Science of the Total Environment 819 (2022) 152931

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Integrated physical-biological treatment system for batik industry wastewater: A review on process selection☆

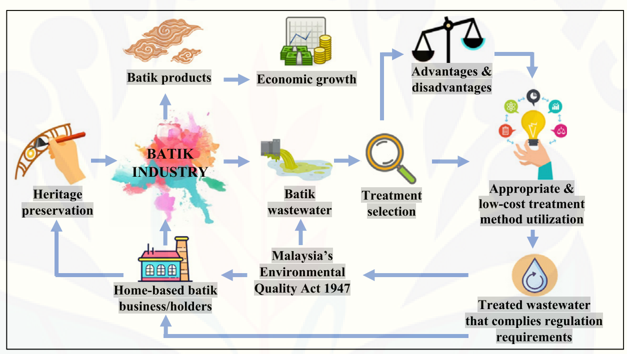
Nurull Muna Daud [a,*], Siti Rozaimah Sheikh Abdullah [a,*], Hassimi Abu Hasan [b], Nur 'Izzati Ismail [a], Yeny Dhokhikah [c]

[a] Department of Chemical and Process Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM, Bangi, Selangor, Malaysia
[b] Research Centre for Sustainable Process Technology (CESPRO), Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM, Bangi, Selangor, Malaysia
[c] Environmental Engineering Study Program, Faculty of Engineering, Universitas Jember, Jalan Kalimantan No. 37, Jember, Jawa Timur, Indonesia

HIGHLIGHTS

- Batik is a traditional and heritage product in Malaysia, Indonesia, Thailand and other countries.
- Batik wastewater may impose environmental pollution and health issues.
- The wastewater management issues on batik industry were briefly discussed in this manuscript.
- The conventional and current batik wastewater treatments were elaborated.
- Future green approaches and low-cost treatments for batik industry wastewater treatment were proposed.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 2 September 2021
Received in revised form 30 December 2021
Accepted 1 January 2022
Available online 7 January 2022

Editor: Huu Hao Ngo

Keywords:
Batik industry
batik wastewater treatment review
green technology
dye-based wastewater
textile wastewater

ABSTRACT

Batik is well known as one of the unique identifiers of the Southeast Asian region. Several countries that still preserve the batik heritage are Malaysia, Indonesia, China and India. The Batik industry holds a significant place in Malaysia's craft-based industry. In Malaysia, batik motifs and patterns are mostly hand-drawn and painted directly on fabric, therefore, each one is unique. The players in the Batik industry are mostly small businesses and cottage industries, particularly in the states of Kelantan, Terengganu, Pahang, Sabah and Sarawak. However, their market growth and contribution are not synchronized with the treatment system. The wastewater generated by this industry rarely meets standard effluent requirements and regulations, thus worrying the authorities. Batik wastewater is categorized as one of the highly polluted wastewaters. The toxicity of pollutants from batik may reduce environmental quality and pose a risk to human health. Batik wastewater needs extensive treatment, since no complete and appropriate treatment has been applied for so many years in specific batik industries. This paper reviews the batik industry in Malaysia, its wastewater generation and the available current treatment practices. It discusses integrated treatments of coagulation-flocculation and phytoremediation technology as a batik wastewater treatment process with potential utility in the batik industry. This review may become part of the guidance for the entire batik industry, especially in Malaysia.

☆ **Highlights:** Wastewater management problems of the batik industry; Current batik wastewater treatment; Future green approaches for batik industry wastewater treatment.

* Corresponding authors.
E-mail addresses: nurullmuna.daud@gmail.com (N.M. Daud), rozaimah@ukm.edu.my (S.R.S. Abdullah).

http://dx.doi.org/10.1016/j.scitotenv.2022.152931

Contents

1. Introduction

Batik is a traditional fabric pattern representing a highly valued heritage and icon to certain countries, especially to Malaysia and Indonesia (Mohamad Akhir et al., 2016). This industry is mainly passed down from one generation to another (Ahmad et al., 2002). In Malaysia, the batik industry operates predominantly as home-based businesses. Other countries that still use batik are African countries (also called *madiba*), Azerbaijan (also called *kalagai*), China (also called *la ran*), Sri Lanka, India and Thailand. Fig. 1 illustrates countries which still preserve and use batik. Batik was mentioned in Malay history as early as the 17th century. However, it was believed to be introduced in Malaysia around 1921 through local traders. They learned the block batik technique from Javanese people in Indonesia and spread batik-making art in several states in Malaysia, such as Terengganu and Kelantan (Teh Athira Yusof, 2019). Compared with Indonesian batik, Malaysian batik is printed/hand-drawn in more vibrant colours with abstracts and floral motifs.

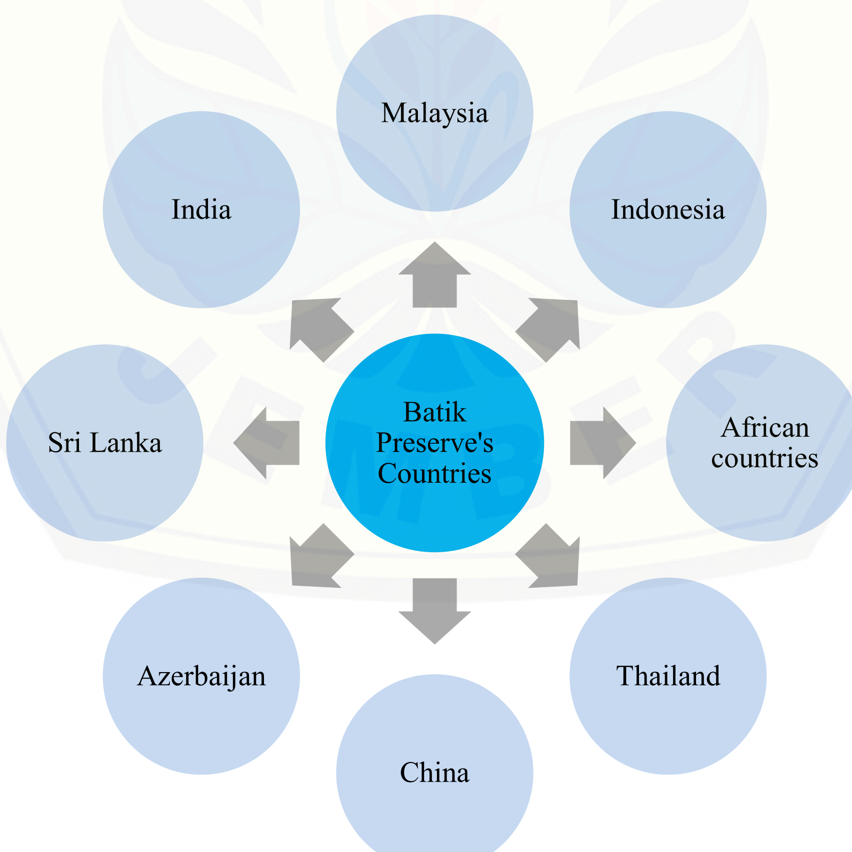


Fig. 1. Countries that preserve the art of Batik.

Batik Indonesia has been recognized as a Masterpiece of Oral and Intangible Heritage of Humanity by The United Nations Educational, Scientific and Cultural Organization (UNESCO) in 2009 (UNESCO, 2020). UNESCO classifies batik into three clusters: hand-drawn batik, block batik, and a combination of both (Nugroho, 2013). The affirmation of batik as one of Representative Intangible Cultural Heritage on Humanity has increased batik popularity in global market and benefits their economy (Shaharuddin et al., 2021). Since then, batik popularity in Indonesia soared and National Batik Day was celebrated on 2nd October every year. In Malaysia, as an effort to support the preservation and growth of the heritage of batik Malaysia, government officer should donning batik every Thursday (Malaysia, 2008). This month, the Prime Minister just declared 3rd December as annual Malaysia Batik Day (Anon, 2021). The declaration was made to unite all races in Malaysia by donning the beauty of local batik, strengthening the local batik industry, and sustaining the batik production chain. Other initiatives made, The Government under the National Creative Industry Policy has provided many initiatives such as funding, marketing, research and commercialization to help batik industry development (Razali et al., 2021; Shaharuddin et al., 2021). Besides, a Kraftangan Malaysia, an agency appointed by the Ministry of Tourism, Arts and Culture, Malaysia, holds the responsibility of commercializing craft products, helping the development of the craft industry and providing support according to the craft industry's needs (Kraftangan Malaysia, 2021). For example, besides giving hand-to-hand support, Kraftangan Malaysia has set up an online shopping platform with a *global reach and a local identity* concept to help Malaysia's craftsmen to market and commercialize their products worldwide.

Nowadays, water and soil contamination are widely reported worldwide due to the rapidly growing population, modern agriculture technologies and massive industrialization (Mohan et al., 2016). Capturing our attention is the specialty of batik fabric and the pollution generated from its production processes. Such processes involve the use of a large quantity of water, as well as chemicals and dye. A significant problem of the dye-based industry, including the batik industry, is the production of a large volume of highly colored wastewater (Mahmood et al., 2005). According to Priya and Selvan (2017), dye-containing wastewater can be considered the most polluted wastewater. Like dye wastewater, batik wastewater can degrade water quality by increasing the water system's colour and turbidity (Warjito and Nurrohman, 2016). Recently, most of the batik industry in Malaysia has been unable to manage its wastewater in an appropriate way and thus has not complied with the requirements stipulated in the Environmental Quality Act of 1974 (Akta Kualiti Alam Sekeliling 1974 (Environmental Quality Act 1974), 2009).

The existing treatment that was previously set up by Kraftangan, Malaysia was not being fully utilized. The installation of an adsorption treatment system using sand and activated carbon is quite costly, and this cost might burden small-to-medium industries like the batik industry (Khandare and Govindwar, 2015; Priya and Selvan, 2017). To make matters worse, the batik industry does not have personnel with adequate knowledge and skills to handle the existing treatment system. A lack of awareness among the batik industry also leads to inappropriate wastewater management (Ramlee et al., 2014). Hence, a less expensive and simpler treatment system may be a better option. Wastewater that is not appropriately treated is not only polluting the environment but also increasing government expenditures.

According to a report released by the Department of Statistics Malaysia (Department of Statistics Malaysia (DoSM), 2018), in June 2020, the amount spent on environmental protection had increased to RM 2.7 billion in 2018 compared with RM2.6 billion in 2017. About RM1.82 billion was spent in the manufacturing sector. This amount includes the expenditure needed for pollution management, waste management and environmental assessment and charges. This expenditure is expected to increase further in the year 2021. The scarcity of water and soil might lead to a decrease in the quantity of life's essential natural resources. As reported by Tahir et al. (2016), 97% of the water on our planet exists as seawater, and only 3% is found as freshwater. About 79% of the freshwater is in the form of glaciers, 20% is available as groundwater and only 1% is accessible for human use. In Malaysia, water consumption recorded in 2019 was 4720 million litres per day (DoSM). Hence, the removal of pollutants and wise management of water and soil has become a crucial issue.

In Malaysia, since batik industry is typically based on small family businesses, access to wastewater treatment is practically non-existent (Rashidi et al., 2013). The current treatment used in Malaysia is sand filtration-adsorption using activated carbon. However, after years of installation, this system has been found costly to be maintained. Indonesia, the largest batik exporter, faces the same problem as the batik industry in Malaysia. Certain batik industries discharge their wastewater directly into the water system without any prior treatment or after treating it partially (Suhardi et al., 2017; Triwiswara, 2019). A study was conducted by Dasgupta et al. (2015) to search for the cleanest production approach to reduce the risks of batik wastewater to humans and the environment. They proposed to use membrane for batik effluent, but this treatment method seems very expensive and could not be afforded by majority of small batik holders especially in Malaysia and Indonesia. The current method used in Indonesia is an end-of-pipe (EOP) method (Sirait, 2018), defined as a treatment is installed at the end of the whole batik printing process to treat the received effluent before being discharged into the environment, without going through any waste minimization towards circular economy initiatives throughout the whole processes prior to the treatment (Kurniawan et al., 2021). There were many studies conducted before to carter this batik effluent treatment issue since 2000s; however, up until today, this issue has still arisen and not been resolved.

Hence, this review aims to increase the knowledge of the batik industry and highlight its importance and contribution in textile industry. It also discusses the generation of batik wastewater and its effect on the environment and human beings. Treatments that have been used and studied previously will be analyzed for their relevance to be applied for home-based batik industries. The appropriate comparison will be reviewed, and we will seek the most appropriate method of treating batik wastewater and reusing the treated wastewater, where possible. Since batik industry process is not the same as what in textile industry, this study can be referred in future as one of important references containing extensive information on batik effluent and its treatment. This study is expected to contribute to the improvement of the existing treatment or utilize a new low-cost treatment for sustainability of the batik industry itself as heritage value and most importantly for ecosystem sustainability.

2. The Batik Industry

2.1. Current market of the batik industry

In Malaysia, the batik industry is classified under textile manufacturing in Small Medium Enterprises (SMEs) (Mokhtar and Ismail, 2012; Mohamad Akhir et al., 2017). According to the Malaysian Handicraft Development Corporation (Malaysian Handicraft Development Corporation (MHDC), 2021), the batik industry has been recognized as the main craft-based economic contributor to Malaysia. The batik industry's market growth shows that batik has contributed much to the local community's economy for so many years, especially in Kelantan and Terengganu, Malaysia (Ahmad et al., 2002). Their uniqueness attracts tourists from all over the world and subsequently supports Malaysia's tourism industry (Choy, 2013). This can be seen in Fig. 2, in which the number of entrepreneurs in the batik industry increases year-by-year in almost every state in Malaysia (Malaysian Handicraft Development Corporation (MHDC), 2021). A study discovered that this number was increased to 651 in 2019 (Shaharuddin et al., 2021). An MHDC report in 2017 showed that batik contributes about RM197 million to the Malaysian economy, which represents 81% of the textile sector sales value. Even for 2019, the batik industry itself managed to contribute about RM158.3 million to the country. Meanwhile, in Indonesia, an increase in the demand for batik was recorded. Based on data from the Ministry of Industry of Indonesia in 2015, the batik industry's

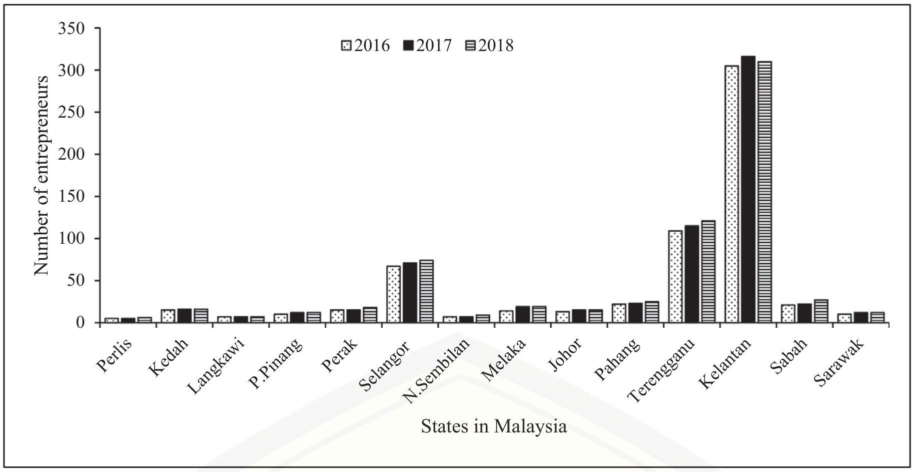


Fig. 2. Number of batik entrepreneurs in Malaysia.

production and average export value reached RM759.4 million (Tambunan et al., 2018).

2.2. Usage of batik

Previously in Malaysia, the use of batik was limited to a daily worn lower garment known as a *sarong*, usually worn by the Malay community. Nowadays, its usage has evolved and extended to many other purposes. Fig. 3 shows some of the batik products produced by Malaysia's batik craftsmen (Ahmad, 2021). Some of them include tablecloths, household accessories, souvenirs, hats, wall hanging decorations, purses, handbags, shoes and even facemasks.

2.3. Batik-making processes and wastewater generation

There are six techniques of batik-making in Malaysia, including batik *canting*, block batik, batik conteng (hand-drawn batik), printing, tie-dye and tritik (stitching), as illustrated in Fig. 4 (Yusof, 2019). A widely used technique for batik making in the small batik industry is batik *canting*. This technique involves the use of a *canting* tool, a pen-like tool to draw the batik design. The traditional batik-making process using the block batik technique is shown in Fig. 5 (Ahmad et al., 2002; Masrom, 2012).

The traditional batik-making process includes six main sub-processes: fabric preparation, wax application, fabric design dyeing, dye fixation, wax removal and product drying. In the fabric preparation process, dye is only used if necessary. The fabric is soaked in the desired colour and dried under the sun. The fabric is dipped in starch solution to give it a silky effect, and then it is rinsed and dried under the sun again. In the wax application process, the block design is chosen, dipped in the wax and applied to the fabric. The design is painted with the desired colours in the fabric design dyeing process. The fabric is first dried before the dye fixing process takes place. In the dye fixing process, the fabric is soaked in sodium silicate solution for 3–24 h. It will then be soaked in water, rinsed and dried. In the wax removal process, the fabric is soaked and boiled for about 1–1.5 h, followed by rinsing and soaking for 18 h before the product drying process takes place. The repeating washing and rinsing process of the fabric is carried out to remove oil, excess wax and leftover dyes.

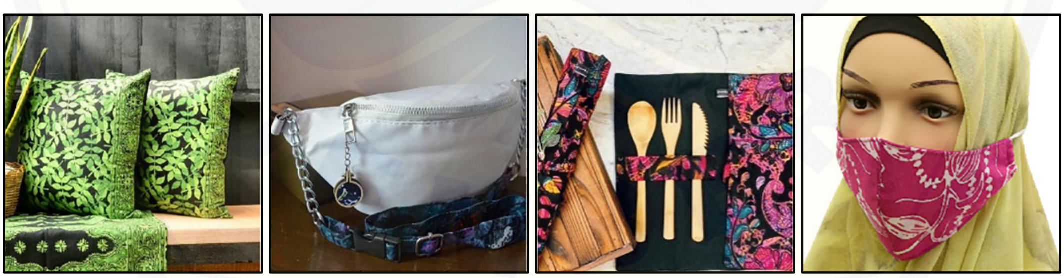


Fig. 3. Malaysia's batik products.

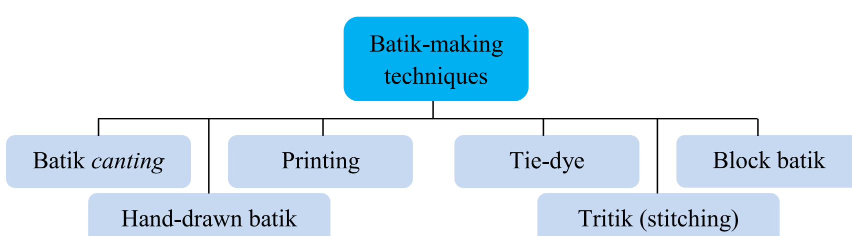


Fig. 4. Batik-making techniques.

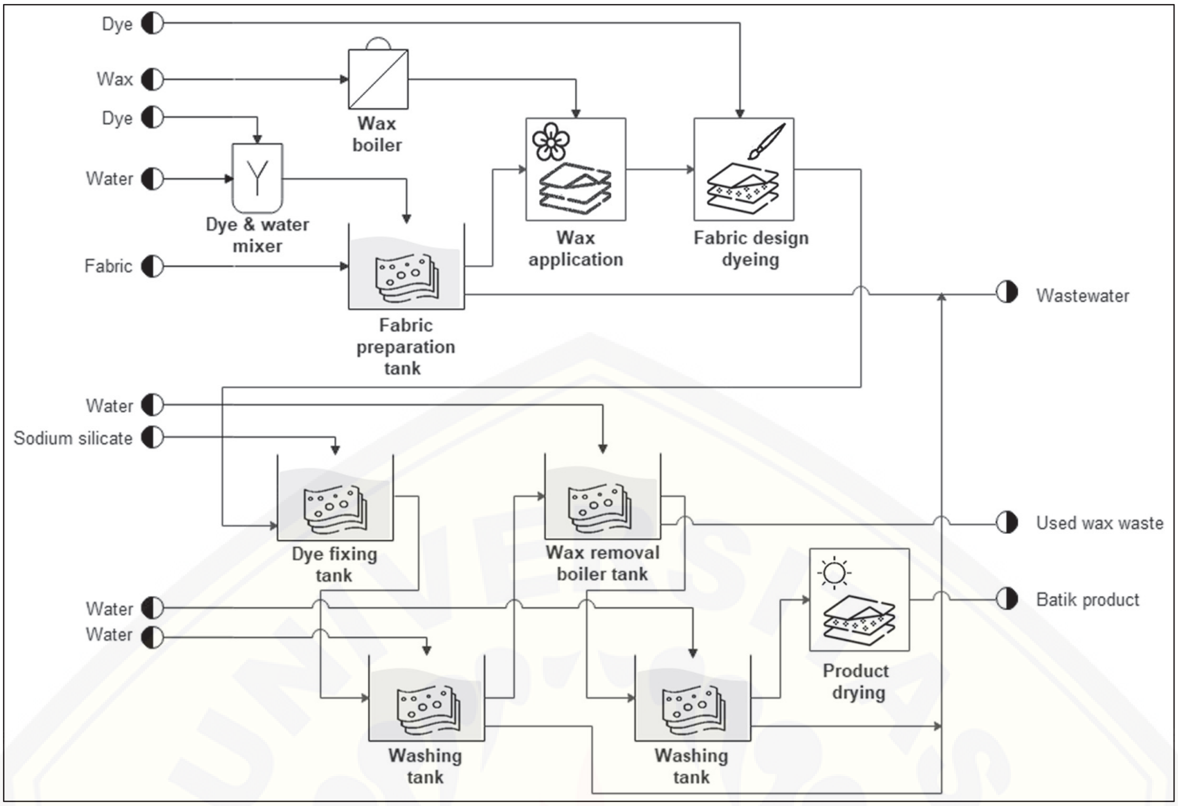


Fig. 5. Traditional process of batik-making using the block batik technique.

Referring to Fig. 5, wastewater is mainly generated from the fabric preparation, dye fixation and wax removal processes. From the fabric preparation to the wax removal processes, several chemicals and other substances, such as alum sulphate, wax, soda ash, ferum sulphate and calcium oxide may be added depending on each batik industry's processes. Since the batik-making process involves adding chemicals, it may cause harmful effects if the effluent is not disposed of properly. Approximately 80%–95% of the water used in the dyeing process is released as wastewater (Setiyono and Gustaman, 2017). It was reported that about 200 L of wastewater is generated in the production of 4 m of batik (Sirait, 2018). However, the amount of wastewater generated was reported to differ from one study to another. This can be shown in the data tabulated in Table 1. The amount of wastewater used and generated may vary due to the process involved in the production of each batik. Exclusive batik production requires a more complex and time- consuming series of processes (Hassan and Hanafiah., 2018). For example, if one batik fabric requires more colours and a more complicated design, a multilayer design is needed to generate the design pattern. This means that several processes must be repeated until the desired design is complete. Hence, a large amount of wastewater will be generated. However, in a study of the grey water footprint, Handayani et al. (2018a, 2018b) stated that a large amount of the wastewater generated normally originates from the dilution process conducted by the batik industry. This dilution process is carried out to assimilate pollutants found in batik wastewater to meet specific water quality standards. The huge amount of wastewater produced by the batik industry draws our concern.

Table 1
Wastewater generation by the batik industry.

Amount of generated wastewater	Fabric size	References
15 L	1 m length	Masrom (2012)
4.68 L	1 m^2	Handayani et al. (2018a)
1309–5549 L	1 m^2	Handayani et al. (2018b)
1.33 L	1 m^2	Nursanti et al. (2018)
200 L	4 m length	Sirait (2018)
2.0 L	1 piece	Afzan et al. (2019)

2.4. Batik effluents and their characteristics

Batik wastewater contains unwanted contents that are unfavourable to human beings and aquatic life. The presence of dye, other chemicals and heavy metals such as resin, wax and silicate in batik wastewater makes it one of the most difficult wastewaters to treat (Rashidi et al., 2013). Certain studies reported that batik wastewater contained grease, wax, heavy metal, surfactant, suspended solids (SS), and dyes (organic and inorganic) (Ahmad et al., 2002; Sutisna et al., 2017). Other contaminants such as phenol and chromium were found in other studies (Setiyono and Gustaman, 2017; Tambunan et al., 2018). The use of wax contributes to the high level of organic pollutants found in batik wastewater (Birgani et al., 2016). Fig. 6(a) shows an image of batik wastewater documented after sampling, and Fig. 6(b) shows the clogging of a batik wastewater flow system caused by the wax content. The colour of batik wastewater may vary depending on the dye used in the batik dyeing process. Batik wastewater is generally

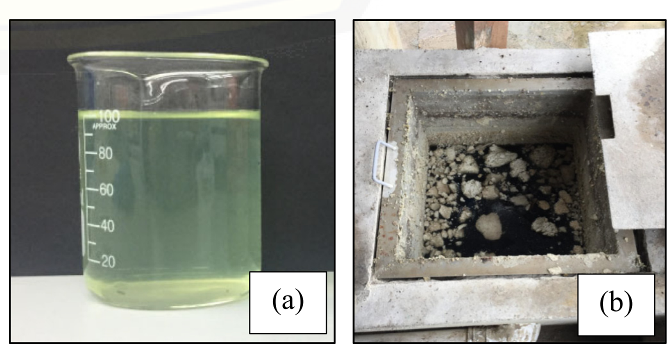


Fig. 6. Batik wastewater (personal documentation).

characterized by alkaline pH, intense colour and a high chemical oxygen demand (COD) and biological oxygen demand (BOD) (Mukimin et al., 2018). These characteristics result from the large volume of wastewater and the high range of pollutants (Minke and Rott, 1999). Based on previous studies, batik wastewater has conditions towards alkaline medium within pH 6–12. The content of contaminants found in batik wastewater varied from one study to another. Table 2 tabulates the characteristics of batik industries reported in previous studies. According to Table 2, batik effluent may contain COD ranging from 34 mg/L up to 20,900 mg/L. Certain studies had even detected heavy metals such as chromium (Cr), lead (Pb), calcium (Ca), silicon (Si), magnesium (Mg), cuprum (Cu), ferum (Fe) and zinc (Zn) in batik wastewater.

As reported previously, a few batik industries in Indonesia release their wastewater into adjacent rivers without performing any proper treatment (Suhardi et al., 2017). The same thing happens in a few batik industries in Malaysia, as reported recently (Afzan et al., 2019). What will happen to water bodies if this kind of effluent enters our water system? Untreated or inappropriately treated batik/textile wastewater may disturb the waterways, pollute the environment and cause significant side effects to the ecosystem and human health. Synthetic ingredients found in batik wastewater, such as chemical dye substances, usually have stable features such as heavy metals of copper, iron, zinc, lead and chromium, which will make them recalcitrant to degradation (Sutisna et al., 2017). Widely used synthetic dyes include Naphthol, Indigo soluble, direct, Remazol and reactive dyes (Handayani et al., 2018a, 2018b). Bleaching of synthetic dyes in batik wastewater may impose skin health issues such as contact dermatitis, which has infected batik industry workers as reported previously (Soebaryo, 2012). The dye substances used in the dyeing process are toxic, causing skin irritation, allergic dermatitis and cancer (Garg et al., 2002). Their dark colours may block sunlight from entering the water stream, interrupting the ecosystem (Choi et al., 2004).

The emergence of the batik industry market is an indication that proper treatment of its wastewater is vital. Batik wastewater is highly toxic and may threaten our biodiversity (Lokhande et al., 2015). Dye-based wastewater and its intermediates are major pollutants because they have the properties of high aromaticity and low biodegradability (Arslan et al., 2000). A

Table 2
Batik wastewater characteristics from previous studies.

No	Wastewater	pH	BOD_5 (mg/L)	COD (mg/L)	SS (mg/L)	TSS (mg/L)	O&G (mg/L)	Colour (ADMI)	Turbidity (NTU)	Heavy metals (mg/L)	Others (mg/L)	References
1	Effluent from the whole process	–	–	–	–	–	–	–	–	Cu: 0.3–0.4 Fe: 1.23–2.0 Zn: 0.03–1.34	–	Subki et al. (2014)
2	Effluent from the soaking process	11.3	–	3950	–	–	–	–	–	Si: 8965 Ca: 4.23 Mg: 0.97 Cu: 0.29 Fe: 3.0 Pb: 0.04	–	Birgani et al. (2016)
3	Effluent from the boiling process	12.1	–	13,600	–	–	–	–	–	Si: 320.5 Ca: 7.27 Mg: 0.89 Cu: 0.5 Fe: 3.71 Pb: 0.57	–	Birgani et al. (2016)
4	Effluent from the first rinsing	7.6	–	428	–	–	–	–	–	Si: 226.3 Ca: 6.13 Mg: 1.71 Cu: 0.11 Fe: 0.61 Pb: 0.03	–	Birgani et al. (2016)
5	Effluent from the second rinsing	6.4	–	34	–	–	–	–	–	Si: 49.95 Ca: 4.32 Mg: 0.92 Cu: 0.18 Fe: 0.26 Pb: 0.01	–	Birgani et al. (2016)
6	Effluent from the fabric preparation process	–	81.74	1320	–	–	9	692.2	89.8	–	–	Felaza and Priadi (2016)
7	Diluted batik effluent											Warjito and Nurrohman (2016)
8	Effluent from the whole process	6	–	4230	–	535	–	–	–	Cr: 0.1385	Ammonia: 5.47	Hardyanti et al. (2017)
9	Effluent from the whole process											Pratiwi et al. (2017)
10	Simulated batik wastewater (wax, dye, sodium silicate with different reactive dyes)	9.2–10.5	–	1300–1500	–	–	–	–	–	–	–	Rashidi et al. (2016)
11	Synthetic batik wastewater	–	–	–	–	–	–	–	–	Pb: 0.5844	–	Riyanto and Puspitasari (2017)
12	Effluent from the whole process	7.18–7.46	–	–	–	–	–	–	–	Cr: 0.0597	–	Setiyono and Gustaman (2017)
13	Effluent from the whole process	–	80	180	–	80	–	–	–	–	–	Sutisna et al. (2017)
14	Effluent from the whole process	9.8	552	870	–	–	23	–	–	–	Ammonia: 5.59	Mukimin et al. (2018)
15	Effluent from the whole process	6.9	5226	20,900	–	2036	–	–	–	–	–	Sirait (2018)
16	Effluent from the whole process	9.8	967	2900	–	268	–	–	–	–	Total ammonia: 1.27 Total chromium: 2.34	Tambunan et al. (2018)
17	Effluent from the printing process	6.55	399	2198	–	51	–	1469	13.1	–	Ammonia-nitrogen: 3.6	Safauldeen et al. (2019)
18	Effluent from the boiling process	–	–	12,000	–	3180	9740	–	–	–	–	Rahmadyanti and Audina (2020)

study conducted by Tahir et al. (2016) claimed that the dye content in wastewater not only pollutes the environment but is also harmful to human health and marine life. Jayanthy et al. (2014) stated that this genotoxic, mutagenic and carcinogenic dye-based wastewater is one of the poorly treated effluents.

2.5. Standard regulations for batik wastewater

Each effluent exiting any industry should meet the requirements of standard regulations governed by their respective country. In Malaysia, the standard regulations are Malaysia's Environmental Law, the Environmental Quality Act, 1974. Effluent from the batik industry must comply with the Environmental Quality Act and Regulations standard for industrial discharge under the Fifth Schedule for Standards A and B, as stated in Environmental Quality (Industrial Effluent) Regulations 2009 (Akta Kualiti Alam Sekeliling 1974 (Environmental Quality Act 1974), 2009). Standard A is applicable to discharge into any inland waters within catchment areas listed in the Third Schedule, while Standard B applies to any inland water. Since batik effluent is categorized as dye-based wastewater, the acceptable discharge limit for COD must comply with COD's national regulatory values for the textile industry under the Seventh Schedule (Regulation 12). Table 3 lists the effluent standard limits in Malaysia in comparison with other

Table 3
Industrial discharge limits for several countries.

Country	Unit	Malaysia		Indonesia		China		Taiwan	Sri Lanka	Thailand
		A	B	East Java		Class 1	Class 2			
Temperature	°C	40	40	–	–			<35	40	40
pH	–	6.0–9.0	5.5–9.0	11.8	6.0–9.0	6.0–9.0	6.0–9.0	6.0–9.0	6.0–9.0	6.0–9.0
BOD_5 at 20 °C	mg/L	20	40	75	60	100	150	50	50	50
COD	mg/L	80	250	200	150	100	300	200	250	400
SS	mg/L	50	100	–	–	70	150	50	–	–
TSS	mg/L	–	–	100	50	–	–	–	50	50
Mercury	mg/L	0.005	0.05	–	–	–	–	ND	0.0005	0.005
Cadmium	mg/L	0.01	0.02	–	–	–	–	0.03	0.1	0.03
Chromium, Hexavalent	mg/L	0.05	0.05	–	Total chromium: 1.0	–	–	0.5	Total chromium: 2.0	0.25
Chromium, Trivalent	mg/L	0.20	1.0	–	–	–	–	2.0	–	–
Arsenic	mg/L	0.05	0.10	–	–	–	–	0.5	0.2	0.25
Cyanide	mg/L	0.05	0.10	–	–	0.5	0.5	1.0	0.2	0.2
Lead	mg/L	0.10	0.5	–	–	–	–	1.0	0.1	0.2
Copper	mg/L	0.20	1.0	–	–	0.5	1.0	3.0	3.0	2.0
Manganese	mg/L	0.20	1.0	–	–	2.0	2.0	10	–	–
Nickel	mg/L	0.20	1.0	–	–	–	–	1.0	3.0	1.0
Tin	mg/L	0.20	1.0	–	–	–	–	–	–	–
Zinc	mg/L	2.0	2.0	–	–	2.0	5.0	5.0	5.0	5.0
Boron	mg/L	1.0	4.0	–	–	–	–	1.0	–	–
Iron	mg/L	1.0	5.0	–	–	–	–	10	–	–
Silver	mg/L	0.1	1.0	–	–	–	–	0.5	–	–
Aluminium	mg/L	10	15	–	–	–	–	–	–	–
Selenium	mg/L	0.02	0.5	–	–	0.1	0.2	0.5	–	–
Barium	mg/L	1.0	2.0	–	–	–	–	–	–	–
Fluoride	mg/L	2.0	5.0	–	–	10	20	15	–	–
Formaldehyde	mg/L	1.0	2.0	–	–	1.0	2.0	3.0	–	–
Phenol	mg/L	0.001	1.0	–	–	0.5	0.5	2.0	1.0	1.0
Free Chlorine	mg/L	1.0	2.0	–	–	0.5	6.5	–	–	–
Sulphide	mg/L	0.50	0.50	–	0.3	0.5	0.5	1.0	2.0	1.0
O&G	mg/L	1.0	10	–	–	–	–	10	–	–
Ammoniacal nitrogen	mg/L	10	20	–	8.0	15	50	20	50	
Colour	ADMI	100	200	–	–	50	80	–	–	–
Regulations		Environmental Quality Act and Regulations 1974		Government of Malang, East Java	Regulation of the Minister of the Environment about Raw Wastewater Quality (Republic of Indonesia, 2014)	National Standard of the People's Republic of China Integrated Wastewater Discharge Standard GB 8978 - 1996		Environmental Protection Administration of the Republic of China on Taiwan	National Environmental (Protection and Quality) Regulations, No. 12008 (Sri Lanka Central Environmental Authority, 2008)	Industrial Effluent Standard (Thailand Ministry of Natural Resources and Environment, Pollution Control Department, 1996)
References		Akta Kualiti Alam Sekeliling 1974 (Environmental Quality Act 1974) (2009)		Sirait (2018)	Textile Industry Wastewater Discharge Quality Standards (2015)	(China Water Risk, 2020)		Tang and Ferris (1997)	Textile Industry Wastewater Discharge Quality Standards (2015)	Textile Industry Wastewater Discharge Quality Standards (2015)

A: applicable to discharge into any inland waters within catchment areas.
B: applicable to discharge into any other inland water or Malaysian waters.
Class 1: mainly for source of water and national nature protection areas.
Class 2: mainly for Class I protection areas, related to categories such as centralised potable water sources, protection areas for rare fishes, spawning grounds for fish and shrimps.
BOD: Biological oxygen demand.
COD: Chemical oxygen demand.
SS: Suspended solids.
TSS: Total suspended solids.
ND: Non-detectable.
O&G: Oil and grease.
ADMI: American Dye Manufacturers Institute.

countries. The standard limits set for temperature, pH, BOD_5 and COD in Malaysia are very similar to those of other countries, the exceptions being China and Thailand.

3. Treatment and integrated treatments for batik wastewater

This section will discuss the current practice applied by batik operators to treat batik effluent. Among these treatment approaches, advantages, issues and challenges faced in the treatment of batik effluent will be critically reviewed and highlighted.

3.1. Current and conventional treatments for batik wastewater

Based on our current visit to specific batik industries in Malaysia, the treatment used is sand filtration-adsorption using activated carbon. Nuzul et al. (2020) and (HTC, 2013) listed four other treatment systems installed in certain batik industries in Malaysia, as shown in Fig. 7. Most treatment systems consist of similar processes of filtration and adsorption. Several treatment processes have been conducted in the past. These include physicochemical treatment such as coagulation, sedimentation, adsorption and electrochemical (electrolysis) processes (Riyanto and Wulandari, 2017).

Other dye treatments studied were membrane filtration, reverse osmosis, irradiation, electrocoagulation, oxidation and precipitation (Pratiwi et al., 2017). Biological approaches have also been explored, including phytoremediation using plants and rhizobacteria and a bio-equalization tank inoculated with immobilized anaerobic seed sludge. Tables 4 and 5 summarise batik wastewater treatment according to the type of treatment processes encompassing physicochemical and biological processes. Membrane technology has been applied by Ahmad et al. (2002), in which synthetic C.I. reactive dye-containing wastewater was treated using a laboratory-scale membrane filtration unit with a 0.45-mm pore size. At pH 7 and hydraulic retention time (HRT) of 120 min, this treatment managed to remove 86% of the dye content from synthetic batik wastewater. A similar treatment was conducted by Ali and Suhaimi (2009) using a 23% aromatic polyether sulphone (PES) polymer at pH 7.4. Their treatment managed to remove >90% of the Mn, Cd and Cu and 80% of the COD content from batik wastewater while Rashidi et al. (2014) managed to remove 80%–95% of the dye from synthetic batik wastewater. Membrane treatment of batik wastewater using a plant-derived surfactant was reported by Aryanti et al. (2019). This green approach gave promising efficiency, in which 97% of COD and 96% of Cr managed to be removed. Standard filtration using charcoal and gravels was used by Kristijanto et al. (2011) to enhance batik wastewater quality. This process was added as a tertiary treatment since primary and secondary treatments were insufficient to fulfil effluent requirements. However, this treatment only managed to remove 2.7% of colour, 12.6% of TDS and 19.8% of COD.

Rashidi et al. (2013, 2016) introduced physical treatment approaches by using a baffle separation tank. Synthetic wastewater in which dye and wax were added to study wax removal efficiency using a baffle separation tank. At an HRT of 60 min and a process temperature of 48 °C, this tank managed to remove 91%–93% of the wax. However, low COD removal of around 7.6%–42.8% was recorded. In 2016, this experiment was repeated using a different process temperature of 70 °C. About 92.5%, 50%, 40.5% and 4.9% of the wax, COD, sodium silicate and dye were removed, respectively. This process is a promising low-cost treatment for the batik industry, but it has not ever been replicated by other researchers, and its capacity to treat real batik wastewater is still unknown. Other physical treatments that have been successfully reported are adsorption and biosorption. Some adsorbent types include palm-shell-based activated carbon (Birgani et al., 2016), SiO_2, bentonite (Hardyanti et al., 2017), pineapple waste (Subki, 2017), *Sargassum cinereum* and *Pleurotus ostreotus* baglog waste (Lestari et al., 2018), Merapi volcanic ash and natural zeolite (Salamah and Wahyuni, 2018), teak sawdust activated carbon (Handayani et al., 2019) and coal bottom ash (Jamaludin, 2020). This type of treatment is quite

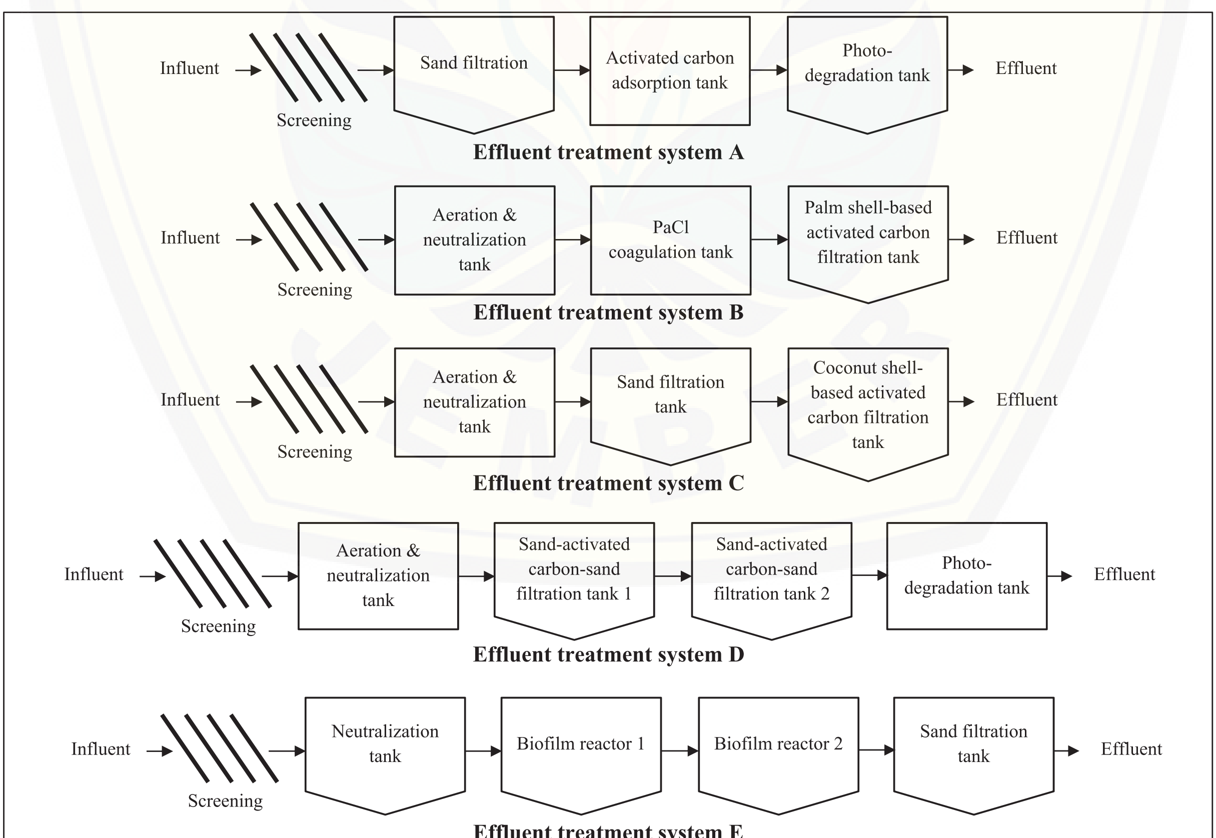


Fig. 7. Five treatment systems installed in certain batik industries in Malaysia.

popular and well-studied because of its green technology, simple operation and ease of handling. The cost of conventional adsorbent is relatively high. Hence, the selective use of natural adsorbent or biosorbent will be quite beneficial in the future. Coagulation and flocculation processes have been studied by Handayani et al. (2019). Alum and lime were used to treat real batik wastewater. This treatment managed to remove approximately 73.3% of the COD.

Previously studied physicochemical methods include photocatalytic treatment in a solar photocatalytic reactor involving a photocatalyst. The use of a TiO_2 photocatalyst to treat batik wastewater showed significant efficiency in two different studies (Sridewi et al., 2011; Sutisna et al., 2017). Both studies managed to remove about 80%–93% of the COD and 50%–98% of the dye. Recently, electrochemical/electrolysis treatment has also gained interest as a potential option for batik wastewater treatment (Riyanto and Puspitasari, 2017; Riyanto and Wulandari, 2017; Mukimin et al., 2018). Results from these studies showed significant contaminant removal. However, these two approaches, photocatalytic technology, and electrochemical treatment, are quite costly and require skilled personnel to carry out the treatment; therefore, they are not suitable for implementation in small-to-medium-sized batik industries.

Referring to Table 5, various types of biological treatments have been studied, such as biological reactor treatment, phytoremediation and in vitro biodegradation treatment. Batik wastewater treatment using a biological reactor that has been performed includes degradation of contaminants by anaerobic bacteria in an anaerobic baffle reactor and aerobic bacteria in a rotating biological contactor (Kristijanto et al., 2011), white-rot fungus degradation in trickle-bed bioreactors (Saputra et al., 2013) and anaerobic degradation in a bioequalization tank (Mukimin et al., 2018). Phytoremediation technology has been widely studied and has shown promising results. Examples of plant types include *Pistia stratiotes*, *Hydrilla verticillate* (Puspita et al., 2011), *Salvinia cucullate* (Setiyono and Gustaman, 2017), *Egeria densa*, *Salvinia molesta* (Tangahu and Putri, 2017), *Vetiver Chrysopogon zizanioides* (L) (Tambunan et al., 2018), *Eichhornia crassipes* (Safauldeen et al., 2019), *Scirpus grossus*, *Iris pseudacorus* (Tangahu et al., 2019), *Canna indica* (Rahmadyanti and Audina, 2020) and *Cyperus haspan* (Wirosoedarmo et al., 2020). In vitro biodegradation treatments were studied, including the use of fungi and bacteria. These include *Ganoderma lucidum*, *Lactobacillus delbrueckii*, *Pleurotus ostreatus*, *Aspergillus* sp. and macroalgae (Nurhaslina et al., 2014; Pratiwi et al., 2017; Dewi et al., 2019; Suhartini et al., 2020).

The dye content of batik wastewater limits the capability of biological treatment. However, treatment using a bio-equalization tank inoculated with immobilized anaerobic seed sludge managed to remove 76% of the BOD and 67% of the COD content at an HRT of 48 h (Mukimin et al., 2018). The authors stated that starch and dissolved wax in batik wastewater are readily degradable carbohydrates and easily converted into CO_2 and H_2O. For biological treatment using phytoremediation technology, they mostly managed to remove more than 60% of the COD and BOD content in batik wastewater. Considering the limited capability of biological processes, an integrated system or combination of a few processes offers a better option.

3.2. Advantages and disadvantages of current treatments

Despite their effectiveness in removing various types of contaminants, there are still some disadvantages that need to be considered. These disadvantages can be classified in terms of faulty equipment, cost, maintenance and so on. Table 6 lists the advantages and disadvantages of batik treatments that have been used previously. Each treatment has its own unique characteristics and benefits. The current and commonly used treatment in the batik industry, adsorption, is suitable for removing a variety of dye components in wastewater, but the cost of the adsorbent might burden the industry. Other types of treatments that impose the same cost issue are electrocoagulation and nanofiltration. Low-cost treatment technologies such as biological reactors, biosorption, bio-coagulation and phytoremediation have some advantages, such as the use of natural and less expensive resources, but they require large treatment areas suitable for less toxic wastewater and require long retention times. A study performed by Rashidi et al. (2016) promoted a single, simple treatment, but their study focused on wax removal, and limited research studies using this treatment have been reported. Another simple treatment, membrane filtration technology, managed to remove all types of dyes, but when dealing with membrane usage, sludge might become concentrated and impose a membrane fault problem. The selection of a treatment to be used in any industry usually depends on wastewater characteristics, the industry itself and the cost related to the selected treatment. The next sub-topic summarises selection tips for batik wastewater treatment.

3.3. Challenges and treatment process selection for the batik industry

In Malaysia, a significant problem faced by most batik businesses is related to waste management. For batik wastewater management, a single treatment process is not suitable since it contains high amount of colour. Referring to the published articles related to batik wastewater, many suggested two or more treatment processes were required to efficiently treat it (Kristijanto et al., 2011; Mukimin et al., 2018; Handayani et al., 2019). For batik effluent, major consideration is the removal of suspended solids and colour. As a low-cost treatment, biological treatment itself is not sufficient to treat batik wastewater since it cannot remove COD and colour effectively (Ahmad et al., 2002). According to Metcalf (2014), several considerations for treatment process selection include design considerations, maintenance cost, compatibility and other factors listed in Fig. 8.

As previously discussed, since the batik industry in Malaysia is mainly run by rural citizens as small-to-medium family businesses, it is not favourable to implement costly, complex and high-technology treatment. High-technology and complex treatment might impose another problem in the future related to a lack of expertise to maintain and operate the treatment system. In this study, an integrated treatment system that consists of two simple treatments are introduced. The first treatment is adsorption treatment using natural adsorbent, and the second treatment is known as a two-stage constructed wetland using phytoremediation technology. Since the dye content in batik wastewater is resistant to degradation and remediation under natural conditions, additional adsorption treatment before phytoremediation treatment may reduce the limitation (Tahir et al., 2016). Rahmadyanti and Audina (2020) suggested that pre- or advanced treatment is needed in combination with phytoremediation treatment to improve efficiency. Even though Pratiwi et al. (2017) stated that high cost and low efficiency make dye removal using physicochemical treatment unfavourable, modification of their adsorbent to a natural adsorbent may help to reduce the treatment cost. Adsorption treatment is easy to apply, operate and maintain and not too complex to be handled by general labourers in small- and medium-sized industries.

As for phytoremediation technology, it is an alternative to treat various kinds of wastewater and has been widely used in developed countries like the USA and Japan (Abdullah et al., 2020). The overwhelmingly positive result of phytoremediation technology makes this technology reliable as a secondary process for batik wastewater treatment. This treatment requires less energy and has been successfully managed to bioconvert pollutants to a stable and non-toxic end product (Kuhad et al., 2004; Diwaniyan et al., 2010). Further details of both treatment processes are discussed further in the following section.

4. Proposed integrated treatment for the batik industry and its SWOT analysis

An integrated system of natural adsorption and phytoremediation can be one of promising green and appropriate wastewater treatment for the batik industry. In this section, some information on the natural adsorption process, phytoremediation and their SWOT analysis (strengths, weaknesses, opportunities and threats analysis) will be discussed further.

Table 4
Physicochemical treatment of batik wastewater.

Treatment	Process	Type of treatment	Type of wastewater	Effluent characteristics	Removal	References
Membrane technology	Microfiltration membrane separation process using a 0.45-mm pore size membrane	Single	Synthetic batik wastewater (contains C.I. reactive blue)	Dye concentration: 5 g/L	Dye: 86%	Ahmad et al. (2002)
Nanofiltration treatment	Membrane: 23% aromatic polyethersulphone (PES) polymer	Single	Synthetic batik wastewater	COD: 300–1500 mg/L	COD: >86% Mn: >90% Cd: >90% Cu: >90%	Ali and Suhaimi (2009)
Filtration	Charcoal & gravel filter	Tertiary	Real batik wastewater	TDS: 1167.5 mg/L Colour: 962 mg/L COD: 888 mg/L Sulphate: 262.7 mg/L NH_3-N: 2.28 mg/L	TDS: 12.6% Colour: 2.7% COD: 19.8% Sulphate: 38.6% NH_3-N: 8.8%	Kristijanto et al. (2011)
Solar photocatalytic by using P(3HB)-TiO_2 nanocomposite films	Decolourization of dye using TiO_2 photocatalyst	Single	Real & synthetic batik wastewater	COD: 14500–20,100 mg/L Dye: 0.01–0.03 mM	COD: 80% Dye: 98%	Sridewi et al. (2011)
Physical baffle tank treatment	Tank volume: 30 L HRT: 60 min Flow rate: 570 L/h Temperature: 48 °C	Primary	Synthetic batik wastewater (contains dye (Remazol turquoise blue & Reactive yellow 145), sodium silicate, wax & resin)	Synthetic batik wastewater (Remazol turquoise blue): COD: 760 mg/L Wax: 200 g Synthetic batik wastewater (Reactive yellow 145): COD: 687 mg/L Wax: 200 g	Synthetic batik wastewater (Remazol turquoise blue): COD: 7.6% Wax: 91% Synthetic batik wastewater (Reactive yellow 145): COD: 42.8% Wax: 93%	Rashidi et al. (2013)
Nanofiltration membrane	Nano membrane separation process	Single	Synthetic batik wastewater	–	Dye: 80.1%–95.2%	Rashidi et al. (2014)
Solar photocatalytic process	Usage of ZnO as photocatalyst at pH 3 for 10 h	Single	Real batik wastewater	COD: 4092 mg/L TSS: 303 mg/L	COD: 91% TSS: 80% Colour: 88.2%	Khalik et al. (2015)
Acidification	Acidification using HCl	Primary	Real batik wastewater	COD: 4915 mg/L Si: 8400 mg/L	COD: 95.3% Si: 48.6%	Birgani et al. (2016)
Treatment using magnesium oxide	Polluted acidic water treatment	Secondary	Real batik wastewater	COD: 1800 mg/L Si: 4300 mg/L	COD: 73.3% Si: 93.3%	Birgani et al. (2016)
Biosorption treatment using palm-shell based activated carbon	Biosorption at low range of pH	Tertiary	Real batik wastewater	COD: 360 mg/L	COD: 72.2%	Birgani et al. (2016)
Electro flotation	Tank volume: 500 mL Coagulant: Alum Voltage: 10 V HRT: 12 min	Single	Real batik wastewater	–	Turbidity: 69.6% Colour: 83.3% TSS: 94%	Warjito and Nurrohman (2016)
Baffle separation tank	Tank volume: 30 L HRT: 60 min Flow rate: 570 L/h Temperature: 70 °C	Primary	Simulated batik wastewater (mix of 16 mg/L reactive dyes, 1 g/L sodium silicate, 7.7 g/L wax)	COD: 1390 mg/L	COD: 50% Wax: 92.5% Sodium silicate: 44.5% Dyes: 4.9%	Rashidi et al. (2016)
Adsorption treatment	Adsorbents: SiO_2 & bentonite HRT: 40 min	Single	Real batik wastewater	COD: 4230 mg/L Fe: 0.287 mg/L	Fe: 49.5%	Hardyanti et al. (2017)
Electrochemical coagulation treatment	Electrode: Al Electrolyte:NaCl Operating volume: 50 mL Optimum conditions: 90 min, 10 V, 1.25 g NaCl	Single	Real batik wastewater	Pb: 0.5844 mg/L	Pb: 72.1%	Riyanto and Puspitasari (2017)
Electrochemical oxidation treatment	Electrode: PbO_2/Pb Electrolyte: 0.4 M $NaSO_4$ Potential voltage: 9 V Time: 3 h	Single	Real batik wastewater	–	Colour: >60%	Riyanto and Wulandari (2017)
Biosorption treatment using pineapple waste	Treatment using dried pineapple crown activated carbon	Single	Synthetic batik wastewater	–	Dye: 38.6%	Subki (2017)
Photocatalytic membrane treatment	Treatment using TiO_2 catalyst coated with polypropylene plastic	Single	Real batik wastewater	–	COD: 93.0% BOD: 23.0% TSS: 71.0% Dye: 50.4%	Sutisna et al. (2017)
Photocatalytic fuel cell	Electrode: ZnO/CF & Pt/C Electrolyte: NaCl Time 6 h pH 9	Single	Real batik wastewater	–	Degradation rate: 74 ± 34.9%	Khalik et al. (2018)
Biosorption treatment using *Sargassum cinereum* and *Pleurotus*	Treatment was carried out using the jar test at 175 rpm for 1 h	Single	Real batik wastewater	COD: 5000 mg/L BOD: 2200 mg/L TSS: 200 mg/L	COD: 77% BOD: 77% TSS: 65%	Lestari et al. (2018)

Table 4 (*continued*)

Treatment	Process	Type of treatment	Type of wastewater	Effluent characteristics	Removal	References
ostreotus baglog waste						
Electrolysis treatment using an electrocatalytic reactor	HRT: 180 min	Secondary	Real batik wastewater	COD: 290 mg/L BOD: 133 mg/L TSS: 108 mg/L NH_3: 1.22 mg/L O&G: 14 mg/L Phenol: 0.02 mg/L	COD: 61.4% BOD: 81.2% TSS: 85.2% NH_3: 85.1% O&G: 91.4% Phenol: >95%	Mukimin et al. (2018)
Adsorption treatment using Merapi volcanic ash	Stirring time: 50 min Adsorbent weight: 50 g	Single	Synthetic batik wastewater	–	Dye: 49.6%	Salamah and Wahyuni (2018)
Adsorption treatment using natural zeolite	Stirring time: 50 min Adsorbent weight: 50 g	Single	Synthetic batik wastewater	–	Dye: 78.9%	Salamah and Wahyuni (2018)
Ultrafiltration membrane treatment using plant derived surfactant	Surfactant: Saponin extract from pericarps of Sapindus rarak Effective surface area of membrane: 9.6 cm^2	Single	Real batik wastewater	COD: 3497 mg/L Cr: 446 mg/L	COD: 96.9% Cr: 95.9%	Aryanti et al. (2019)
Fenton oxidation treatment	Fenton reagents: Fe(II) & Fe(III) and in situ zero valent iron Fe(0). HRT: 5 min Assisted by H_2O_2	Single	Real batik wastewater	pH: 5 COD: 6127 mg/L BOD: 205 mg/L Colour: 8011 PtCo	Colour: >89%	Sajab et al. (2019)
Coagulation-flocculation treatment using Alum + CaO (Lime)	pH: 6 Alum dosage: 1 g/L CaO dosage: 3 g/L Rapid mixing rate & time: 100 rpm & 15 min Slow mixing rate & time: 60 rpm & 20 min Retention time: 24 h	Primary	Real batik wastewater	COD: 6972 mg/L BOD: 2161 mg/L Zn: 41 mg/L	COD: 73.3% BOD: 73.6% Zn: 44.5%	Handayani et al. (2019)
Adsorption treatment using Teak sawdust based activated carbon	Dosage: 26 g/L Contact time: 220 min	Secondary	Real batik wastewater	COD: 1863 mg/L BOD: 570 mg/L Zn: 22.8 mg/L	COD: 87.6% BOD: 88.2% Zn: 91.9%	Handayani et al. (2019)
Adsorption treatment using coal bottom ash	Treatment in a fixed bed column Adsorbent size: 0.45 mm	Single	Real batik wastewater	–	TSS: 41.6% BOD: 65.3% Turbidity: 75.6%	Jamaludin (2020)

4.1. Natural adsorption

The adsorption process is a process of separating liquid or gas substances that bind to the adsorbent's exterior or interior surfaces (Crini et al., 2019). This treatment usually takes place in a fixed bed reactor or column under a batch or continuous process. A schematic diagram of the adsorption process is illustrated in Fig. 9.

The adsorbent used in the adsorption process can either be manufactured or occur naturally. The main characteristics of the adsorbent include porosity, pore structure, pore size (macropores, mesopores and micropores) and the nature of the adsorbing surface. The ranges of pore size diameters for macropores, mesopores and micropores are >50 nm, 2–50 nm and <2 nm, respectively. Types of adsorbents are silica gel, activated alumina, carbons, zeolites, polymers and clay. Nowadays, the use of adsorbent from natural sources in the adsorption process has been reported widely. These include teak sawdust, *Sargassum cinereum* and *Pleurotus ostreotus* baglog waste.

There are several operational factors in the adsorption treatment process, as summarised in Fig. 10. As reported in several studies, the initial pH of wastewater plays an important role in the adsorption process (Siti Zuraida et al., 2013). Their research showed that adsorption treatment of dye wastewater reportedly reached optimum conditions in a medium pH of 6. According to Handayani et al. (2019), the dosage of adsorbent may affect the number of contaminants being absorbed. The high dosage is proportional to the large number of active particles that influence the adsorption process. However, once the equilibrium state is reached, increasing the dosage might have no effect at all. This condition also applies to the adsorption time factor; a shorter time taken for the adsorption process might limit the removal performance. An extended period taken might only prolong the treatment time and decrease overall performance.

According to Crini et al. (2019), adsorption mechanisms are not fully understood as there are many possible interactions involved. These interactions include physisorption, surface adsorption, van der Waal interactions, hydrogen bonding, electrostatic interactions, ion-exchange, complexation, chelation, acid-base interactions, proton displacement, precipitation, hydrophobic interactions, oxidation, inclusion complex formation, diffusion into the network of the material and covalent bonding. These interactions are further simplified and classified into four main mechanisms as follows (Fig. 11). Based on the literature, the main mechanism of adsorption is normally physisorption, and for dye-based adsorption, it normally involves ion-exchange mechanisms.

4.2. Phytoremediation

Phytoremediation technology uses plants to remediate the soil, groundwater, sediment, surface water and air by extracting, degrading or translocating the contaminants to above-ground tissues of the plant to be harvested later (McCutecheon and Schnoor, 2003; Ismail et al., 2014; Jayanthy et al., 2014; Jiang et al., 2015). The contaminants will undergo detoxification to be converted into a harmless form (Suresh and Ravishankar, 2004). This technology is widely known as an alternative to existing physicochemical treatment and used in certain developed countries such as the United Kingdom, Ukraine and Holland (Rani et al., 2011; Witters et al., 2012; Jiang et al., 2015). It is an approach utilizing plants with the assistance of rhizosphere microbes to detoxify and remove different types of pollutants, including hydrocarbons (Al-Baldawi et al., 2017; Allamin et al., 2021; Almansoory et al., 2021; AL Sbani et al., 2021), dye (Abdulqader et al., 2019; Al-Baldawi et al., 2020), heavy metals (Ismail et al., 2020; Purwanti et al., 2020; Kamaruzzaman et al., 2020; Titah et al., 2019) and nutrients (Jehawi et al., 2020; Said et al., 2021; Nash et al., 2020; Al-Ajalin et al., 2020; Kadir et al., 2020) from waste or wastewater (Abdullah et al., 2020; Rahman et al., 2020). Although this technology requires a long treatment time compared with existing physicochemical treatments, it offers a wide range of advantages, such as a low cost of

Table 5
Biological treatment of batik wastewater.

Treatment	Process	Type of treatment	Wastewater	Wastewater characteristics	Removal	References
Anaerobic baffled reactor (ABR)	HRT: 72 h	Primary	Real batik wastewater	TDS: 2611.3 mg/L Colour: 1572.7% COD: 3197.9 mg/L Sulphate: 189 mg/L NH_3-N: 11 mg/L	TDS: 66.3% Colour: 78% COD: 76.4% Sulphate: 26.6% NH_3-N: 82%	Kristijanto et al. (2011)
Rotating biological contactor (RBC)	Involvement of aerobic bacteria to degrade the contaminants	Secondary	Real batik wastewater	TDS: 2516.1 mg/L Colour: 636.3 mg/L COD: 1327.7 mg/L Sulphate: 168 mg/L NH_3-N: 3.1 mg/L	TDS: 69% Colour: 10.1% COD: 4.8% Sulphate: 11.9% NH_3-N: 19.4%	Kristijanto et al. (2011)
Phytoremediation treatment using *Eichhornia crassipes*	HRT: 9 days	Single	Real batik wastewater	Cr: 0.076 mg/L	Cr: 49.6%	Puspita et al. (2011)
Phytoremediation treatment using *Pistia stratiotes*	HRT: 9 days	Single	Real batik wastewater	Cr: 0.076 mg/L	Cr: 33.5%	Puspita et al. (2011)
Phytoremediation treatment using *Hydrilla verticillate*	HRT: 9 days	Single	Real batik wastewater	Cr: 0.076 mg/L	Cr: 10.8%	Puspita et al. (2011)
Biological treatment using white rot fungi in trickle-bed bioreactors	Application of white rot fungi *Marasmius* sp. at *Luffa* sp. at HRT 7 days	Primary	Real batik wastewater	BOD: 13200 mg/L COD: 19446 mg/L TSS: 1640 mg/L Sulphide: 0.77%	BOD: 82.7% COD: 80.7% TSS: 32.5% Sulphide:5.19%	Saputra et al. (2013)
Submerged anaerobic membrane bioreactor	Application of *Lactobacillus delbrueckii*	Single	–	–	–	Ramlee et al. (2014)
Bioremediation using *Ganoderma lucidum*	HRT: 30 days	Single	Real batik wastewater plus synthetic dye	Colour: 100 mg/L pH: 5–6	COD: 81% Colour: 60.5%	Pratiwi et al. (2017)
Phytoremediation treatment using *Eichhornia crassipes*	HRT: 5 days	Single	Real batik wastewater	Cr: 0.0546 mg/L	Cr: 30.8%	Setiyono and Gustaman (2017)
Phytoremediation treatment using *Pistia stratiotes*	HRT: 5 days	Single	Real batik wastewater	Cr: 0.0464 mg/L	Cr: 48.3%	Setiyono and Gustaman (2017)
Phytoremediation treatment using *Salvinia cucullate*	HRT: 5 days	Single	Real batik wastewater	Cr: 0.0488 mg/L	Cr: 35.5%	Setiyono and Gustaman (2017)
Phytoremediation treatment *Egeria densa*	HRT: 15–20 days	Single	Synthetic wastewater	BOD: 261 mg/L COD: 1066 mg/L TSS: 5120 mg/L NH_3-N: 91.8 mg/L	BOD: 20%–30% COD: 10%–20%	Tangahu and Putri (2017)
Phytoremediation treatment *Egeria densa*	HRT: 15–20 days	Single	Real batik wastewater	BOD: 8126 mg/L COD: 10158 mg/L TSS: 9408 mg/L NH_3-N: 22.8 mg/L	BOD: 30%–40% COD: 15%–20%	Tangahu and Putri (2017)
Phytoremediation treatment *Salvinia molesta*	HRT: 15–20 days	Single	Synthetic wastewater	BOD: 261 mg/L COD: 1066 mg/L TSS: 5120 mg/L NH_3-N: 91.8 mg/L	BOD: 20%–30% COD: 20%–30%	Tangahu and Putri (2017)
Phytoremediation treatment *Salvinia molesta*	HRT: 15–20 days	Single	Real batik wastewater	BOD: 8126 mg/L COD: 10158 mg/L TSS: 9408 mg/L NH_3-N: 22.8 mg/L	BOD: 30%–40% COD: 15%–20%	Tangahu and Putri (2017)
Biological treatment using immobilized microalgae *Chlorella* sp.	Treatment in batch culture mode at HRT 4 days (optimum conditions: pH 8)	Single	Real batik wastewater	pH: 11.56 BOD: 155 mg/L COD: 536 mg/L TN: 112 mg/L	BOD: 49% COD: 49.6% TN: 43.8%	Kassim et al. (2018)
Anaerobic degradation treatment using bioequalization tank	Immobilized anaerobic sludge Average OLR: 0.9 kg COD $m^{-3}d^{-1}$ HRT: 48 h	Primary	Real batik wastewater	COD: 870 mg/L BOD: 552 mg/L TSS: 388 mg/L NH_3: 5.59 mg/L	COD: 66.7% BOD: 75.9% TSS: 72.2% NH_3: 78.2%	Mukimin et al. (2018)
Phytoremediation treatment using *Vetiver Chrysopogon zizanioides* (L)	Wastewater strength: 50, 75 & 100% HRT: 49 days	Single	Real batik wastewater	100% strength COD: 788.64 mg/L BOD: 164.21 mg/L Cr: 2.17 mg/L	COD: 88.7% BOD: 97.8% Cr: 8.85%	Tambunan et al. (2018)
Phytoremediation treatment using *Eichhornia crassipes*	Wastewater strength: 20, 30 & 60% HRT: 0–28 days Optimum HRT: 7 days	Single	Mixture of printing and washing process effluent	pH: 7.15 COD: 533 mg/L Colour: 885 ADMI TSS: 72 mg/L	COD: 60%–70% Colour: 20%–75% TSS: 20%–50%	Safauldeen et al. (2019)
Phytoremediation treatment using *Scirpus grossus* and *Iris pseudacorus*	HRT: 12–17 days	Single	Real batik wastewater	pH: 10.8 COD: 3855 mg/L BOD: 2710 mg/L	COD: 89% BOD: 90%	Tangahu et al. (2019)
Phytoremediation treatment in a hybrid constructed wetland using *Canna indica*	HRT: 3 days	Single	Real batik wastewater	pH: 12.1 COD: 13600 mg/L	COD: 89.6% TSS: 98.5% O&G: 89.5%	Rahmadyanti and Audina (2020)
Phytoremediation treatment using *Cyperus haspan*	Batik wastewater strength: 25% HRT: 8 days	Single	Real batik wastewater	pH: 8.7 BOD: 500–800 mg/L COD: 2500–3000 mg/L Cr: 15.1 mg/L	BOD: 68.1% COD: 57.8% Cr: 28%	Wirosoedarmo et al. (2020)

Table 6
Advantages and disadvantages of different types of batik wastewater treatment processes.

Treatment	Advantages	Disadvantages	References
Adsorption	Fairly high removal. Good removal of a wide variety of dyes.	But only over a low concentration range. Costly adsorbent.	Ahmad et al. (2002) Muthusamy et al. (2018)
Baffle separation treatment	Simple manufacturing operating conditions. User-friendliness.	Limited research studies.	Rashidi et al. (2016)
Biological	Low-cost technology.	Not applicable to highly toxic wastewater.	Ahmad et al. (2002) Birgani et al. (2016)
Biosorption	Maximises natural resource usage.	Difficulties in its preparation. Requires a long retention time. Requires a large area.	Ahmad et al. (2002) Ramlee et al. (2014) Lestari et al. (2018)
Coagulation-chemical	Effective at removing contaminants and dye.	Involves the use of chemicals. Imposes health-related problems.	Bhatia et al. (2007)
Coagulation-natural	Produces less sludge than chemical coagulation. Environmentally friendly. Does not impose any disposal problems. Low cost.	Difficulties in maintaining removal efficiencies.	Bhatia et al. (2007) Saraswathi and Saseetharan (2012)
Electrocoagulation	Degradation products are non-hazardous.	Expensive in terms of energy cost.	Ahmad et al. (2002)
Fenton oxidation	Effective at removing dye content and colour.	Involves sludge generation.	Ahmad et al. (2002)
Membrane filtration	Removes all dye types.	Concentrated sludge production. Need to deal with faulty membrane.	Ahmad et al. (2002)
Nanofiltration	Low energy consumption. Up-scaling is relatively simple. Separation can be carried out continuously.	Concentrated sludge production that leads to fouling problems. Quite expensive.	Ahmad et al. (2002) Birgani et al. (2016)
Photocatalytic	Simple operation. Proven in removing organic contaminants.	Limited to environment conditions.	Hussein and Abass (2010)
Phytoremediation	Low cost. Chemical-free process. Simple operation.	Requires a long retention time. Limited by environmental conditions. Large area required.	Rahmadyanti and Audina (2020) Abdullah et al. (2020)
Rotating biological contactor	Minimal maintenance. Consistent process.	Mainly effective for TSS removal.	Kristijanto et al. (2011)
Ultrafiltration	Quality of treated water more uniform. Does not require highly skilled operator.	High chances of a filter faulty, especially with high amounts of suspended solids in the effluent.	Ahmad et al. (2002) Birgani et al. (2016)

operation, easy implementation, flexibility of in situ and ex situ treatment, a low environmental impact, habitat restoration and low production of secondary waste (Koelmel et al., 2014; Tambunan et al., 2018). The advantages of this technology are illustrated in Fig. 12.

For a small-to-medium industry like the batik industry, this simple and low-cost technology can be considered one of the best options for wastewater treatment. Plants used in phytoremediation technology usually have rapid growth and easy-to-breed characteristics, which will facilitate the implementation of phytoremediation technology. Application of phytoremediation technology in batik industry is also favourable since most batik industry is located near waterways/rivers, which is a suitable habitat for plant growth. The use of nearly zero chemicals in the whole process makes this technology a natural means of environmental clean-up for land, soil and water (Suresh and Ravishankar, 2004). The application of phytoremediation technology in real industrial plants usually includes the development of artificial wetlands or retention ponds (Tambunan et al., 2018; Norhan et al., 2021). Moreover, the plants used in any phytoremediation treatment system will instantly restore habitat for land or aquatic creatures.

Apart from industrial applications, phytoremediation is also used to rehabilitate contaminated sites such as those at uranium-contaminated sites in Chernobyl (Schnoor, 1997). The amount of waste produced by phytoremediation technology is also relatively small and only in terms of crops and biomass from the plant. Much research has been studied using phytoremediation crops as a source of renewable energy production through thermochemical conversion (Witters et al., 2012; Jiang et al., 2015). Another interesting idea for converting waste to a product is the use of plants, for example, rapeseed (*Brassica napus*) as a biodiesel fuel (Ginneken et al., 2007). Since this technology produces almost zero waste, no disposal site is required (Suresh and Ravishankar, 2004). The advantages of this technology benefit not only the industry itself but also the environment.

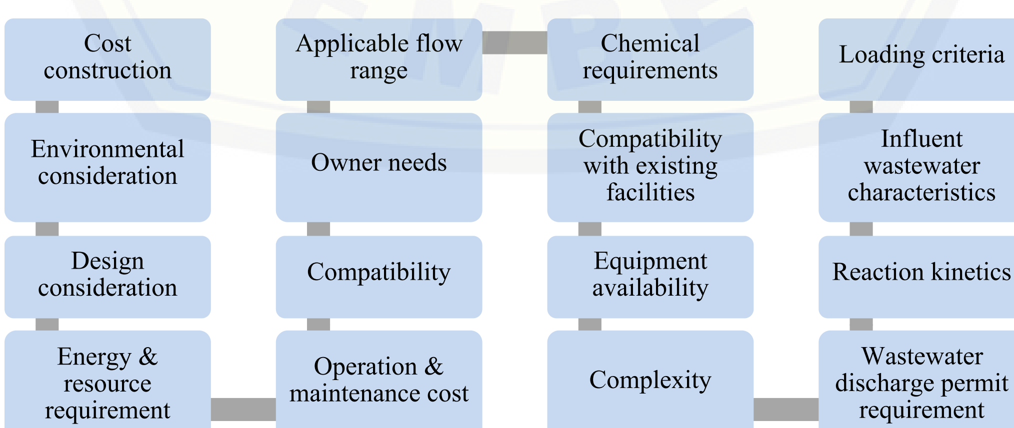


Fig. 8. Factors to be considered in treatment process selection.

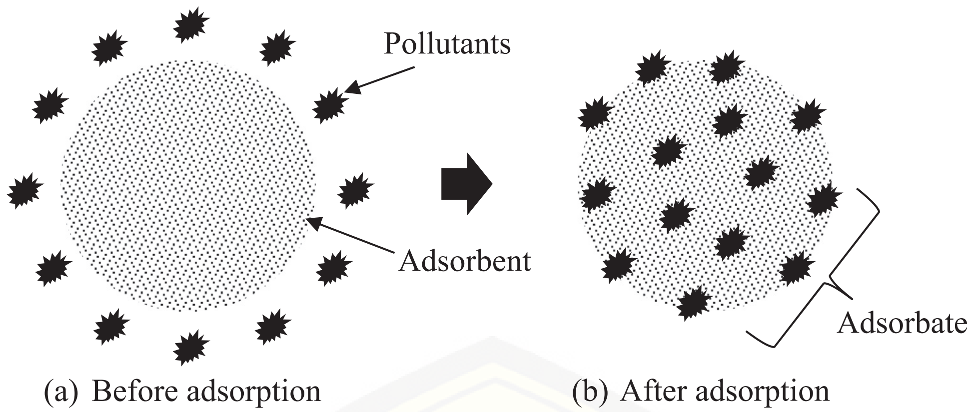


Fig. 9. Schematic diagram of the adsorption process in wastewater treatment.

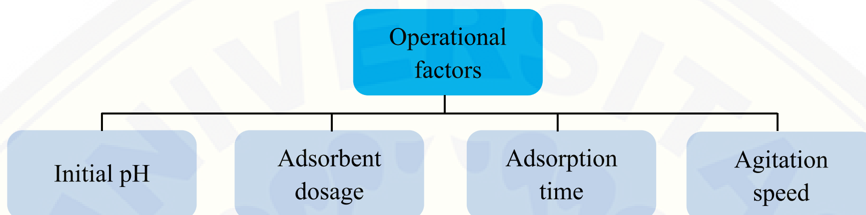


Fig. 10. Operational factors in adsorption.

According to Zhou and Xiang (2013), dye-rich wastewater phytoremediation can be performed using a wide range of plants. This means there is no restriction on selecting a suitable plant for batik wastewater. As summarised in Table 5, there are various plants used for batik wastewater phytoremediation. Some of the successful plants include *Eichhornia crassipes*, *Pistia stratiotes*, *Hydrilla verticillate*, *Salvinia cucullate*, *Egeria densa*, *Scirpus grossus* and many more. Even a phytoremediation study by Jayanthy et al. (2014) successfully treated batik-like wastewater using the *Leucaena leucocephala* plant. In our upcoming research, phytoremediation treatment using two plants simultaneously will be introduced. Hence, a two-stage constructed wetland approach will be used to treat real batik wastewater. Two of Malaysia's native plants that are widely and easily grown will be used: *Scirpus grossus* and *Eichhornia crassipes*. According to Tangahu et al. (2019), the combination of plants may enhance phytoremediation efficiency. Even a study done by Mbuligwe (2005) concluded that a constructed wetland system managed to increase the decolourization rate twofold compared with a single plant phytoremediation treatment system.

There are several processes included in the phytoremediation treatment method. As illustrated in Fig. 13, the six processes are (1) phytostabilization/phytoimmobilization, (2) phytofiltration/rhizofil tration, (3) phytostimulation/rhizodegradation, (4) phytoaccumulation/ phytoextraction, (5) phytodegradation and (6) phytovolatilization. The phytostabilization/ phytoimmobilization process is responsible for limiting or reducing the mobility of contaminants from the soil near root tissue. Contaminants will be bound to the soil particles, making them less accessible for plant or human uptake. For the phytofiltration/rhizofiltration process, it involves the filtration of wastewater through the root system, and this process is usually suitable for the uptake of heavy metals or radioactive elements. The phytostimulation/rhizodegradation process involves

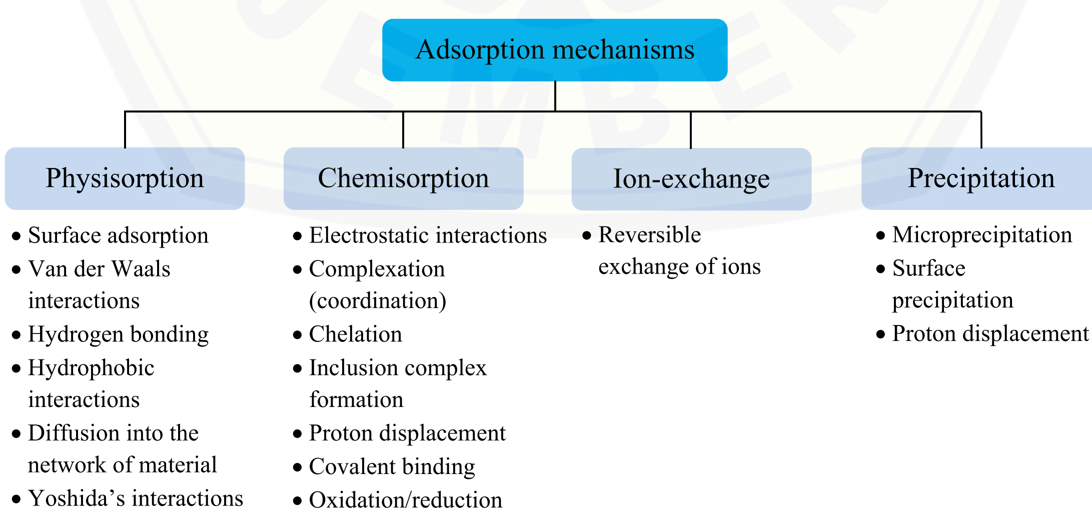


Fig. 11. Main adsorption mechanisms (Crini et al., 2019).

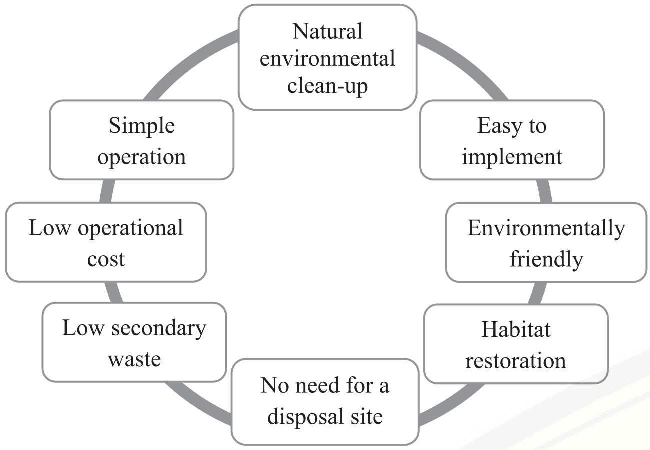


Fig. 12. Advantages of phytoremediation technology.

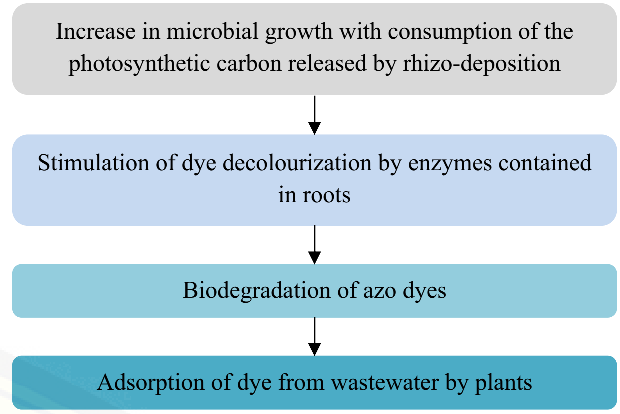


Fig. 14. Bio-decolourisation mechanism of dye by plants.

microbial activity to degrade mostly organic contaminants. This process usually occurs within the rhizosphere, which is the layer of soil that surrounds the root system. According to Abdullah et al. (2020), phytovolatilization is normally used to remove low-molecular-weight compounds (aromatic) and phytodegradation for non-volatile compounds (aliphatic), whereas phytoextraction is used for other organic compounds.

Phytoaccumulation/phytoextraction is a process of contaminant absorption by roots followed by translocation and accumulation of the pollutants in the stem cells or leaves. This process is mainly used for metal uptake. While phytoextraction is mostly used to accumulate metals, phytodegradation helps to degrade organic contaminants inside plants cell using certain enzymes. In the phytovolatilization process, contaminants will be absorbed by the roots, converted into volatile, non-toxic forms and then released into the atmosphere. Since batik wastewater is basically one type of textile wastewater, any treatment used in the batik industry should cope with problems related to the dye. Phytoremediation studies have been proven to reduce the amount of colour in textile or dye-based wastewater (Jayanthy et al., 2014). Zhou and Xiang (2013) discussed the bio-decolourization pathway, which promotes by the plant mechanisms through phytoremediation technology. A summary of bio-decolourization pathways is shown in Fig. 14 below. The biodegradation of azo dyes involves the breakdown process of the azo dye bond to reduce the colour content in the wastewater.

4.3. SWOT analysis of natural adsorption and two-stage constructed wetland integrated system

As mentioned in the previous section, there are many advantages of both natural adsorption and phytoremediation. However, there are certain aspects, such as their weaknesses and threats, that must be taken into consideration. Fig. 15 summarises the strength-weaknesses-opportunities-thread (SWOT) analysis of this integrated treatment system. Some strengths of this integrated treatment method are its simple operation and ease of implementation, which have led to the low cost of its implementation and maintenance. Since most batik industries already have adsorption facilities, only minimal site destruction is required for them to convert to a natural adsorption process and install a two-stage constructed wetland. This analysis also shows that this integrated system offers green technology, which is environmentally friendly and produces a low amount of waste. Waste produced through this green technology treatment is not harmful to adjacent

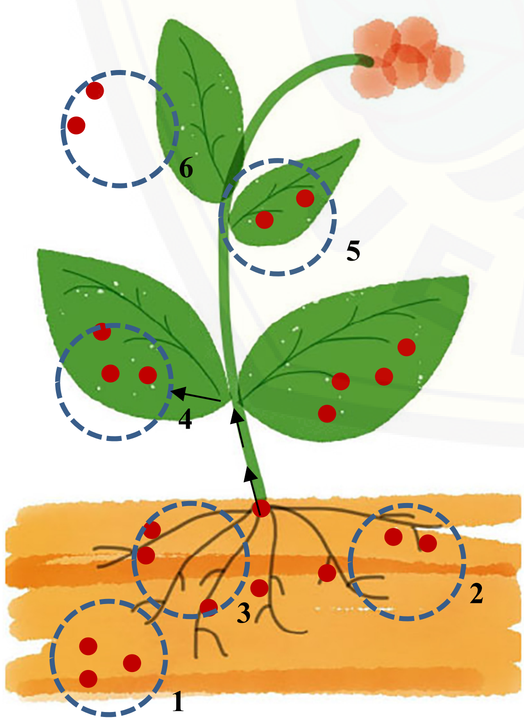


Fig. 13. Contaminant uptake by a plant through phytoremediation technology.

Fig. 15. SWOT analysis of natural adsorption and a two-stage constructed wetland integrated system.

river ecosystems. Despite the numerous advantages of natural adsorption and two-stage constructed wetland systems, natural treatment normally requires long treatment times compared with conventional physicochemical treatment. Since there are limited study resources related to batik wastewater treatment using natural adsorbents and native plants, the selection of suitable adsorbents and plants might require detailed study. When dealing with plants, crop disposal might impose another problem to industry. However, through consistent and detailed research, we are hoping that this integrated system can be a promising green technology for the batik industry.

5. Conclusions

The batik industry is the heritage of Malaysia and some Southeast Asian countries; hence, maintaining this industry is essential to sustaining this valuable asset. However, from the process involved in this industry another environmental pollution issue has emerged that needs to be resolved. Conventional and existing treatments are unable to decrease contaminant levels in batik wastewater to the permitted level. A costly problem arises from the existing treatment. The dye and COD content in batik wastewater makes it difficult to treat with a single treatment process. Hence, a combination of physical and biological treatments might be an option to improve the current treatment system. The ability and performance of an integrated approach using adsorption by a natural adsorbent and a two-stage constructed wetland can offer a better option and will be investigated in the future.

CRediT authorship contribution statement

Contributions	Authors
Writing - original draft	Nurull Muna Daud
Writing - review and editing	Nurull Muna Daud
	Siti Rozaimah Sheikh Abdullah
Data collection	Nurull Muna Daud
	Siti Rozaimah Sheikh Abdullah
	Yeny Dhokikah
Visualization	Nurull Muna Daud
	Siti Rozaimah Sheikh Abdullah
Fieldwork	Nurull Muna Daud
	Hassimi Abu Hasan
Supervision	Siti Rozaimah Sheikh Abdullah
Conceptualization	Nurull Muna Daud
	Siti Rozaimah Sheikh Abdullah
Funding	Siti Rozaimah Sheikh Abdullah
	Hassimi Abu Hasan
	Nur 'Izzati Ismail

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

This research was fully funded by Universiti Kebangsaan Malaysia through a research grant of DIP-2021-002.

References

Abdullah, S.R.S., Al-Baldawi, I.A., Almansoory, A.F., Purwanti, I.F., Al-Sbani, N.H., Sharuddin, S.S.N., 2020. Review: plant-assisted remediation of hydrocarbons in water and soil: application, mechanisms, challenges and opportunities. Chemosphere 247, 125932.

Abdulqader, E., Abdullah, S.R.S., Hasan, H.A., Rahim, R.A.A., Idris, M., Kamaruzzaman, M.A., Ismail, N.I., 2019. Isolation and identification of tolerant bacteria from roots of Scirpus grossus exposed to mixed synthetic dye. Plant Arch. 19 (Supplement 2), 2034–2039.

Afzan, S., Izzuddin, M.N., Raihan, A., 2019. Penapis saluran efluens. 9th National Conference in Education-Technical & Vocational Education and Training (CiE-TVET) 2019 1138.

Ahmad, A.L., Harris, W.A., Syafiie, Seng, O.B., 2002. Removal of dye from wastewater of textile industry using membrane technology. Jurnal Teknologi 36, 31–44.

Ahmad, F., 2021. Produk batik Iskandar, kreatif, unik. Utusan Malaysia 25 Januari 3 March 2021 https://www.utusan.com.my/gaya/2021/01/produk-batik-iskandar-kreatif-unik/.

Akta Kualiti Alam Sekeliling 1974 (Environmental Quality Act 1974), 2009. International Law Book Services. Direct Art Company, Kuala Lumpur, Malaysia.

AL Sbani, N.H., Abdullah, S.R.S., Idris, M., Hasan, H.A., Halmi, M.I.E., Ismail, N.I., Jehawi, O.H., 2021. PAH-degrading rhizobacteria of Lepironia articulata for phytoremediation enhancement PAH-degrading rhizobacteria for phytoremediation enhancement. Journal of Water Process Engineering 39 (2021), 101688. https://doi.org/10.1016/j.jwpe.2020.101688.

Al-Ajalin, F.A.H., Idris, M., Abdullah, S.R.S., Kurniawan, S.B., Imron, M.F., 2020. Evaluation of reed bed performance for real domestic wastewater treatment. Environ. Technol. Innov. 20 (2020), 101110. https://doi.org/10.1016/j.eti.2020.101110.

Al-Baldawi, I.A., Abdullah, S.R.S., Anuar, N., Idris, M., 2017. Bioaugmentation for the enhancement of hydrocarbon phytoremediation by rhizobacteria consortium in pilot horizontal subsurface flow constructed wetlands. Int. J. Environ. Sci. Technol. 14 (1), 75–84. https://doi.org/10.1007/s13762-016-1120-2.

Al-Baldawi, I.A., Abdullah, S.R.S., Almansoory, A.F., Ismail, N.I., Hasan, H.A., Anuar, N., 2020. Role of Salvinia molesta in biodecolorization of methyl orange-dye from water. Sci. Rep. 10 (2020), 13980. https://doi.org/10.1038/s41598-020-70740-5.

Ali, N., Suhaimi, N.S., 2009. Performance evaluation of locally fabricated asymmetric, nanofiltration membrane for batik industry effluent. World Appl. Sci. J. 5, 46–52.

Allamin, I.A., Yasid, N.A., Abdullah, S.R.S., Halmi, M.I.E., Shukor, M.Y., 2021. Phytotolerance degradation of hydrocarbons and accumulation of heavy metals by of Cajanus cajan (pigeon pea) in petroleum-oily-sludge-contaminated soil. Agronomy 11 (6), 1–17. https://doi.org/10.3390/agronomy11061138 1138.

Almansoory, A.F., Idris, M., Abdullah, S.R.S., Anuar, N., Kurniawan, S.B., 2021. Response and capability of Scirpus mucronatus (L.) in phytotreating petrol-contaminated soil. Chemosphere 269 (2021), 128760. https://doi.org/10.1016/j.chemosphere.2020.128760).

Anon, 2021. PM Ismail Sabri declares Dec 3 as Malaysia Batik Day. Bernama, 1 December.

Arslan, I.A., Balcioglu, D.W., Bahnemann, 2000. Phytoremediation studies at Milan army ammunition plant. Dyes and Pigments 47.

Aryanti, N., Nafiunisa, A., Irmalasari, L.N., Nisa, I.M.K., Wardhani, D.H., 2019. Sriwijaya International Conference on Science, Engineering, and Technology. IOP Conf. Series: Materials Science and Engineering 620. IOP Publishing Ltd.

Bhatia, S., Othman, Z., Ahmad, A.L., 2007. Coagulation–flocculation process for POME treatment using Moringa oleifera seeds extract: optimization studies. Chem. Eng. J. 133 (1–3), 205–212.

Birgani, P.M., Ranjbar, N., Abdullah, R.C., Wong, K.T., Lee, G., Ibrahim, S., Park, C., Yoon, Y., Jang, M., 2016. An efficient and economical treatment for batik textile wastewater containing high levels of silicate and organic pollutants using a sequential process of acidification, magnesium oxide, and palm shell based activated carbon application. J. Environ. Manag. 1–11.

China Water Risk, 29 July 2020. Maximum Allowable Discharge Concentrations for Other Pollutants in China National. China Water Risk. www.chinawaterrisk.org.

Choi, J.W., Song, H.K., Lee, W., Koo, K.K., Han, C., Na, B.K., 2004. Reduction of COD and colour of acid and reactive dyestuff wastewater using ozone. Korean J. Chem. Eng. 21, 398.

Choy, E.A., 2013. Pembangunan pelancongan lestari di Melaka: perspektif pelancong. Geografia Malays. J. Soc. Space 9 (3), 12–23.

Crini, G., Lichtfouse, E., Wilson, L., Morin-Crini, N., 2019. Adsorption-oriented processes using conventional and non-conventional adsorbents for wastewater treatment. Green Adsorbents for Pollutant Removal. Environmental Chemistry for a Sustainable World 18. 23–71, Springer Nature.

Dasgupta, J., Sikder, J., Chakraborty, S., Curcio, S., Drioli, E., 2015. Remediation of textile effluents by membrane-based treatment: a state of art review. J. Environ. Manag. 147, 55–72.

Department of Statistics Malaysia (DoSM), 2018. Official Portal, The Source of Malaysia's Statistics. 15 May 2020 https://www.dosm.gov.my/v1/index.php?r=column/cthemeByCat&cat=407&bul_id=eFI1NlJXQjQ3cTNRVXVNSWZ0cTQ0UT09&menu_id=NWVEZGhEVlNMeitaMHNzK2htRU05dz09.

Dewi, R.S., Kasiamdari, R.S., Martani, E., Purwestri, Y.A., 2019. Efficiency of Aspergillus sp. 3 to reduce chromium, sulfide, ammonia, phenol, and fat from batik wastewater. IOP Conference Series: Earth and Environmental Science 308. IOP Publishing Ltd.

Diwaniyan, S., Kharb, D., Raghukumar, C., Kuhad, R.C., 2010. Decolorisation of synthetic dyes and textile effluents by basidiomycetous fungi. Water Air Soil Pollut. 210, 409–419.

Felaza, E., Priadi, C.R., 2016. Implementation of cleaner production in a natural dye batik industry SME: A way to enhance biodegradability of batik wastewater? Indonesia Climate Change Forum and Expo (ICCFE 2016). MATEC Web of Conferences 62

Garg, A., Bhat, K., Bock, C., 2002. Mutagenicity of aminoazobenzene dyes and related structures: a QSAR/QPAR investigation. Dyes Pigments 55, 35–52.

Ginneken, L.V., Meers, E., Guisson, R., Ruttens, A., Elst, K., Tack, F.M.G., Vangronsveld, J., Diels, L., Dejonghe, W., 2007. Phytoremediation for heavy metal - contaminated soils combined with bioenergy production. J. Environ. Eng. Landsc. Manag. 15 (4), 227–236.

Handayani, P.A., Cholifah, U., Ulviana, R., Chafidz, A., 2019. "Batik" industry wastewater treatment via coagulation-flocculation process and adsorption using teak sawdust based activated carbon. J. Bahan Alam Terbarukan 8 (1), 8–13.

Handayani, W., Kristijanto, A.I., Hunga, A.I.R., 2018. Are natural dyes eco-friendly? A case study on water usage and wastewater characteristics of batik production by natural dyes application. Sustainable Water Resources Management 4, 1011–1021. https://doi.org/10.1007/s40899-018-0217-9.

Handayani, W., Kristijanto, A.I., Hunga, A.I.R., 2018b. A water footprint case study in jarum village, klaten, Indonesia: the production of natural-colored batik. Environ. Dev. Sustain. 21 (4), 1919–1932.

Hardyanti, I.S., Nurani, I., Septyaningsih, D.H.Hp, Apriliani, E., Prastyo, E.A., 2017. Pemanfaatan silika (SiO2) dan bentonit sebagai adsorben logam Berat fe pada limbah batik batik. J. Sains Terap. 3 (2), 37–41.

Hassan, S.A., Hanafiah., 2018. Teknologi pemprosesan batik melayu di Kelantan. Jurnal Wacana Sarjana 2 (2), 1–8.

HTC, 2013. Proses Enviro-Tex untuk perawatan air sisa kilang batik. Cabaran Inovasi 2013.

Hussein, F.H., Abass, T.A., 2010. Solar photolysis and photocatalytic treatment of textile industrial wastewater. Int. J. Chem. Sci. 8 (3), 1409–1420.

Ismail, N.I., Abdullah, S.R.A., Idris, M., AL Sbania, N.H., Hasan, H.A., Jehawi, O.H., 2014. Preliminary test of mining wastewater containing Iron (III) and Aluminium (III) on Lepironia articulata in phytoremediation. Australian Journal of Basic and Applied Sciences 8 (19), 168–171.

Ismail, N.I., Abdullah, S.R.S., Idris, M., Kurniawan, S.B., Halmi, M.I.E., AL Sbani, N.H., Jehawi, O.H., Hasan, H.A., 2020. Applying rhizobacteria consortium for the enhancement of Scirpus grossus growth and phytoaccumulation of Fe and Al in pilot constructed wetlands. Journal of Environmental Management 267 (2020), 110643. https://doi.org/10.1016/j.jenvman.2020.110643.

Jamaludin, M.Z., 2020. Study on removal of pollutant from batik wastewater using coal bottomash (CBA). IOP Conference Series: Earth and Environmental Science. 476. IOP Publishing Ltd, p. 1.

Jayanthy, V., Geetha, R., Rajendran, R., Prabhavathi, P., Karthik Sundaram, S., Dinesh Kumar, S., Santhanam, P., 2014. Phytoremediation of dye contaminated soil by Leucaena leucocephala (subabul) seed and growth assessment of Vigna radiata in the remediated soil. Saudi J. Biol. Sci. 21 (4), 324–333.

Jehawi, O.H., Abdullah, S.R.S., Idris, M., Kurniawan, S.B., Ismail, N.I., AL Sbani, N.H., Muhamad, M.H., Hasan, H.A., 2020. Performance of pilot Hybrid Reed Bed constructed with aeration system on nutrient removal for domestic wastewater treatment. Environmental Technology & Innovation 19 (2020), 100891. https://doi.org/10.1016/j.eti.2020.100891.

Jiang, Y., Lei, M., Duan, L., Longhurst, P., 2015. Integrating phytoremediation with biomass valorization and critical element recovery: a UK contaminated land perspective. Biomass Bioenergy 83, 328–339.

Kadir, A.A., Abdullah, S.R.S., Othman, B.A., Hasan, H.A., Othman, A.R., Kurniawan, S.B., Ismail, N.I., 2020. Dual function of Lemna minor and Azolla pinnata as phytoremediator for palm oil mill effluent and as feedstock. Chemosphere 259 (2020), 127468. https://doi.org/10.1016/j.chemosphere.2020.127468.

Kamaruzzaman, M.A., Abdullah, S.R.S., Hasan, H.A., Othman, A.R., Hassan, M., Idris, M., 2020. Characterization of pb-resistant plant growth-promoting rhizobacteria (PGPR) from Scirpus grossus. Biocatal. Agric. Biotechnol. 23 (2020), 101456. https://doi.org/10.1016/j.bcab.2019.101456.

Kassim, M.A., Latif, N.F.A., Hashim, N.F., 2018. Decolorisation and total nitrogen removal from batik effluent using alginate immobilized freshwater microalgae chlorella sp. J. Appl. Biomater. Biomech. 6 (6), 26–34.

Khalik, W.F., Ho, L.N., Ong, S.A., Voon, C.H., Wong, Y.S., Yusuf, S.Y., Lee, S.L., 2018. Enhancement of simultaneous batik wastewater treatment and electricity generation in photocatalytic fuel cell. Environ. Sci. Pollut. Res. 25 (35), 35164–35175.

Khalik, W.F., Ho, L.N., Ong, S.A., Wong, Y.S., Yusoff, N.A., Ridwan, F., 2015. Decolorization and mineralization of batik wastewater through solar photocatalytic process. Sains Malays. 44 (4), 607.

Khandare, R.V., Govindwar, S.P., 2015. Phytoremediation of textile dyes and effluents: current scenario and future prospects. Biotechnol. Adv. 33 (8), 1697–1714.

Koelmel, J., Prasad, M.N.V., Pershell, K., 2014. Bibliometric analysis of phytotechnologies for remediation: global scenario of research and applications. Int. J. Phytoremediation 17 (2), 145–153.

Kristijanto, A., Handayani, W., Levi, P.A.A., 2011. The effectiveness of anaerobic baffled reactor and rotating biological contactor in batik wastewater treatment. Makara J. Technol. 15 (2), 168–172.

Kuhad, R.C., Sood, N., Tripathi, K.K., Singh, A., Ward, O.P., 2004. Advances in Applied Microbiology. 56. Elsevier, pp. 185–213.

Kurniawan, S.B., Ahmad, A., Said, N.S.M., Abdullah, S.R.S., Hasan, H.A., Othman, A.R., Purwanti, I.F., Imron, M.F., 2021. Macrophytes as wastewater treatment agent: Nutrient uptake and potential of produced biomass utilization toward circular economy initiative. Science of the Total Environment 790 (2021), 1–14 148219.

Lestari, S., Sudarmadji, Tandjung, S.D., Santosa, S.J., 2018. Cr(VI) and dye biosorption in batik wastewater using biosorbent in the tea bag. International Conference on Energy, Environmental and Information System (ICENIS 2018). E3S Web of Conferences 73.

Lokhande, V.H., Kudale, S., Nikalje, G., Desai, N., 2015. Hairy root induction and phytoremediation of textile dye, reactive green 19A-HE4BD, in a halophyte, Sesuvium portulacastrum (L.) L. Biotechnol. Rep. 8, 56–63.

Mahmood, Q., Zheng, P., Islam, E., Hayat, Y., Hassan, M.J., Jilani, G., Jin, R.C., 2005. Lab scale studies on water hyacinth (Eichhornia crassipes marts Solms) for biotreatment of textile wastewater. Casp. J. Environ. Sci. 3 (2), 83–88.

Malaysia, 2008. Pemakaian Pakaian Batik Malaysia Oleh Pegawai Awam Pada Hari Khamis. Surat Pekeliling Perkhidmatan Bilangan 1 Tahun 2008 (JPA(S)TT 193/37 Klt. 5, p. 38.

Malaysia, Kraftangan, 2021. Official website for malaysian handicraft development corporation. https://www.kraftangan.gov.my/en Accessed on 8th July 2021.

Malaysian Handicraft Development Corporation (MHDC), 2021. Malaysian Handicraft Annual Report 2013. 23 August 2020. Malaysia Handicraft Development Corporation. https://www.nst.com.my/news/nation/2019/01/452503/preserving-batik-heritage.

Zhou, X., Xiang, X., 2013. Effect of different plants on azo-dye wastewater bio-decolorization. Procedia Environ. Sci. 18, 540–546.