 2012, Doi: 10.1016/J.Bej.2011.12.011.

[36] J. G. Murnane, B. Ghanim, L. O'donoghue, R. Courtney, T. F. O'dwyer, And J. T. Pembroke, "Advances In Metal Recovery From Wastewaters Using Selected Biosorbent Materials And Constructed Wetland Systems," In Water And Wastewater Treatment, Intechopen, 2019, Pp. 1–26. Doi: 10.5772/Intechopen.84335.

[37] W. Mulyani, S. Mulyono, And A. C. Ayomi, "Pemanfaatan Karbon Aktif Kayu Besi Untuk Mengurangi Kadar Tss, Cod Dan Fosfat Limbah Laundry," Gema Kesehatan, Vol. 17, No. 1, Pp. 33–40, Jun. 2025, Doi: 10.47539/Gk.V17i1.480.

[38] Mukhlis Et Al., "Optimization Of Contact Time And Stirring Speed In The Adsorption Of Cd(Ii) Using Acacia Crassicarpa Bark Powder As Adsorbent," ***Journal Of Chemical Analysis***, Vol. 08, No. 02, Pp. 111–120, 2025, Doi: 10.20885/Ijca.Vol8.Iss2.Art2.

[39] A. Miarti And R. S. Anike, "Efektifitas Karbon Aktif Tongkol Jagung Terhadap Kadar Ph, Tss Dan Tds Pada Limbah Cair Pt Perta Samtan Gas Effectiveness Of Corn Cob Active Carbon On Ph, Tss And Tds Levels In Liquid Waste Pt Perta Samtan Gas," ***Jurnal Teknik Patra Akademika***, Vol. 13, No. 01, 2022.

[40] R. S. D. Lestari, D. K. Sari, A. Rosmadiana, And B. Dwipermata, "Pembuatan Dan Karaktersasi Karbon Aktif Tempurung Kelapa Dengan Aktivator Asam Fosfat Serta Aplikasinya Pada Pemurnian Minyak Goreng Bekas," ***Jurnal Teknika***, Vol. 12, No. 3, Pp. 419–430, 2016.

[41] D. Ikhsany, D. Kuriawati, E. Nasra, And M. Khair, "Engaruh Waktu Kontak Dan Kecepatan Pengadukan Terhadap Penyerapan Zat Warna Methylene Blue Pada Biji Kelengkeng (Dimocarpus Longan Lour) Dengan Metode Batch***," Jurnal Pendidikan Tambusai***, Vol. 8, No. 1, Pp. 15497--15504, 2024.

[42] Y. Novianti, E. Muliana, And D. Andriani, "Signage Sebagai Elemen Perancangan Kota Dalam Peningkatan Citra Kota (Studi Kasus Gampong Lancang Garam Kecamatan Banda Sakti Kota Lhokseumawe)," ***Jurnal Solusi Masyarakat Dikara***, Vol. 1, No. 1, Pp. 46–53, 2021.

[43] M. Lempang, "Pembuatan Dan Kegunaan Arang Aktif," Info Teknis Eboni, Vol. 11, No. 2, Pp. 65–80, 2014.

[44] G. Fitriyani, I. Nurhayati, J. Sutrisno, And Sugito, "Adsorpsi Logam Krom (Cr) Total Limbah Cair Batik Menggunakan Karbon Aktif Ampas Kopi," ***Waktu: Jurnal Teknik Unipa***, Vol. 22, No. 02, Pp. 39–46, Jul. 2024, Doi: 10.36456/Waktu.V22i02.8961.

[45] M. Z. Ahmad And M. S. Roychansyah, "Kajian Teoritis Hubungan Smellscape Terhadap Place Attachment," Reka Ruang, Vol. 5, No. 1, Pp. 10–23, 2022.

[46] S. Hokkanen, A. Bhatnagar, And M. Sillanpää, "A Review On Modification Methods To Cellulose-Based Adsorbents To Improve Adsorption Capacity," Water Res., Vol. 91, Pp. 156–173, Mar. 2016, Doi: 10.1016/J.Watres.2016.01.008.

[47] B. Wang, J. Lan, C. Bo, B. Gong, And J. Ou, "Adsorption Of Heavy Metal Onto Biomass-Derived Activated Carbon: Review," Rsc Adv., Vol. 13, No. 7, Pp. 4275–4302, Jan. 2023, Doi: 10.1039/D2ra07911a.

[48] Hajrah, Ruslan, And Prismawiryanti, "Pemanfaatan Karbon Aktif Biji Kelor (Moringa Oleifera) Sebagai Penyerap Logam Timbal Dalam Oli Bekas," Kovalen, Vol. 4, No. 3, Pp. 297–303, 2018.

[49] H. Panda, N. Tiadi, M. Mohanty, And C. R. Mohanty, "Studies On Adsorption Behavior Of An Industrial Waste For Removal Of Chromium From Aqueous Solution," S. Afr. J. Chem. Eng., Vol. 23, Pp. 132–138, Jun. 2017, Doi: 10.1016/J.Sajce.2017.05.002.

[50] F. Asadi, H. Shariatmadari, And N. Mirghaffari, "Modification Of Rice Hull And Sawdust Sorptive Characteristics For Remove Heavy Metals From Synthetic Solutions And Wastewater," J. Hazard. Mater., Vol. 154, No. 1–3, Pp. 451–458, Jun. 2008, Doi: 10.1016/J.Jhazmat.2007.10.046.

[51] A. Jamshaid Et Al., “Cellulose-Based Materials For The Removal Of Heavy Metals From Wastewater – An Overview,” Chembioeng Reviews, Vol. 4, No. 4, Pp. 240–256, Aug. 2017, Doi: Https://Doi.Org/10.1002/Cben.201700002.

[52] K. Zarkasi, A. D. Moelyaningrum, And P. T. Ningrum, “Penggunaan Arang Aktif Kulit Durian (Durio Zibethinus Murr) Terhadap Tingkat Adsorpsi Kromium (Cr 6+) Pada Limbah Batik,” Efektor, Vol. 5, No. 2, 2018.

[53] R. Kusumawardani, T. Anita Zaharah, And L. Destiarti, “Adsorpsi Kadmium(Ii) Menggunakan Adsorben Selulosa Ampas Tebu Teraktivasi Asam Nitrat,” Jurnal Kimia Khatulistiwa, Vol. 7, No. 3, Pp. 75–83, 2018.

[54] R. Liu, D. Han, H. Zhang, Y. Ma, And X. Hao, “Reviewing And Diagnosing Upgradation Strategies Of Wastewater Treatment Plants In China,” Journal Of Water Process Engineering, Vol. 71, Mar. 2025, Doi: 10.1016/J.Jwpe.2025.107267.

[55] F. F. Andarista, M. M. Huda, And R. Dewati, “Adsorpsi Logam Timbal Pada Limbah Cair Artifisial Menggunakan Arang Aktif Eceng Gondok,” Jurnal Teknik Kimia, Vol. 18, No. 1, Pp. 33–39, 2023.

[56] S. Z. Aisyahlika, M. L. Firdaus, And R. Elvina, “Kapasitas Adsorpsi Arang Aktif Cangkang Bintaro (Cerbera Odollam) Terhadap Zat Warna Sintetis Reactive Red-120 Dan Reactive Blue-198,” Alotrop, Jurnal Pendidikan Dan Ilmu Kimia, Vol. 2, No. 2, Pp. 148–155, 2018.

[57] I. Syauqiah, M. Amalia, And H. A. Kartini, “Analisis Variasi Waktu Dan Kecepatan Pengaduk Pada Proses Adsorpsi Limbah Logam Beratdengan Arang Aktif,” Info Teknik, Vol. 12, No. 1, Pp. 11–19, 2011.