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FOCUS AND SCOPE

Jurnal Riset Teknologi Pencegahan Pencemaran Industri (Research Journal of Industrial Pollution Prevention Technology) seeks to promote and disseminate original research as well as review, related to following area:

Environmental Technology : within the area of air pollution technology, wastewater treatment technology, and management of solid waste and harzardous toxic substance.

Process Technology and Simulation : technology and/or simulation in industrial production process aims to minimize waste and environmental degradation.

Design Engineering : device engineering to improve process efficiency, measurement accuracy and to detect pollutant.

Material Fabrication : environmental friendly material fabrication as subtitution material for industry.

Energy Conservation : process engineering/ technology/ conservation of resources for energy generation.

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PREFACE

Thanks to Allahu Robbie 'Alamin, Journal of Industrial Pollution Prevention Technology (JRTPPI) again will publish scientific articles, especially in the field of environmental technology for volume 12 no 1. Our high appreciation is directed to the authors and editorial board who have actively participated so as to maintain consistency of quality and punctuality of our periodic publications. We would like to acknowledge our high appreciation to the head at center of industrial pollution prevention technology, Ministry of Industry.

This edition of the issue is sixth series published that in full-text English. This continous policy is an attempt of the editorial board to improve the author's performance in delivering the results of their researches. Articles in full-text English are more likely to be read by broader audience so that it will increase the number of citations. This policy is also applied in order to actualize our hope of being a globally indexed international journal.

The articles contained in this edition consist of water and wastewater technologies online monitoring and modeling in cleaner production option. The wastewater treatments use biological method, while water teratment use advanced material and activated carbon as adsorption process. Online monitoring as respon a current issue in Indonesia for real evaluation some effluent industry and bodi river quality. The five manuscripts accepted and published in this edition are from researcher and lecturer in Lambung Mangkurat University, Center of Pulp and Paper, Tadulako University, Politeknik Negeri Padang, and Barawijaya University. The duration of submission, review, and editing of the manuscripts ranged from 2-7 months.

Hopefully, these scientific articles may be new source of knowledge and experience for readers from academic, researcher, industry, and society at large. We realize that nothing is perfect until the improvement of all parties involved is continuously done.

Semarang, May 2021

Chief Editor

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ABSTRACT

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PVDF-TiO_2 Hollow Fibre Membrane For Water Desalination

Jurnal Riset Teknologi Pencegahan Pencemaran Industri, May 2021, Vol. 12, No. 1, p. 1-6, 3 ill, 1 tab, 21 ref

The clean water crisis is increasing along with the increasing human population. Seawater is one of the largest water sources that can be utilized on the earth. However, the high salt concentration dissolved in seawater must be treated before it can be used. Desalination is the directly technology for treating seawater with PVDF-TiO2 hollow fibre membrane via pervaporation process. This research aimed to determine the performance of PVDF-TiO_2 hollow fibre membrane against variations of feed temperature in the artificial seawater pervaporation process. Method for fabrication membrane is using dry-wet spinning method. The membrane was fabricated with TiO_2 3 wt%, PVDF 21 wt% and DMAC 75 wt%. The result showed that the highest flux permeate of 8.96 $kg.m^{-2}.h^{-1}$occurred at feed temperature of 60°C, with salt rejection > 92.86%. The SEM result showed that of the membrane surface morphology, there is a white spot on the membrane surface is TiO_2 because the dope solution is too thick. The PVDF-TiO_2 hollow fibre membrane in this research is can be applied for seawater pervaporation.

(Author)

Keywords: Hollow fibre membrane, PVDF-TiO2, Desalination, Pervaporation

Andri Taufick Rizaluddin[1], Henggar Hardiani[1] ([1]Center for Pulp and Paper, Jl. Raya Dayeuhkolot No.132 Bandung, Indonesia)

Online Monitoring of Effluent Quality for Assessing the Effect of Wastewater Treatment Plant

Jurnal Riset Teknologi Pencegahan Pencemaran Industri, May 2021, Vol. 12, No. 1, p. 7-19, 1 ill, 6 tab, 38 ref

In general, industry uses water in its production process so that it will produce wastewater that contains many contaminants, it will affects the surrounding environment by contaminating the water bodies. Information on monitoring the quality of industrial wastewater is very important to be perceive by examining changes in water quality. Industrial wastewater monitoring is a device system that collects real time data. Online monitoring technology is one part that plays an important role in supporting activities to control water environmental pollution. Real-time monitoring of wastewater quality remains an unresolved problem to the wastewater treatment industry. One of the problem in most industries in Indonesia is the nonoptimal condition of operational and performance of wastewater treatment plants (WWTP), and need improvement. The application of industrial technology concept 4.0 and automation systems in the industry is expected to improve the WWTP supervision process which has advantages such as reducing down time, reducing consumption of raw materials, reducing the energy used, etc. The cost savings that can be made by implementing it may reach up to 20-40% (estimation) with several assumptions applied. This review is to provide information about the assessment of WWTP performance through online monitoring of wastewater effluent quality.

(Author)

Keywords: Industrial wastewater, Industrial technology 4.0, online Monitoring, Wastewater treatment plant (WWTP)

Abdul Gani Akhmad[1], Saiful Darman[2], Aiyen[2], Wildani Pingkan S. Hamsens[2] ([1]Faculty of Engineering, Tadulako University, Palu, [2]Agricultural Science Doctoral Study Program, Postgraduate, Tadulako University, Palu)

Removal of Total Coliform and TSS for Hospital Wastewater by Optimizing the Role of Typha Angustifolia and Fine Sand-Gravel

Media in Horizontal Sub Surface Flow Constructed Wetland

Jurnal Riset Teknologi Pencegahan Pencemaran Industri, May 2021, Vol. 12, No. 1, p. 20-31, 2 ill, 7 tab, 34 ref

This study aims to evaluate the performance of a pilot-scale Horizontal Subsurface Flow Constructed Wetland (HSSF-CW) utilizing Typha angustifolia and fine sand-gravel media in removing total coliform and TSS from hospital wastewater. Three pilot-scale HSSF-CW cells measuring 1.00 x 0.45 x 0.35 m^3 were filled with gravel sand media with a diameter of 5 - 8 mm as high as 35 cm with a submerged media depth of 0.30 m. There were three treatments, namely the first cell (CW1) without plants, the second cell (CW2) was planted with a density of 12 Typha angustifolia plants, and the third cell (CW3) was planted with a density of 24 Typha angustifolia plants. The three HSSF-CW cells received the same wastewater load with total coliform and TSS contents of 91000 MPN/100 mg and 53 mg/L, respectively, with Hydraulic Loading Rates 3.375 m^3 per day. Wastewater was recirculated continuously to achieve the equivalent HSSF-CW area requirement. The experimental results show that the performance of CW3 is more efficient than CW1 and CW2 in total coliform and TSS removal for hospital wastewater. The pollutant removal efficiency at CW3 reached 97.69% for total coliform with two days hydraulic retention time and 43.00% for TSS with one day of hydraulic retention time. This study concludes that the HSSF-CW system using sand-gravel media with a diameter of 5 - 8 mm with a submerged media depth of 0.30 m and planted with Typha angustifolia with a tighter spacing proved to be more efficient in removing total coliform and TSS from hospital wastewater.

(Author)

Keywords: Constructed wetland, Typha angustifolia, Sand-gravel media, Hospital wastewater

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Yuli Yetri[1], Dwi Astuti Marantika[2], Rahmi Hidayati[3], Sukatik[3], Nurry Putri Tissos[4] ([1]Mechanical Engineering Department, Politeknik Negeri Padang, Kampus Limau Manis, Padang, 25163, Indonesia, [2]Chemistry Department Faculty of Mathematics and Natural Sciences, Andalas University Kampus Limau Manis, Padang, Indonesia, [3]Civil Engineering Department, Politeknik Negeri Padang, Kampus Limau Manis, Padang, 25163, Indonesia, [4]Physics Department Faculty of Mathematics and Natural Sciences Andalas University, Kampus Limau Manis, Padang, 25163, Indonesia)

Potential Activated Carbon of Theobroma cacao Shell for Pool Water Purification

Jurnal Riset Teknologi Pencegahan Pencemaran Industri, May 2021, Vol. 12, No. 1, p. 32-38, 7 ill, 2 tab, 23 ref

Research has been carried out to improve the quality of the yellow pool water. The water is used as a source of clean water for the academics of the Politeknik Negeri Padang, so it needs to be improved in accordance with the quality standards of clean water and is suitable for daily use. The adsorption process was carried out using activated carbon of Theobroma cacao shells which was carbonated at 400oC for 1 hour and activated with H3PO4. Characterization of functional groups using Frontier Transform Infra Red, and morphology of surface using Scanning Electron Microscopy. The quality of clean water standard analyzed is turbidity, Total Dissolved Solids, color, Total Suspended Solids, and Fe and Mn content. Functional group analysis exhibits that the activated carbon produced has a pattern of absorption with O-H, C-H, and C-O bond types. At the optimum condition of the activation process, a good adsorbent is absorbed in pool water purification at a flow rate of 5 mL/min with a mass of 2 grams. The efficiency value after the adsorption process showed 67% for turbidity, 71% for TDS, 97% for color, 86% for TSS, 38% for Fe content, and 66% for Mn content. The surface morphology of activated carbon showed the presence of pore cavities, and after the adsorption process, the cavities became saturated. This shows that there has been an absorption by activated carbon so that the water becomes clear. Cacao shell activated carbon is very effective in the process of purifying pool water into clean water and fulfilling clean water standards according to Permenkes 416/MENKES/PER/IX/1990, so it is suitable for being used.

(Author)

Keywords: Adsorption, Pool water, Theobroma cacao, Activated carbon

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Siti Ajizah[1], Nur Hidayat[1], and Sri Suhartini[1] ([1]Brawijaya University, Malang, Indonesia)

Modelling Green Production Process in the Natural Dyes Batik Industry Using Cleaner Production Options

Jurnal Riset Teknologi Pencegahan Pencemaran Industri, May 2021, Vol. 12, No. 1, p. 39-54, 3 ill, 7 tab, 29 ref

Sustainable production policy has encouraged batik industry to switch synthetic dyes to natural dyes. However, the production process still brings negative impacts on the environment and humans. To solve this problem, the batik industry needs to develop green production process model using cleaner production options. The purpose of this research is to identify opportunities for implementing cleaner production, to select clean production options, and to present a green production process model of the natural dyes batik industry. The research was conducted in the natural dyes batik industry "Mbah Guru". Mbah Guru Industry is located in Lamongan, East Java. The research used Bayes method to assess and determine cleaner production options based on technical, economical, and environmental aspects. The last decision making of the options was used a feasibility study by using Pay Back Period (PBP). The Bayes method was used to make conclusions quickly. The results showed that Mbah Guru Industry produces waste per year as much as 72 kg of wax waste, 648 kg of ginger and natural dyes material waste, and 42.075 m^3 of wastewater. The wastewater contains BOD of 343.71 mg/L, COD of 1352 mg/L, TSS of 2828.57 mg/L, oil and fat of 5.97 mg/L, and pH of 3.65. The best option is "natural dyes wastewater reusing". it becomes the most priority of the options and has the best feasibility value with a payback period of 0.11. The batik industry will be more profitable if it is able to implement the recommended process improvements so that the negative impacts, both on the environment and humans, can be minimized. The model would give a clear guidance to existing entrepreneurs and aspiring entrepreneurs on how to green the natural dyes batik industry.

(Author)

Keywords: Green production process, Cleaner production options, Natural dyes batik, Bayes method

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PVDF-TiO_2 Hollow Fibre Membrane For Water Desalination

Muthia Elma [1,3]*, Mahmud[2], Nurul Huda[1,3], Zaini L. Assyaifi[1,3], Elsa Nadia Pratiwi[4], Mita Riani Rezki[4], Dewi Puspita Sari[4], Erdina L. A. Rampun[3], Aulia Rahma[3]

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ABSTRACT

The clean water crisis is increasing along with the increasing human population. Seawater is one of the largest water sources that can be utilized on the earth. However, the high salt concentration dissolved in seawater must be treated before it can be used. Desalination is the directly technology for treating seawater with PVDF-TiO2 hollow fibre membrane via pervaporation process. This research aimed to determine the performance of PVDF-TiO_2 hollow fibre membrane against variations of feed temperature in the artificial seawater pervaporation process. Method for fabrication membrane is using dry-wet spinning method. The membrane was fabricated with TiO_2 3 wt%, PVDF 21 wt% and DMAC 75 wt%. The result showed that the highest flux permeate of 8.96 $kg.m^{-2}.h^{-1}$occurred at feed temperature of 60ºC, with salt rejection > 92.86%. The SEM result showed that of the membrane surface morphology, there is a white spot on the membrane surface is TiO_2 because the dope solution is too thick. The PVDF-TiO_2 hollow fibre membrane in this research is can be applied for seawater pervaporation.

1. INTRODUCTION

The clean water crisis is increasing along with the increased human population. Water is a very important material for all organism. Seawater is one of the most abundant sources of its existence on the earth. However, seawater consist of various kinds of solids and gases dissolved in it. Organic salts that come from living organisms are substances dissolved in seawater (Sefentry 2020). One of the water treatment technologies has a fairly high performance by using membrane technology (Husnah 2018).

Membrane technology is becoming more popular and widely used in separation processes, especially in water treatment (Rahman et al. 2020). Membrane technology has inherent characteristics, namely membrane technology has high efficiency, simple operation, stability and flexibility and high selectivity (Elma et al. 2020b). Another advantage,

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there is no need to add chemicals and is more efficient in production costs (Rahman et al. 2020).

The desalination process for seawater treatment can be carried out with pervaporation membranes. Pervaporation is a promising desalination technology to treat clean water with relatively low energy consumption compared to reverse osmosis membranes. Pervaporation can be operated at high temperatures and produces a relatively high flux permeate (Rahma et al. 2019). It also does not require a heavy piping system and pumping, so it does not produce too much fouling like the reverse osmosis membrane and can be operated using a variety of renewable energies such as the sun and geothermal (Halakoo and Feng 2020). Pervaporation operates in a phase of change to separate water molecules and hydrated ions under vacuum using a membrane (Lestari et al. 2020b).

Pervaporation can be carried out using a hollow fibre membrane. The advantages of hollow fibre membranes are easy membrane maintenance and high separation efficiency (Wang et al. 2016a). In addition, hollow fibre membranes have a higher packing density compared to flat sheets and tubular membranes (Koonaphapdeelert and Li 2007). Generally, the fabrication of hollow fibre membrane uses the dry-wet spinning method to produce an asymmetric cross-sectional structure. When it is compared with other methods such as dry spinning, polymer pyrolysis and phase inversion, the dry-wet spinning method is superior because it is more simple and faster (Othman et al. 2017).

Effectiveness of the pervaporation process requires a membrane that has the most optimum performance (Kujawska et al. 2020). Temperature is an important parameter in the pervaporation process. In their research, Wang et al. (2016b) mentioned that heating feed with a certain temperature can cause diffusivity and can reduce the viscosity of the solution. Previously, Fang et al. (2012) has conducted a research on seawater desalination process using hydrophobic alumina hollow fibre membranes and obtained the best operating conditions with an operating pressure of 0.4 bar, flux permeate is 42.9 L/h.m^2 and salt rejection of 99.5%. Therefore, this research was carried out using PVDF-TiO_2 hollow fibre membranes to determine the quality of PVDF-TiO_2 hollow fibre membranes in determining optimum temperature in the pervaporation process.

2. METHOD

Material used in this research consists of Polyvinylidene fluoride (PVDF, Kynar 760 powder series), TiO_2 (commercial), dimethylacetamide (DMAc, QReC), ethanol, aquadest, epoxy resin (E30CL Loctite Corporation, USA), liquid nitrogen and seawater artificial (3.5% NaCl).

The manufacture of PVDF-TiO_2 hollow fibre membrane in this research is divided into 3 stages, based on research conducted by Othman et al. (2017), namely: (1) preparation of the dope solution, by drying 21 wt% PVDF and 3 wt% commercial TiO_2 in an oven at 50°C for 24 h to remove moisture, (2) making a dope solution by mixing PVDF and commercial TiO2 with DMAC as a solvent and stirring until the dope solution is homogeneous and (3) membrane spinning using the dry-wet spinning method. The membranes were characterized using Scanning Electron Microscope (SEM) analysis.

The performance of PVDF-TiO_2 hollow fibre membrane pervaporation process is determined by passing the various types of feeds through the PVDF-TiO_2 hollow fibre membrane at various feed temperatures, at 25°C, 40°C and 60°C. Feeds used in this research were aquadest and 3.5% NaCl. The feed was mixed using magnetic stirrer for homogenous purpose. The set up of pervaporation process was shown in Figure 1. The membrane was put into a beaker glass which filled with the feed. During pervaporation, the feed selectively transported across the membrane. The feed phase was changed from liquid to gaseous by using a vacuum. A clean permeate cooled by liquid nitrogen and collected in a cold trap. The salt rejection was determined based on Equation 1 and water flux was determined based on Equation 2.

$$\%\,Salt\ Rejection = \frac{C_i - C_o}{C_i} \quad \dots (1)$$

Explanation:

R= Rejection value (%), C_i = The feed concentration of salt (% wt), C_o= The feed concentration of permeate (% wt)

$$F = \frac{W}{A \, x \, t} \qquad .... (2)$$

Explanation:

F= Water flux (kg.m^{-2}.h^{-1}), W= the mass of permeate (kg), A= The surface active area (m^2), Δt = The time measurement (h)

Desalination pervaporation set up can be seen in Figure 1:

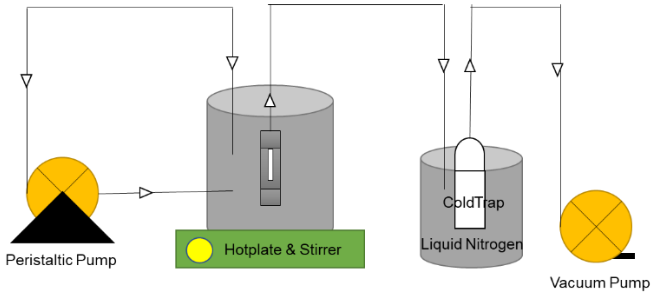

Figure 1. Desalination pervaporation set up

3. RESULT AND DISCUSSION

3.1. The analysis of morphological structure of PVDF-TiO₂ hollow fibre membrane

The morphological structure of the PVDF-TiO_2 hollow fibre membrane was analyzed by SEM analysis. The PVDF-TiO_2 hollow fibre membrane pore structure on the membrane surface was analyzed by using SEM analysis. SEM analysis was carried out to determine the surface morphological structure of the membrane.

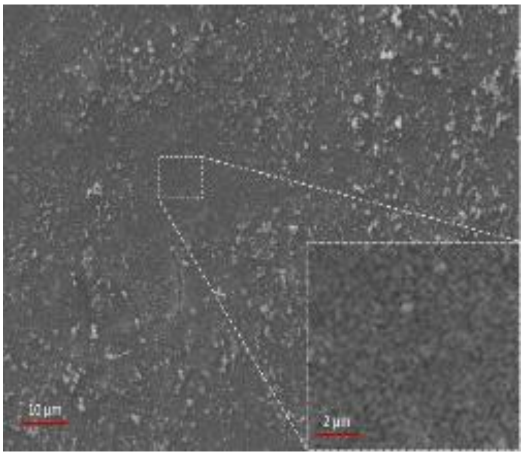

Figure 2. Surface of SEM Image of PVDF-TiO_2 Hollow Fibre Membrane

Figure 2 depicted the surface of PVDF-TiO_2 hollow fibre membrane. On the surface of the membrane, there were visible white dots. These white dots were TiO_2. The TiO_2 seen on the membrane surface was caused by the dope solution being too thick. The addition of TiO_2 to the polymer solution can increase the viscosity thus affecting the phase inversion and aggregation of TiO_2 particles in the dope solution. TiO_2 also caused the membrane surface to be rugged, compared to membranes without using TiO_2 (Sakarkar et al. 2020). Bore fluid functions to form the diameter of the membrane. Bore fluid velocity depends on the dope solution flow rate. While the air gap is the distance between the spinnerets and the water surface in the coagulation tank. The bigger the air gap, then the membrane thickness will be smaller (Humairo 2015).

3.2. The performance of PVDF-TiO₂ hollow fibre membranes under variations in feed temperature

The performance of PVDF-TiO_2 hollow fibre membranes which have been fabricated with TiO_2 3 wt%, PVDF 21 wt% and DMAC 75 wt% for seawater artificial desalination was then tested using a pervaporation process with variations in feed temperature (NaCl 3.5%). Water flux and salt rejection pf the membrane can be seen in Figure 4, as follow:

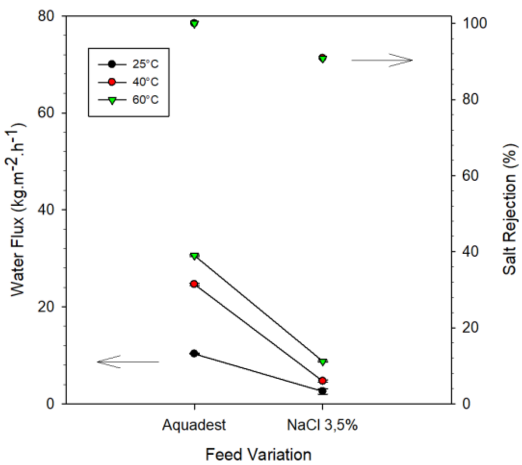

Figure 3. Effect of Variations in Feed Temperature (~25°C, 40°C and 60°C) Against Water Flux and Salt Rejection on PVDF-TiO_2 Hollow Fiber Membrane

Figure 3 illustrates the relationship between the value of water flux and salt rejection to temperature variations in feed, during 20 minutes pervaporation time The highest NaCl water flux value was 8.96 $kg.m^{-2}.h^{-1}$ at 60°C. Figure 3 showed that when feed temperature increased, the rejection of salt in the permeate decreased. At room temperature (25°C), the salt rejection value was 90.87%. When the feed temperature increased to 40°C, there was deflation in the rejection value of salt. When the feed temperature increased to 60°C, there was a slight drop in salt rejection by 0.01%.

Due to the variation in salt concentration in each bait, this research was using NaCl (0.3% to 7.5% NaCl) variation as already conducted by Elma et al. (2015) as feed. The high concentration of salt in water caused polarization in concentration, which had a negative impact on reducing membrane performance (Elma et al. 2012). The decline of salt rejection when feed temperature increased was caused by the random thermal movement of the polymer chains, which resulted in free volume, causing permeate molecules to diffuse through the membrane (Jyoti Ghoshna 2015). Based on the results of this research, it can be concluded that the pervaporation process using PVDF-TiO_2 hollow fibre membrane has a good performance because it produced a higher permeate flux of 8.96 $gm^{-2}.h^{-1}$ and the salt removal produced in this study was 90.86%.

Table 1 showed the performance of various types of membranes for seawater artificial desalination (NaCl 3.5%). This study showed a permeate flux value of 8.96 $kg.m^{-2}.hr^{-1}$ and salt rejection of 90.86% at 60°C. **Table 1** showed a higher permeate flux value compared to the research conducted by Elma et al. (2020a). Whereas, the research using a 0.1% silica pectin membrane with a calcination temperature of 300°C which was applied to 0.3% NaCl produced a water flux of 5.45 $kg/m^{-2}.h^{-1}$ with a percentage of salt rejection of 91.94%. In addition, in research conducted by Lestari et al. (2020a) using 3.5% NaCl produced a water flux of 0.2290 $kg/m^{-2}.h^{-1}$ with a salt rejection percentage of 99%. Unlike the research produced by Elma et al. (2013) using 0.3% NaCl feed which resulted in a water flux of 9.5 $kg/m^{-2}.h^{-1}$ with a salt rejection percentage of 99.6%.

This may be due to the type of membrane and the temperature used for the feed. Hollow fibre membranes are good for the desalination process of seawater using the pervaporation process because the hollow fibre membrane has a good density due to its very small diameter and thin wall thickness. (Fang et al. 2012).

Table 1. Performance of Various Types of Membranes for Seawater Desalination

Membrane Variation	Feed Temperature (°C)	Feed Variation	Water Flux ($kg.m^{-2}.h^{-1}$)	Salt Rejection (%)	Reference
PVDF-TiO_2 Hollow Fibre Membrane	60°C	NaCl 3.5%	8.96	90.86	This work
Silica Membrane	22°C	NaCl 0.3%	9.5	99.6	(Elma et al. 2013)
Silica Pectin Membrane 0.1% With Calcination 300°C and 400°C	25°C	NaCl 0.3%	5.45-13.70	91.94-92.08	(Elma et al. 2020a)
Organo Silica Membrane	50°C	NaCl 3.5%	0.2290	99	(Lestari et al. 2020a)

4. CONCLUSION

PVDF-TiO_2 hollow fibre membranes have been successfully fabricated and characterized by SEM analysis. Membrane characterization through SEM analysis showed that the outer diameter of the membrane was 1800 μm and the inner diameter was 1100 μm so that the membrane had a thickness of 700 μm. The membrane in this research can be categorized as hollow fibre because the outer diameter of the membrane is >500 μm. The performance of the PVDF-TiO_2 hollow fibre membrane had a good effect on the increase in feed temperature from 25°C to 60°C as measured by the water flux value and salt rejection. The optimum water flux and salt rejection resulted at a temperature of 60°C, namely 8.96 $kg.m^{-2}.h^{-1}$ and >90.6%. Thus, it can be said that the PVDF-TiO_2 hollow fibre membrane is good for the seawater desalination process.

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REFERENCE

Elma, M., M. Mahmud, A. Akhbar, L. Suryani, F. R. Mustalifah, A. Rahma, D. Rahmah, and N. Baity. 2020a. "Aplikasi Membran Silika-Pektin Untuk Desalinasi Air Payau" *Jukung (Jurnal Teknik Lingkungan)* 6 (1)

Elma, M., E. L. Rampun, A. Rahma, Z. L. Assyaifi, A. Sumardi, A. E. Lestari, G. S. Saputro, M. R. Bilad, and A. Darmawan. 2020b. "Carbon templated strategies of mesoporous silica applied for water desalination: A review" *Journal of Water Process Engineering* 38:101520

Elma, M., D. K. Wang, C. Yacou, and J. C. D. da Costa. 2015. "Interlayer-free P123 carbonised template silica membranes for desalination with reduced salt concentration polarisation" *Journal of Membrane Science* 475:376-383

Elma, M., C. Yacou, J. C. Diniz da Costa, and D. K. Wang. 2013. "Performance and long term stability of mesoporous silica membranes for desalination" *Membranes* 3 (3):136-150

Elma, M., C. Yacou, D. K. Wang, S. Smart, and J. C. Diniz da Costa. 2012. "Microporous silica based membranes for desalination" *Water* 4 (3):629-649

Fang, H., J. Gao, H. Wang, and C. Chen. 2012. "Hydrophobic porous alumina hollow fiber for water desalination via membrane distillation process" *Journal of membrane science* 403:41-46

Halakoo, E., and X. Feng. 2020. "Layer-by-layer assembly of polyethyleneimine/graphene oxide membranes for desalination of high-salinity water via pervaporation" *Separation and Purification Technology* 234:116077

Humairo, F. Y. 2015. Preparasi Dan Karakterisasi Membran Serat Berongga Pvdf/Peg400-Tio2 Untuk Pemisahan Limbah Sintetik Air-Minyak, Institut Teknologi Sepuluh Nopember.

Husnah, H. 2018. "Aplikasi Membran Keramik Buatan Dengan Pretreatment Pada Penjernihan Air Sungai Musi" *Jurnal Redoks* 3 (1):1-8

Jyoti Ghoshna, A. K., J. Anandkumar. 2015. "Review on Pervaporation: Theory, Membrane Performance, and Aplication to Intensification of Esterification Reaction" *Journal of Engieering*:1-24.http://dx.doi.org/10.1155/2015/927068.

Koonaphapdeelert, S., and K. Li. 2007. "Preparation and characterization of hydrophobic ceramic hollow fibre membrane" *Journal of Membrane Science* 291 (1-2):70-76

Kujawska, A., K. Knozowska, J. Kujawa, G. Li, and W. Kujawski. 2020. "Fabrication of PDMS based membranes with improved separation efficiency in hydrophobic pervaporation" *Separation and Purification Technology* 234:116092

Lestari, A. E., M. Elma, S. Rabiah, E. L. A. Rampun, A. Rahma, and A. E. Pratiwi. 2020a. Performance of Mesoporous Organo Silica Membrane for Desalination. Paper read at Materials Science Forum.

Lestari, R. A., M. Elma, A. Rahma, D. Suparsih, S. Anadhliyah, N. L. Sari, D. A. Pratomo, A. Sumardi, A. Lestari, and Z. L. Assyaifi. 2020b. Organo Silica Membranes for Wetland Saline Water Desalination: Effect of membranes calcination temperatures. Paper read at E3S Web of Conferences.

Othman, M. H. D., S. K. Hubadillah, M. R. Adam, A. F. Ismail, M. A. Rahman, and J. Jaafar. 2017. Silica-based hollow fiber membrane for water treatment. In *Current Trends and Future Developments on (Bio-) Membranes*: Elsevier, 157-180.

Rahma, A., M. Elma, M. Mahmud, I. Chairul, E. Amalia, Pratiwi, and L. Erdina, A, Rampun. 2019. "Penyisihan Bahan Organik Alami pada Desalinasi Air Rawa Asin Menggunakan Proses Koagulasi-Pervaporasi" *Jurnal Kimia Sains dan Aplikasi*

Rahman, S. K., E. L. A. Rampun, A. Rahma, and M. Elma. 2020. "Deconvolution of carbon silica templated thin film using ES40 and P123 via rapid thermal processing method" *Materials Today: Proceedings*

Sakarkar, S., S. Muthukumaran, and V. Jegatheesan. 2020. "Polyvinylidene Fluoride and Titanium Dioxide Ultrafiltration Photocatalytic Membrane: Fabrication, Morphology, and Its Application in Textile Wastewater Treatment" *Journal of Environmental Engineering* 146 (7):04020053

Sefentry, A. 2020. "Pemanfaatan Teknologi Membran Reverse Osmosis (RO) Pada Proses Pengolahan Air Laut menjadi Air Bersih" *Jurnal Redoks* 5 (1):58-64

Wang, D. K., M. Elma, J. Motuzas, W.-C. Hou, D. R. Schmeda-Lopez, T. Zhang, and X. Zhang. 2016a. "Physicochemical and photocatalytic properties of carbonaceous char and titania composite hollow fibers for wastewater treatment" *Carbon* 109:182-191

Wang, Q., N. Li, B. Bolto, M. Hoang, and Z. Xie. 2016b. "Desalination by pervaporation: A review" *Desalination* 387:46-60. https://doi.org/10.1016/j.desal.2016.02.036.

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Online Monitoring of Effluent Quality for Assessing the Effect of Wastewater Treatment Plant

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ABSTRACT

In general, industry uses water in its production process so that it will produce wastewater that contains many contaminants, it will affects the surrounding environment by contaminating the water bodies. Information on monitoring the quality of industrial wastewater is very important to be perceive by examining changes in water quality. Industrial wastewater monitoring is a device system that collects real time data. Online monitoring technology is one part that plays an important role in supporting activities to control water environmental pollution. Real-time monitoring of wastewater quality remains an unresolved problem to the wastewater treatment industry. One of the problem in most industries in Indonesia is the nonoptimal condition of operational and performance of wastewater treatment plants (WWTP), and need improvement. The application of industrial technology concept 4.0 and automation systems in the industry is expected to improve the WWTP supervision process which has advantages such as reducing down time, reducing consumption of raw materials, reducing the energy used, etc. The cost savings that can be made by implementing it may reach up to 20-40% (estimation) with several assumptions applied. This review is to provide information about the assessment of WWTP performance through online monitoring of wastewater effluent quality.

1. INTRODUCTION

River is one of the environmental components that has important functions for human life, including to support economic development. In general, industries use water for the production process, which consequently will produce wastewater. Currently, the quality has deteriorated due to increasingly uncontrolled water pollution. One of the causes is the existence of industrial activities that produce a lot of wastewater. Wastewater that is disposed of without being treated first will result in an increase environmental pollution and decreasing river water quality. Pollution that occurs in the some rivers in Indonesia has begun to raise concern for Indonesian Goverment. To avoid more dangerous impact of pollution, the government has determined that all business units has to treat their produced waste to qualify with the quality standards before being discharged into the surrounding water environment. Industrial wastes are usually containing organic and inorganic materials at various levels of concentration, while the wastewater is generally strong and may contain toxic pollutants.

The application of wastewater treatment technology abroad are already at more advanced stage including fenton oxidation, photocatalys, ozonation, etc., while in Indonesia most of the industries are still on the optimalization of biological treatment. Online monitoring is one of the tools to quickly determine the performance of the wastewater treatment plant (WWTP) and also to

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determine whether or not the technology used is compatible with standard effluent.

The purpose and objective of this literature review is to provide information about the assessment of WWTP performance through online monitoring of wastewater effluent quality before discharge into the receiving river. In addition, this paper may provide information for the industry and may be used as a tool in monitoring WWTP performance.

2. ISSUES AT WASTEWATER TREATMENT PLANT

Industrial wastewater treatment systems vary greatly, the process can be in the form of primary, secondary or tertiary treatment. Generally used technologies are: coagulation and/or flocculation, membranes (microfiltration, nanofiltration and reverse osmosis), adsorbents (silica, clay, granular activated carbon, natural and bio-synthetic adsorbents), oxidation (Fenton-reagent, photocatalyis, oxidation process advanced, ozonation) and biological treatments (aerobic and anaerobic). The application of wastewater treatment technology depends on the characteristic of wastewater produced. The characteristics of wastewater are specific, so that each industrial wastewater must be characterized in advance and the same exact wastewater treatment system does not necessarily apply to every type of industry or type of wastewater.

The WWTP performance cannot be monitored continuously, this is a problem in the industry. This is due to the high operational costs related to labor and testing. It is necessary to introduce an automation system in the field that can reduce downtime, reduce consumption of raw materials, reduce the energy used, increase productivity, improve product quality and utilize resources and processes efficiently, with the aim of reducing overall operational costs. Currently, the control process is still done manually, so by introducing the application of the automation system it is also expected to reduce human error that occurs so as to increase system efficiency.

To quickly detect industrial waste contamination, a continuous and efficient monitoring system is needed. One of the efforts to implement a reliable industrial wastewater quality monitoring technology can be monitored in real-time (instantaneously) and online (connected to the internet). This online wastewater quality monitoring technology could be installed at the wastewater effluent outlet of the industrial Wastewater Treatment Plant (WWTP) that leading to the river body. The wastewater quality data may be monitored continuously, thus, may immediately determine whether the WWTP is effective or not. While real-time or online automation and control technologies cannot eliminate all the variabilities in WWTP operations, they can eliminate significant ones. Applying an automation system to sewage treatment might produce wastewater quality that cannot be achieved manually.

3. STUDY OF AUTOMATION AND ONLINE MONITORING APPLICATION ON WWTP PROCESSES

WWTP automation system and realtime monitoring will follow the development of industry 4.0 by using a microcontroller-based device that is connected to the Programmable Logic Controller (PLC) and then integrated through the internet with a machine-human interface such as a smartphone and PC media via an internet network from Wi-Fi or hotspot points cellular access that can be controlled automatically or manually. Microcontrollers are small computers on one integrated circuit, which are used in automatically controlled products and devices, such as car engine control systems, implantable medical devices, remote control, office machines, equipment, electrical equipment, toys and other embedded systems. The microcontroller-based device will decode the incoming analog data into a signal that will be sent to the PLC. The PLC itself can be programmed to have a certain optimal range of values in a parameter, where if the incoming signal is outside the optimal range programmed, the PLC will carry out an operation on WWTP automatically such as opening or closing a valve or motor, depending on programs that have been included on the

PLC. Human-Machine Interface itself will translate the program into graphical visualization that can be monitored by operators or online managers from anywhere, and does not have to be in the factory (Figure 1).

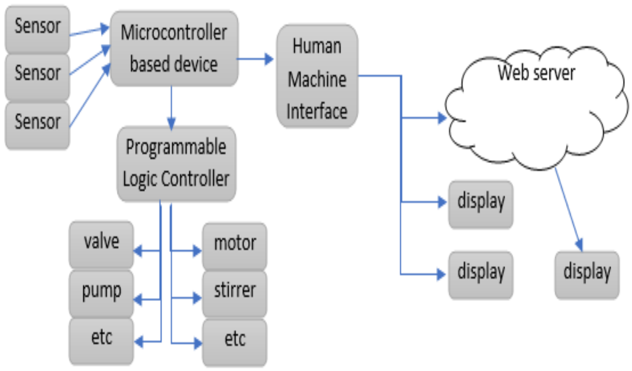

Figure 1. Typical Diagram of Online Monitoring Automation system

Sensors for important parameters are already available on the market and already being studied from previous study, which was showed by Table 1. These sensors are capable to measure the parameters, send analog data, and adequate compatibility with PLC. pH sensor is the most common sensor on the studies and it was also easily available on the market with a range of price. Temperature parameter is also usually measured with other sensor such as pH, DO or UV sensor (Table 1) thus make temperature parameter easily available. pH sensor was the most common application because it is may be applied on primary or secondary treatment. The importance of pH sensor on both primary and secondary treatment will be discussed on the following section.

The suitable application of technology industry 4.0 on wastewater treatment plant depends on the type of wastewater plant, the amount of motors, type of sensor, etc (Table 2, 3 and 4). Installation of instrumentation and automation technology in WWTPs is not yet a common thing in the industry in Indonesia. There needs to be studies to describe the level of success, advantages, disadvantages and other things that need to be considered in the application of this automation technology. In addition, we also need to observe at which operating units and process units any automation system may be applied in addition to studies application and experiences that we may take lessons to improve the success rate of applying this industrial automation 4.0 technology to WWTPs in Indonesia.

The implementation of sensor data can be monitored in real time through the LCD screen on the panel, in addition for being able to be viewed graphically via a smartphone or PC anytime and anywhere through the internet network. The system's connection to the internet allows supervision by operators/managers not only from onsite but also from off site which can be separate from the location. One important supporting instrument in the application of industrial technology 4.0 in WWTP is the availability of sensors. A sensor is a device used to record changes in the system.

PLC will act as controller for all components. Instruments at WWTP such as valves, pumps, stirrer, motors, etc. will be connected to the PLC as input output devices. The signal sent to the PLC by the WWTP instrument can act as a trigger for subsequent actions. The PLC can then send the actuation signal to various actuators to perform the specified task.

3.1. Automation and Online Monitoring Application on Primary Treatment

The potential application of the online monitoring and control system to the WWTP primary process can be seen on Table 2. The application of online monitoring in WWTP primary process is usually the monitoring of pH (Andhare & Palkar, 2014; Animireddy & Rao, 2016; Harivardhagini & Raghuram, 2015; Hiray et al., 2017) and temperature (Safonyk, Bomba, & Tarhonii, 2019) which will affect the effectivity of the primary treatment process; turbidity (Andhare & Palkar, 2014; Bersinger, Pigot, Bareille, & Le Hecho, 2013; Haimi et al., 2010; Qin, Gao, & Chen, 2012), TSS (Haimi et al., 2010; Qin et al., 2012), COD (Qin et al., 2012), and conductivity (Haimi et al., 2010) as the wastewater quality; also water flow (Farah, 2017; Safonyk et al., 2019) and water level (Farah, 2017) as the wastewater quantity. The Implementation of automation systems to the clarification or sedimentation processes is usually in monitoring or control of pH as well as the addition of coagulant chemicals.

Table 1. Application of each sensor parameters on WWTP

Sensor Parameters	Standard	Brand used on literature	Spesification and performance brand used on literature	Parameter application on reviewed literatures
pH	Precision ±0.02 pH unit Accuracy ±0.05 pH unit. (SNI 6989.11:2019), (Standard Method for the Examination of Water and Waste Water 23rd 2017 Washington DC: APHA, AWWA, and WEF. Section 4500-H^+, pH Value)	pH sensor E201-C Leici Instrument Incorporated (Yu, Liu, Sui, & Wei, 2015)	pH range 0-14 Temperature range 0-60°C Zero point pH value 7 + 0.25 Repeatability <0.017 (Aliexpress.com, 2020)	(Andhare & Palkar, 2014; Animireddy & Rao, 2016; Bagyaveereswaran, Vijayan, Manimozhi, & Anitha, 2016; Dries, 2016; Harivardhagini & Raghuram, 2015; Hiray, Chinchkar, Butte, & Pyla, 2017; Mundhe & Somani, 2017; Patil, Patil, Patil, & Patil, 2015; Robles et al., 2015; Ruano, Ribes, Seco, & Ferrer, 2012; Souza, Belchior, Pontes, & Junior, 2009; Won & Ra, 2010; Yu et al., 2015)
		Hach pHD sc (Ruano et al., 2012)	pH range 0-14 Accuracy ±0.002 pH Pressure max 10.7 bar Repeatability ±0.05pH Sensitivity ±0.01 pH Transmission distance 100m Operating temperature: -5-105°C (analog sensor), and -5-70°C (digital sensor) Temperature accuracy: ±0.5°C (uk.Hach.com, 2020)	
Temperature	Bias 0.1°C (Standard Method for the Examination of Water and Waste Water 23rd 2017 Washington DC: APHA 2550)	PT100-sensor (Patil et al., 2015)	Temperature precision: ±0.5°C Measuring range: -50-230°C Calibration factor (Patil et al., 2015)	(Patil et al., 2015; Robles et al., 2015; Ruano et al., 2012; Souza et al., 2009)
TSS ; TDS	TSS precision %RSD 6.13%, accuracy %R 80-115%, %bias=(-20)-15% (SNI 6989.3:2019)	S::CAN spectro::lyser (Byrne et al., 2011)	TSS: 0-3000 ppm (for paper mill and municipal) Accuracy standard solution (>1ppm): COD ±2% + 10/optical pathlength in mm (s::can Messtechnik GmbH, 2020) Measuring range UV-Vis 190-720 nm Operating temperature 0-45°C Temperature sensor: -10-50°C Resolution temperature sensor: 0.1°C COD: 0-5000 ppm (for paper mill)	(Bagyaveereswaran et al., 2016; Haimi, Mulas, & Vahala, 2010; Mundhe & Somani, 2017; Robles et al., 2015)
COD	COD %RSD 3.79%, akurasi %R 90-108%, bias (-10)-8% (SNI 6983.2 :2019)			(Qingyi, Wei, & Sixiang, 2013)
DO	DO accuracy 0.1 mg DO/L, precision 0.05 mg DO/L (Standard Method for the Examination of Water and Waste Water 23rd 2017 Washington DC: APHA 4500 O)	Hach LDO (Ruano et al., 2012)	Accuracy ±0.05 (DO<5ppm) Accuracy ±0.1 ppm (DO>5ppm) Measurement range: 0-20.00 mg/L Operating Temperature: 0-50°C Temperature accuracy: ±0.2°C Response time 40-60 s (at 20°C) Pressure max 3.5 bar Repeatability ±0.1 ppm Resolution 0.01 ppm (Hach, 2020)	(Animireddy & Rao, 2016; Dries, 2016; Haimi et al., 2010; Ruano et al., 2012; Wade, Sanchez, & Katebi, 2005; Won & Ra, 2010; Zhu & Qiu, 2017)

Table 2. Potential application of automated and monitoring control on physical and chemical treatment

Process	Scale	Monitoring and Automation	Sensor location and fuction	Literature
Skimmer tank	Laboratory scale	Control: conveyor motor, valve	Conveyor motor might be adjusted automatically	(Nandkumar et al., 2017)
Netralization tank	Simulation	Sensor: pH, Control: chemical dosing	pH was monitored online	(Animireddy & Rao, 2016)
Netralization tank	Pilot plant	Sensor: pH Control: chemical dosing	pH sensor was located on the Continuous Stirred Tank Reactor (CSTR)	(Harivardhagini & Raghuram, 2015)
Clarifier tank	Simulation	Sensor: pH, turbidity Control: chemical dosing pump, stirrer motor, valve	Dosing was conducted automatically based on water quality, with pH and turbidity monitored online. RPM of the blade was controlled online.	(Andhare & Palkar, 2014)
Clarifier tank	Simulation	Sensor: pH, Control: chemical dosing, pump motor	Coagulant feed rates and dosage was automatic based on flow variation and water quality	(Animireddy & Rao, 2016)
Clarifier tank	Laboratory scale	Control: chemical dosing pump, stirrer motor, valve	Stirrer motor was controlled online	(Nandkumar et al., 2017)
Sedimentation tank	Field application	Sensor: pH, Control: flow	pH water was monitored online	(Hiray et al., 2017)
Sedimentation tank	Field application	Sensor: water level, water flow	Level sensors were located on the inlet of sedimentation tank	(Farah, 2017)
Electrocoagulation system	Simulation	Sensor: water flow, temperature, pressure	Electrocoagulation treatment with flow rate and temperature monitored	(Safonyk et al., 2019)
Electrocoagulation and electroflotation	Pilot plant	Sensor: COD, TSS, oil and grease	COD and TSS were monitored through UV/Vis Spectrometer	(Qin et al., 2012)
Primary clarifier	Field application	Sensors: TSS, turbidity, conductivity,	Conductivity, turbidity and TSS were used for the estimation of wastewater quality	(Haimi et al., 2010)

The application of pH sensors with a combination of chemical dose control could make the sedimentation process more effective by keeping wastewater within the effective pH of the coagulant chemicals used (example: aluminium sulphate 5.8-6.5, polyaluminium chloride 5.0-8.0, alumunium chlorohydrate 6.5-7.5, ferric sulfate and ferric chloride 4.0-12.0 (Gebbie, 2006; Reynolds & Richards, 1996)). Coagulant dosage may be controlled by adjusting dosing pump or valve from control room or adjusted automatically based in wastewater flow and quality (Animireddy & Rao, 2016). The application of pH sensors on netralization tank for pH monitoring and control of the tank is usually involving acid tank and alkaline tank which function were to maintain the neutral condition for wastewater (Aparna, 2014; Harivardhagini & Raghuram, 2015). Automation system also may involved the control of motors such as conveyor motor or stirrer motor (Nandkumar, Sanjay, Yusuf, & Jagtap, 2017).

Primary wastewater treatment is generally in the form of coagulation-flocculation process which accompanied by sedimentation process. The coagulation-flocculation process is greatly influenced by the effectiveness of coagulant and flocculant chemicals which generally have an effective pH and temperature range. Thus the application of pH and temperature online monitoring for the coagulation-flocculation process may help WWTP operators to ensure the process is conducted at its optimal condition hence ensure the effectiveness of the process. In the end, it can ensure the conformity of wastewater with government quality standards.

Online monitoring may quickly estimate the WWTP performance, which so far currently has not been possible or difficult to measure because of time required for laboratory testing of the wastewater parameter qualities for every stage.

3.2. *Automation and Online Monitoring Application on Secondary and Tertiary Treatment*

Secondary wastewater treatment has quite of number of parameters that directly or undirectly have an important effect on the success of the ongoing treatment, such as pH, DO, COD/BOD, temperature, nutrient content, TSS, VFA, etc. Apart from the primary treatment, utilization of pH sensors is also very important in online monitoring applications in biological processes or secondary treatment at WWTP (Dries, 2016; Robles et al., 2015; Ruano et al., 2012; Won & Ra, 2010; Yu et al., 2015). The application of an automatic monitoring and control system can be applied to the aerobic system with DO, temperature, pH, conductivity, TSS , nitrogen and nutrient or COD/BOD sensors in wastewater. Online control strategy for aerobic process may involving DO control with oxygen uptake rate and time monitoring. Air flow and DO sensors are the most common technology to implement in the aeration system (Animireddy & Rao, 2016; Dries, 2016; Haimi et al., 2010; Ruano et al., 2012). DO was monitored with online DO meter, which may integrated with blower control and may be maintained automatically within a range which regulated with on/off controller blowers or adjustable blower speed. The oxygen uptake rate (OUR) may calculated online to create DO on/off strategy. The conductivity sensor is utilized to estimate the nitrogen load that will enter the aerobic reactor (Haimi et al., 2010). Conductivity value also may be related and utilized to estimate total suspended solids (TSS) and total dissolved solids (TDS) (Bagyaveereswaran et al., 2016; Bersinger et al., 2013; Irwan & Afdal, 2016). Online control strategy for anoxic process may involving DO control, with oxygen reduction potential (ORP), volume, and moving slope change (MSC) monitoring. Furthermore, the time required for anoxic process phase may determined from ORP control strategy. To obtain a full parameter monitoring for aerobic and anoxic processes, the online monitoring may be accompanied with laboratory testing and calculations, for calibration and also manual measurements such as COD, BOD, MLSS, sludge loading rate, nitrogen loading rate etc.

The application of an automatic monitoring and control system can be applied to the anaerobic system with temperature, pH, TSS and ORP sensors in wastewater. Organic loading rate (OLR) may be calculated from COD which may be correlated with online TSS and TDS monitoring (Robles et al., 2015). Keeping the pH in conditions suitable for the anaerobic process will make this specific process more effective. In the anaerobic reactor, biogas-pH automation monitoring and control may provide a self regultion pH buffer and a more stable pH environment, through two reactors which are acidification reactor with enriched VFA and methanogenesis reactor with enriched ammonium-bicarbonate buffer solution. VFA may be monitored via Middle infrared (MIR) sensor (Bongards, Gaida, Trauer, & Wolf, 2014) while ammonium may be monitored via ammonium analyzer (Ruano et al., 2012). The potential application of the monitoring and control system to the WWTP secondary and tertiary processes may be seen on Table 3 and Table 4 respectively. Some of the specification and performance of the sensors could be seen on Table 1.

Biological wastewater treatment has quite a lot of parameters that must be monitored, this makes the treatment quite vulnerable to problems and non-optimality. The application of online monitoring, besides being able to improve and guarantee the optimization of this biological processing, it can also prevent the biological treatment from problems that may arise and cause it to be inefficient and effective. In the end it may ensure the conformity of the wastewater effluent with the government's quality standards.

Table 3. Potential application of automated and monitoring control on biological treatment

Process	Scale	Monitoring and Automation	Sensor type, location, and fuction	Literature
Biological reactor	Simulation	Sensors: DO, Control: pumps, blower control	Simulation study using SCADA DO was measured online and number/speed of blowers were adjucted automaticly according to DO	(Animireddy & Rao, 2016)
Activated sludge basin	Field application	Sensors: DO, TSS, NH_4-N, conductivity, pH Control: air flow and air pressure, chemical feed, influent pump, excess and return sludge pump, flow measurement	Optical DO sensors Nutrient sensors were located at activated sludge basin and effluent Conductivity sensors were used for nitrogen load prediction Most sensors would work/function properly.	(Haimi et al., 2010)
Anoxic-aeration batch reactor	Field application	Sensor: pH Control: air flow, mixer, flow measurement	Sensors were placed in the aerator tank. pH profile was monitored online. Real time control is also successful and feasible.	(Won & Ra, 2010)
Anoxic-aeration batch reactor	Laboratory scale	Sensor: DO, pH, nitrate UV Control: air flow	Sensors were placed in the sequencing batch reactor. Nitrate and DO were monitored online. Online monitoring was succesfully studied the dynamic process of anoxic-aeration batch reactor	(Dries, 2016)
Anoxic-aerobic batch reactor	Pilot plant	Sensor: pH, DO, temperature, nitrate, ammonium, oxygen reduction potential (ORP) Control: blower speed (air flow), waterflow, nitrification controller, denitrification controller	pH sensor was Hach pHD-S sc DO sensor was Hach LDO Sensors were located in the aerobic and anoxic reactors Nitrogen and DO profiles were monitored online. pH and ORP sensors successfully control the biological nitrogen removal on the pilot plant	(Ruano et al., 2012)
Anaerobic membrane bioreactor	Laboratory scale	Sensor: pH, ORP Control: water flow, gas flow	pH sensor was E201-C Leici Instrument Incorporated Sensors were located in the methanogenesis reactor. pH and ORP profiles were monitored online. pH control strategy were used to prevent feed overload and underload of methanogenesis reactor.	(Yu et al., 2015)
Anaerobic membran bioreactor	Pilot plant	Sensor: pH, temperature, TSS, ORP Control: waster flow, gas flow, sludge wasting, pressure, temperature	Sensors were low cost sensors type	(Robles et al., 2015)
Biogas plants of anaerobic digestion	Laboratory and field application	Sensor: UV/vis and middle infrared (MIR) spectroscopic for volatile fatty acids (VFA)	UV/vis was used to monitor organic acid concentration, while MIR was used to monitor VFA Controlled laboratory standard errors of cross-validation 0.372 g/L (VFA: R^2 = 0.971)	(Bongards et al., 2014)

Table 4. Potential application of automated and monitoring control on tertiary treatment

Process	Scale	Monitoring and Automation	Performance and sensor location	Literature
Desinfection	Field application	Sensor: UV absorbance for residual chlorine	UV sensor was S::CAN spectro::lyser Sensor was located at the end of the treatment process, after the filtration Chlorine residue profile was monitored online and may detect the chlorination dosing performance	(Byrne et al., 2011)
Filter	Field application	Sensor: water level, water flow, TSS	Level sensors were located on the filter tank to check the level in the filter	(Farah, 2017)
Rapid sand filter	Simulation	Backwash	Backwashing was controlled by the SCADA system	(Andhare & Palkar, 2014)

Table 5. Advantage of Automation and Online Monitoring

Expected Advantages	Feature	Advantages detail	Literatures
Labour saving	Automatic operation may lead to labour cost efficiency	40% saving (estimation)	(Animireddy & Rao, 2016)
Efficiency energy	Cost estimation or simulation showed a more energy efficient process	20% saving (estimation)	(Animireddy & Rao, 2016)
		21.4% saving (estimation)	(Safonyk et al., 2019)
Efficiency chemicals	Closer control of chemical dosing sysitem may increase the efficiency of chemical utilization	30% saving (estimation)	(Animireddy & Rao, 2016)
Data record and log	Chronological record for any changes at the system	Any stored data may be recalled at any time	(Andhare & Palkar, 2014)
	Easier to find the root of a failure		(Bagyaveereswaran et al., 2016)
	Able to estimate and predict the quality and quantity of wastewater using a simulator or software		(Haimi et al., 2010)
Real time and online alarm	Automatic notification if any problem occurs	creates a quick response in case of anomalies	(Andhare & Palkar, 2014)
Real time and online control	Command set as a programming tools to control WWTP process	Enable automation features such as automatic pumps, valves etc	(Andhare & Palkar, 2014)
Real time and online monitoring	Capable to visually displaying real time data, trends and other sophisticated monitoring tools	Provide operator and manager a more visualized information	(Andhare & Palkar, 2014)
	Enable monitoring and control from remote location		(Dinis & Popa, 2014)
More smooth output (not oscillated)	Smooth output may be obtained instead of oscillated result	Through the application of Sliding Mode Controller	(Dinis & Popa, 2014; Harivardhagini & Raghuram, 2015; Robles et al., 2015)
Time efficiency	Reduce the time to check the parameters		(Patil et al., 2015)
Potential integration	Programmable controller has potential to integrate wastewater treatment plant stations		(Korodi, Huple, Silea, & Stefan, 2017)
Easier operation for operators	Provides more monitoring information and remote control for operators		(Dinis & Popa, 2014)
	May provides more specific information		(Davies, 2017)
More effective process	Process monitoring and controlling strategy allows a more effective operation process		(Yu et al., 2015)
		25% saving (estimation)	(Animireddy & Rao, 2016)

Table 6. Weaknesses/Limitation of Automation and Online Monitoring

Potential weaknesses	Parameters	Scale	Literature
There are sharp variations of measured values as an instinsic weaknesses of the equipment	Flow, pH, temperature	Upflow Anaerobic Sludge Blanket (UASB) reactor	(Souza et al., 2009)
Lack of well trained existing personnel	Physical (such as flow etc), and non physical parameters (such as documentation etc)	WWTP	(Korodi & Silea, 2014)
• Wastewater treatment processes are not considered as a core activity in SME thus lack of well trained and sceptical existing operators • Investment costs are generally considered too high • Design of the existing WWTP did not allow for real time control	DO, Nitrogen, pH, chemical dosing, sludge concentration, toxicity, TOC, flow measurement	Industrial WWTPs	(Cornelissen et al., 2018)
• Calibration is quite chalenging • Simulation and modelling software is not considered yet	DO, nitrogen, chemical feed, flow (pump),	Industrial WWTP	(Haimi et al., 2010)
• Adequate maintenance should always be conducted for sensors and actuators. • Cost-benefit analysis should be considered before implementation. • Specific aspect should be considered for different mill • Separate zone need special control	DO, flow meter, pH ammonium, sludge control	A review of Aerobic process on WWTP	(Åmand, Olsson, & Carlsson, 2013)
• Power failure might caused a system halt (fail-safe) • Limited capability of multiprogramming in PLC • Skilled operator is needed • PLC need a strong financial support	pH	Sewage water treatment plant	(Hiray et al., 2017)

4. ADVANTAGES AND WEAKNESSES OF AUTOMATION AND ONLINE MONITORING

The utilization of online, automatic monitoring and control instruments may be expected to provide several advantages as described in Table 5. The automatic monitoring and control system is expected to reduce the involvement of operators and laboratory personels, thus give the advantage of a more efficient workforce. It may estimate the performance of the WWTP and estimate online the parameters that are less than optimal or problematic so that it might be followed up more quickly. Improved and more stable results may be expected because of a more uniform quality and flow, especially with automatic and more evenly distributed motor, thus creates a less oscillation wastewater quality. The consumption of chemicals also may becoming more efficient because of the use of monitor and controls that are more stringent and also automatic system. Energy consumption also may become more efficient due to tighter process control and use of automatic air blowers. The utilization of programmable controller also may disclose some potentials of integration of WWTP with other stations such as fresh water stations, white water stations, etc.

The cost savings that can be made by implementing online monitoring can reach up to 20-40% (estimation) with several assumptions applied. However, the application of automated monitoring and control may also need advanced preparation which would affected the effectiveness of the system applied as described in Table 6. These advanced preparation are such as competencies of WWTP operators, proper design for the automatic system, alternative strategy for low-cost sensor to improve reliability and accuracy, separate control for separate zone, system basic requirements and safety, adjustable automated system design, regulation from Government, integration of online control, maintenance plan, etc.

5. CONCLUSION

Information on monitoring the quality of wastewater in industry is very important to be perceived by examining changes in effluent conditions that are getting better or worse. It is necessary to develop a system that monitors the condition of industrial wastewater. It may improve the optimization of either or both primary and secondary wastewater treatment, and also prevent some problems that may arose due to parameter changes that might occured and caused inefficient and ineffective performance.

The application of industrial technology concept 4.0 and automation systems in the industry is expected to improve the WWTP supervision process which has advantages such as reducing down time, reducing consumption of raw materials, reducing the energy used, increasing productivity, improving product quality, making efficient use of resources and processes, so as to reduce industrial operating costs, etc. The cost savings that can be made by implementing online monitoring can reach up to 20-40% (estimation) with several assumptions applied.

However, there are severals important affair that need to be addressed and considered so that the application of this technology could be effective, such as competencies of WWTP operators, proper design for the automatic system, alternative strategy for low-cost sensor to improve reliability and accuracy, separate control for separate zone, system basic requirements and safety, adjustable automated system design, regulation from government, integration of online control, maintenance plan, etc.

The results of the above review indicate that online effluent quality monitoring technology may help the industry to quickly monitor the effectiveness of WWTP performance.

REFERENCE

Aliexpress.com. (2020). Shanghai Leici E-201-C rechargeable /PH composite electrode electrode / pH electrode pH detection electrode. Retrieved November 13, 2020, from https://www.aliexpress.com/i/32824471101.html

Åmand, L., Olsson, G., & Carlsson, B. (2013). Aeration Control – A Review. *Water Science and Technology*, *67*(11), 2374–2398. https://doi.org/10.2166/wst.2013.139

Andhare, S. L., & Palkar, P. J. (2014). SCADA a Tool to Increase Efficiency of Water Treatment Plant. *Asian Journal of Engineering and Technology Innovation*, *02*(04), 7–14.

Animireddy, S., & Rao, T. C. S. (2016). Need of Automation in Common Effluent Treatment Plant. *Pakistan Journal of Biotechnology*, *13*(Special II), 121–124.

Aparna, V. (2014). Development of automated pH monitoring and control system through USB Data Acquisition. *Proceedings of 6th IEEE Power India International Conference, PIICON 2014*, (December). https://doi.org/10.1109/34084POWERI.2014.7117602

Bagyaveereswaran, V., Vijayan, A., Manimozhi, M., & Anitha, R. (2016). Automation and On-Line Monitoring Of Effluent Treatment Plant. *International Journal of*

Chemical Sciences, *14*(4), 3167–3178. Retrieved from https://www.semanticscholar.org/paper/Automation-and-On-Line-Monitoring-of-Effluent-Plant-Bagyaveereswaran-Vijayan/5352652b9b0e64c245aa68b9052c75190b9a4298

Bersinger, T., Pigot, T., Bareille, G., & Le Hecho, L. (2013). Continuous monitoring of turbidity and conductivity: A reliable, easy and economic tool for sanitation management. *WIT Transactions on Ecology and the Environment*, *171*(March), 151–162. https://doi.org/10.2495/WRM130141

Bongards, M., Gaida, D., Trauer, O., & Wolf, C. (2014). Intelligent Automation and IT for the Optimization of Renewable Energy and Wastewater Treatment Processes. *Energy, Sustainability and Society*, *4*(19), 1–12. https://doi.org/10.1186/s13705-014-0019-3

Byrne, A. J., Chow, C., Trolio, R., Lethorn, A., Lucas, J., & Korshin, G. V. (2011). Development and Validation of Online Surrogate Parameters for Water Quality Monitoring at a Conventional Water Treatment Plant Using a UV Absorbance Spectrolyser. In *2011 IEEE* (pp. 200–204). Adelaide, Australia: IEEE.

Cornelissen, R., Van Dyck, T., Dries, J., Ockier, P., Smets, I., Van den Broeck, R., … Feyaerts, M. (2018). Application of Online Instrumentation in Industrial Wastewater Treatment Plants – A Survey in Flanders , Belgium. *Water Science and Technology*, *78*(4), 957–967. https://doi.org/10.2166/wst.2018.375

Davies, T. (2017). *Wastewater Automation – The Development of a Low Cost Distributed Automation System*. Engineering Institute of Technology.

Dinis, corina maria, & Popa, gabriel nicolae. (2014). Measurements in SCADA System Used at a Wastewater Treatment Plant. *ANNALS of Faculty Engineering Hunedoara - International Journal of Engineering*, *12*(4), 207–215. Retrieved from http://annals.fih.upt.ro/pdf-full/2014/ANNALS-2014-4-36.pdf

Dries, J. (2016). Dynamic Control of Nutrient-Removal from Industrial Wastewater in a Sequencing Batch Reactor , using Common and Low-cost Online Sensors. *Water*, *73*(4), 740–745. https://doi.org/10.2166/wst.2015.553

Farah, F. B. (2017). *Use of SCADA System for Remote Monitoring of Khartoum State Water Corporation*. Sudan University of Science and Technology.

Gebbie, P. (2006). An Operator Guide to Water Treatment Coagulants. In University Central Queensland Campus (Ed.), *31st Annaual Water Industry Workshop - Operation Skills* (Vol. July, pp. 14–20). Rockhampton: University Central Queensland Campus. https://doi.org/10.1001/archinte.1980.00330230119026

Hach. (2020). Hach LDO sc Model 2 , DO Probe with Luminescent Dissolved Oxygen Technology. Retrieved November 12, 2020, from https://www.hach.com/hach-ldo-sc-model-2-do-probe-with-luminescent-dissolved-oxygen-technology/product-details?id=10182183350

Haimi, H., Mulas, M., & Vahala, R. (2010). Process Automation in Wastewater Treatment Plants : the Finnish Experience. *E-Water*, (October).

Harivardhagini, S., & Raghuram, A. (2015). Variable Structure Control of pH Neutralization of a Prototype Waste Water Treatment Plant Using LabVIEW. In *2015 IEEE Conference on System, Process and Control (ICSPC 215)* (pp. 18–20). Bandar Sunway, Malaysia.

Hiray, A., Chinchkar, O., Butte, P., & Pyla, V. (2017). PLC and SCADA Based Sewage Water Treatment Plant. *International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering*, *5*(5), 38–41. https://doi.org/10.17148/IJIREEICE.2017.5507

Irwan, F., & Afdal. (2016). Analisis Hubungan Konduktivitas Listrik Dengan Total Dissolved Solid (TDS) Dan Temperatur Pada Beberapa Jenis Air. *Jurnal Fisika Unand*, *5*(1), 85–93.

Korodi, A., Huple, T., Silea, I., & Stefan, O. (2017). IGSS Higher-Level SCADA Optimal Resource Allocation to Integrate Water and Waste Water Pumping Stations. In *2017 21st International Conference on*

Control System and Computer Science (pp. 93–98). https://doi.org/10.1109/CSCS.2017.19

Korodi, A., & Silea, I. (2014). Specifying and Tendering of Automation and SCADA Systems : Case Study for Waste Water Treatment Plants. In *2014 IEEE Multi-conference on System and Control* (pp. 1503–1508). Antibes, France.

Mundhe, M., & Somani, S. B. (2017). Industrial Waste Water Online Monitoring System. *International Journal of Electronics, Electrical and Computational System*, *6*(7), 444–449. Retrieved from http://academicscience.co.in/admin/resources/project/paper/f201707301501420393.pdf

Nandkumar, Z. P., Sanjay, S. S., Yusuf, S. H., & Jagtap, D. B. (2017). PLC and SCADA Based Automatuc Industrial Waste Water Filtration. *International Engineering Research Journal*, (Special Issue), 487–489.

Patil, K., Patil, S., Patil, S., & Patil, V. (2015). Monitoring of Turbidity , PH & Temperature of Water Based on GSM. *International Journal for Research in Emerging Science and Technology*, *2*(3), 16–21.

Qin, X., Gao, F., & Chen, G. (2012). Wastewater quality monitoring system using sensor fusion and machine learning techniques. *Water Research*, *46*(4), 1133–1144. https://doi.org/10.1016/j.watres.2011.12.005

Qingyi, M., Wei, Z., & Sixiang, Z. (2013). Research of On-line MOnitoring System of COD in Waste Water Based on the Light Absorption Method. In *2013 Fourth International Conference on Digital Manufacturing & Automation* (pp. 1018–1021). https://doi.org/10.1109/ICDMA.2013.239

Reynolds, T. D., & Richards, P. A. (1996). *Unit Operations and Processes in Environmental Engineering*. (J. Plant, Ed.) (2nd ed.). Boston: PWS Publishing Company.

Robles, Á., Durán, F., Ruano, M. V., Ribes, J., Rosado, A., Seco, A., & Ferrer, J. (2015). Instrumentation, Control, and Automation for Submerged Anaerobic Membrane Bioreactors. *Environmental Technology*, *36*(14), 1795–1806. https://doi.org/10.1080/09593330.2015.1012180

Ruano, M. V, Ribes, J., Seco, A., & Ferrer, J. (2012). An Advanced Control Strategy for Biological Nutrient Removal in Continuous Systems Based on pH and ORP Sensors. *Chemical Engineering Journal*, *183*, 212–221. https://doi.org/10.1016/j.cej.2011.12.064

s::can Messtechnik GmbH. (2020). spectro::lyser™. Retrieved November 13, 2020, from http://www.s-can.at/medialibrary/datasheets/spectrolyser_ww_EN.pdf

Safonyk, A., Bomba, A., & Tarhonii, I. (2019). Modeling and Automation of the Electrocoagulation Process in Water Treatment. In N. Shakhovska & M. O. Medykovskyy (Eds.), *Advances in Intelligent Systems and Computing III* (Vol. 871, pp. 451–463). Lviv, Ukraine: Springer, Cham. https://doi.org/10.1007/978-3-030-01069-0

Souza, F. A. A., Belchior, C. A. C., Pontes, R. S. T., & Junior, C. A. (2009). Low Cost Remote Automatic Monitoring System of a Wastewater Treatment Plant. In REV (Ed.), *The 6th Remote Engineering and Virtual instrumentation Conference (REV 2009)* (pp. 359–362). Bridgeport, Connecticut: REV.

uk.Hach.com. (2020). Hach pHD sc Online Process pH Sensor - pH Sensor for Clean Water. Retrieved November 12, 2020, from https://uk.hach.com/hach-phd-sc-online-process-ph-sensor-ph-sensor-for-clean-water/product-details?id=24929177847

Wade, M. J., Sanchez, A., & Katebi, M. R. (2005). On Real-Time Control and Process Monitoring of Wastewater Treatment Plants : Real-Time Process Monitoring. *Transactions of the Institute of Measurement and Control*, *27*(3), 173–193. https://doi.org/10.1191/0142331205tm140oa

Won, S. G., & Ra, C. S. (2010). Biological Nitrogen Removal with a Real-time Control Strategy using Moving Slope Changes of pH(mV)- and ORP-time Profiles. *Water Research*, *45*(1), 171–178. https://doi.org/10.1016/j.watres.2010.08.030

Yu, D., Liu, J., Sui, Q., & Wei, Y. (2015). Biogas-pH Automation Control Strategy for Optimizing Organic Loading Rate of Anaerobic Membrane Bioreactor Treating High COD Wastewater.

BIORESOURCE TECHNOLOGY, *203*, 62–70. https://doi.org/10.1016/j.biortech.2015.12.010

Zhu, H., & Qiu, X. (2017). The Application of PLC in Sewage Treatment. *Journal of Water Resource and Protection*, *9*(7), 841–850. https://doi.org/10.4236/jwarp.2017.97056

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Removal of Total Coliform and TSS for Hospital Wastewater by Optimizing the Role of Typha Angustifolia and Fine Sand-Gravel Media in Horizontal Sub Surface Flow Constructed Wetland

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ABSTRACT

This study aims to evaluate the performance of a pilot-scale Horizontal Subsurface Flow Constructed Wetland (HSSF-CW) utilizing Typha angustifolia and fine sand-gravel media in removing total coliform and TSS from hospital wastewater. Three pilot-scale HSSF-CW cells measuring 1.00 x 0.45 x 0.35 m^3 were filled with gravel sand media with a diameter of 5 - 8 mm as high as 35 cm with a submerged media depth of 0.30 m. There were three treatments, namely the first cell (CW1) without plants, the second cell (CW2) was planted with a density of 12 Typha angustifolia plants, and the third cell (CW3) was planted with a density of 24 Typha angustifolia plants. The three HSSF-CW cells received the same wastewater load with total coliform and TSS contents of 91000 MPN/100 mg and 53 mg/L, respectively, with Hydraulic Loading Rates 3.375 m^3 per day. Wastewater was recirculated continuously to achieve the equivalent HSSF-CW area requirement. The experimental results show that the performance of CW3 is more efficient than CW1 and CW2 in total coliform and TSS removal for hospital wastewater. The pollutant removal efficiency at CW3 reached 97.69% for total coliform with two days hydraulic retention time and 43.00% for TSS with one day of hydraulic retention time. This study concludes that the HSSF-CW system using sand-gravel media with a diameter of 5 - 8 mm with a submerged media depth of 0.30 m and planted with Typha angustifolia with a tighter spacing proved to be more efficient in removing total coliform and TSS from hospital wastewater.

1. INTRODUCTION

It was hoped that a hospital's presence with the complexity of its activities would not increase environmental pollution. In the Regulation of the Minister of Health of the Republic of Indonesia Number 7 of 2019, it was stipulated that the hospital must have a Wastewater Treatment Plant (WWTP) with wastewater treatment results that meet quality standards as required in the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number: P.68/Menlhk/General Secretariat/Kum.1/8/2016. Maximum levels of Biological Oxygen Demand (BOD) 30 mg/L, Chemical Oxygen Demand (COD) 100 mg/L, Total Suspended Solids (TSS) 30 mg/L, oil and fat 5 mg/L, ammonia 10 mg/L, and total coliform 3000 MPN/100 ml.

Some research results show the low performance of WWTP in several hospitals. B. & Mallongi (2018) examined the characteristics and quality of BOD and COD of wastewater in general hospitals in the Jeneponto Regency.

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The results showed that BOD levels at WWTP outlets, on average 58 mg/L, did not meet quality standards, and COD levels at WWTP outlets were on average 92,3 mg/L does not meet quality standards. Harlisty, Akili, & Kandou (2016) analyzed the ammonia and coliform total content of public hospital wastewater in Bitung City. The results showed that the total coliform content at WWTP outlets averaged 160,000 MPN/100 ml did not meet quality standards. Prayitno, Kusuma, Yanuwiadi, & Laksmono (2013) examined the characteristics and efficiency of WWTP hospitals in Malang City. The results showed that the characteristics of wastewater in three hospitals in Malang City contained contaminants that exceeded quality standards, such as BOD 31%, orthophosphate 24%, phenol 50%, 42% free chlorine, and 17% lead higher than the quality standard with an average efficiency of WWTP of 58%. Rahmawati & Azizah (2005) examined the content of BOD, COD, TSS, and total coliform in hospital wastewater in Nganjuk. The results showed that the average BOD level after treatment was 30.57 mg/L, and the total coliform level after treatment was 9,943 MPN/100 ml, which did not meet the quality standard. The performance of hospital WWTP in Palu was also reported to below, where the average total coliform range of 45,000 - 676,000 MPN/100 ml and TSS 59 - 147 mg/L at the hospital WWTP outlets still exceeded the quality standard (Akhmad, Darman, Aiyen, & Hamsens, 2020).

Research, development, and implementation of wetland construction (CW) are currently receiving attention in both developed and developing countries. According to Puspita, L., Ratnawati, E., Suryadiputra, I.N.N. dan Meutia (2005), CW is an artificial ecosystem designed by utilizing complex interactions between media/substrate, water plants, and microorganisms to treat almost all types of wastewater. The media/substrate acts as a place where microorganisms attach, thereby expanding the constructed wetland system's surface. The substrate also plays a role in supporting aquatic plants, assisting the filtration process (especially in subsurface flow constructed wetland), and collecting sediment. Water plants act as providers of oxygen for decomposing pollutants, media for the growth and development of microorganisms, restrain the flow rate from facilitating the solids sedimentation process, and assist in the filtration process (especially the root parts of plants). Moreover, prevent erosion, absorb nutrients and other pollutants, and prevent the growth of pathogenic viruses and bacteria by releasing certain substances such as antibiotics. Microorganisms act as decomposers of pollutants. Microorganism life grows well because of the transfer of oxygen from plant roots. CW is considered a green and sustainable technique that requires lower energy input, less operational and maintenance costs, and adds aesthetic value (Kumar & Dutta, 2019).

In general, there are two types of CW systems, namely surface flow systems, and subsurface flow systems (Leady, 1997). There are two types of subsurface flow systems: Vertical Subsurface Flow Constructed Wetland (VSSF-CW) and Horizontal Subsurface Flow Constructed Wetland (HSSF-CW). In the VSSF-CW, water is flowed on the system's surface and then seeps through the substrate and plant roots until it reaches the bottom of the wetland to get out of the system. Meanwhile, in the HSSF-CW, wastewater flows below the media's surface horizontally through the water plants' root zone between gravel/sand. Wastewater treatment with subsurface flow systems is recommended for the following reasons: It can treat domestic, agricultural, and some industrial wastes including heavy metals; High processing efficiency (80%); and, The planning, operation, and maintenance costs are cheap and do not require high skills (Tangahu & Warmadewanthi, 2001). Also, according to Kadlec & Knight (1996), the subsurface flow CW system has advantages, such as simple construction, making it easy to manufacture; flexible in choosing placement locations; flexibility in operating systems; low cost, because if we use a gravitational system, the only energy from the outside is sunlight; since the waste does not come into contact with the outside air, it will not smell; performance is reliable; not being a place for mosquitoes to grow; and can be presented as a garden that has aesthetic value.

The research results by Akhmad et al. (2020) stated that HSSF-CW has the opportunity to be adopted as an alternative to hospital wastewater treatment systems in Indonesia, especially in Palu. Several factors support such as the tropical climate and various water plants that thrive throughout the year. Khiatuddin (2003) mentions that the types of plants often used for subsurface constructed wetland are submerged plants or amphibious plants. In Palu, water plants are abundant, namely Typha Angustifolia. This plant is a sizeable grass-like plant that inhabits wetland, especially near the coast and in the mountains. However, until now, this plant has not been utilized properly. Recently, Typha Anguistofolia has begun to be used as a filter plant to increase constructed wetland effectiveness as part of industrial wastewater treatment plants (Abdulgani, H., M. Izzati, 2013). Because studies on the use of HSSF-CW, especially for hospital wastewater treatment, are still minimal, it is essential to research the performance of HSSF-CW in total coliform and TSS removal for hospital wastewater in Palu using the Typha Angustifolia.

Horizontal Sub Surface Flow Constructed Wetland (HSSF-CW) typically produces low effluent of organic matter and suspended solids. However, for E. coli removal, this system was suitable in combination with other technologies, such as chlorine or ultra-violet disinfection (Headley et al., 2013). However, the practice of disinfection with chemicals such as chlorine can create other health and ecological problems due to trihalomethane formation (Toscano et al., 2013). Also, UV disinfection was not always suitable for disinfection of waste from HSSF-CW because the development of a biofilm-like coating on light bulbs can block UV rays (Richter & Weaver, 2003). A modified HSSF-CW developed by Headley *et al.* (2013) using 8-16 mm gravel media with a depth of 1.00 m added with artificial aeration was proven to reduce the E. coli concentration deficient levels consistently. It was just that at a relatively high loading level, an extensive electrical input was required to drive the air pump. The increased removal of Fecal Coliform in aeration filters may be due to aerobic conditions that allow free-living protozoa and other predators to become active even in winter. However, other removal mechanisms, such as competition, sedimentation, filtration, and proteolysis, may also occur (Mara & Johnson, 2006). The strategy carried out in this study to optimize aerobic conditions in HSSF-CW was to maximize the role of Typha angustifolia roots, using river gravel sand media that is finer with a diameter of 5 - 8 mm, and the depth of the submerged media was limited to 0.30 m.

Typha angustifolia can develop aerenchyma in its root cortex and release oxygen so that dissolved oxygen concentrations increase in the rhizosphere, facilitating the aerobic degradation of pollutants (Pincam & Jampeetong, 2020). The roots of water plants emit exudate to create an environment unsuitable for the survival of the pathogen (Avelar, de Matos, de Matos, & Borges, 2014a). Also, act as filter media and reduce water velocity, thereby increasing sedimentation (Saeed & Sun, 2012). The effect of more acceptable media is very significant on Total Coliform, Escherichia coli, and Escherichia Fecal removal (Morató et al., 2014), also providing conducive conditions for root growth. The depth of submerged media is limited to 0.30 m, considering adjusting the depth that can generally penetrate the roots of Typha angustifolia. Thus, the anaerobic zone can be minimized when the aerobic zone becomes optimal in the HSSF-CW cell without using an air pump.

This study aims to evaluate the performance of a pilot-scale HSSF-CW in removing total coliform and TSS from hospital wastewater, with the target of processing results meeting the standards of the Minister of Environment and Forestry Regulation No. P.68/MENLKH-SETJEN/2016 with shorter hydraulic retention times.

2. METHOD

2.1. Location of Wastewater Sources Used in Experiments

The wastewater used in this experiment comes from the inlet of the WWTP in a public hospital in Palu; located at 0 ° 53'57.38 ″ S, 119 ° 50'52.63 ″ E at an altitude of approximately 100 m asl; areas with an annual rainfall of less than 1000 mm and an average annual temperature of 27 ° C ("Palu, Indonesia Travel Weather Averages." Weatherbase. Retrieved 4 August 2020). The wastewater used is mixed wastewater from household activities in hospitals, hospital clinical activities, and laboratory activities.

2.2. Experimental Design and Setup

There were three HSSF-CW cells made of glass fiber with dimension of length (L) 1.00 m, width (W) 0.45 m, and height (h) 0.35 m. The slope of the base cell (S) was set to 0.005. Submerged media depth (d) 0.30 m. According to USEPA (1993), gravel sand media with a diameter of 5 - 8 mm have porosity (n) and hydraulic conductivity (K_s) values of 0.35 and 5000 $m^3/m^2/h$, respectively. Using (Equation 1), the maximum hydraulic loading rate (Q) that can be charged to the HSSF-CW is 3.375 m^3/day.

The surface area of the HSSF-CW system (A_s) was set based on the hydraulic retention time (t) equal to 1 for easy calculation. By using (Equation 2), the A_s value is equal to 32 m^2. The surface area of the existing pilot CW cell was only 0.45 m^2. Therefore, to achieve an equivalent area of 32 m^2, the effluent must continuously recirculate back to the influent tank.

$$Q = A_C . K_S . S \quad (1)$$

$$A_S = \frac{Q \, . \, t}{d \, . \, n} \quad (2)$$

Where, Q: Hydraulic Loading Rate (m^3/d); A_c: Cross-sectional Area CW (m^2); K_s: Hydraulic Conductivity (m^3/m^2/day), and; S: Cell Base slope; A_s: Surface Area CW (m^2); t: Hydraulic Retention Time (days); d: Submerged Media Depth (m), and; n: Media Porosity.

The surface area of the existing CW reactor is only 0.45 m^2 As = reactor length x reactor width = 1.00 x 0.45 = 0.45 m^2 Since the available reactor surface area is only 0.45 m^2 while the ideal reactor surface area is 32 m^2, we continuously circulate the influent (Figure 1). We assume that the influent circulates continuously for 24 hours in a reactor with a surface area of 0.45 m^2 equivalent to a 32 m^2 reactor.

2.3. Description of Experimental and Construction Arrangements

The experimental arrangement is as shown in Figure 1. There were three pilot-scale CW cells with different treatments, all filled with sand gravel media 5 -8 mm as high as 0.35 m with a submerged media depth of 0.30 m. The first cell (CW1) without planting, the second cell (CW2) was planted with a density of 12 Typha angustifolia plants, and the third cell (CW3) was planted with a density of 24 Typha angustifolia plants. Each HSSF-CW unit consists of three components: the first component is an influent storage tank equipped with a distribution pipe, a water level sensor, a flow meter, and a discharge control valve. Influent was flowed by gravity through the distribution pipe to the inlet cell CW with a maximum controlled flow rate of 3.375 m^3/day; The second component was a CW cell as a place for the processing equipped with a water temperature gauge. The CW cell inlet pipe was placed at the height of 0.30 m from the bottom of the cell, while the outlet pipe was placed at the base of the CW cell with the top elevated 0.30 m to maintain consistency of the water level in the CW cell. In the CW cell, the influent flows slowly through the sand-gravel medium in a horizontal path until it reaches the outlet zone; The third component was the effluent storage tank. The effluent storage tank was equipped with a water pump to circulate the effluent back to the influent tank continuously. The water pump was equipped with an on-off switch connected to the water level sensor in the influent tank.

2.4. Operation of HSSF-CW

The HSSF-CW operation was carried out with the following procedures. 1) Filtering the sand-gravel material to obtain sand-gravel media with 5 - 8 mm granules. It washed clean, then filled in CW cells as high as 0.35 m. 2) Installing and setting the HSSF-CW unit components, regulating the control valve with a maximum outflow of 3.375 m^3/day. 3) Testing the HSSF-CW unit to ensure that all system components were functioning correctly. This test uses tap water. 4) Collecting the Typha angustifolia from natural populations that grow locally and then planted in CW cells 5) Acclimatization process for two weeks. 6) The main experiment, draining the tap water and then filling the hospital wastewater until the influent tank and CW cells were full. The HSSF-CW system was operated by opening the valve on the influent tank.

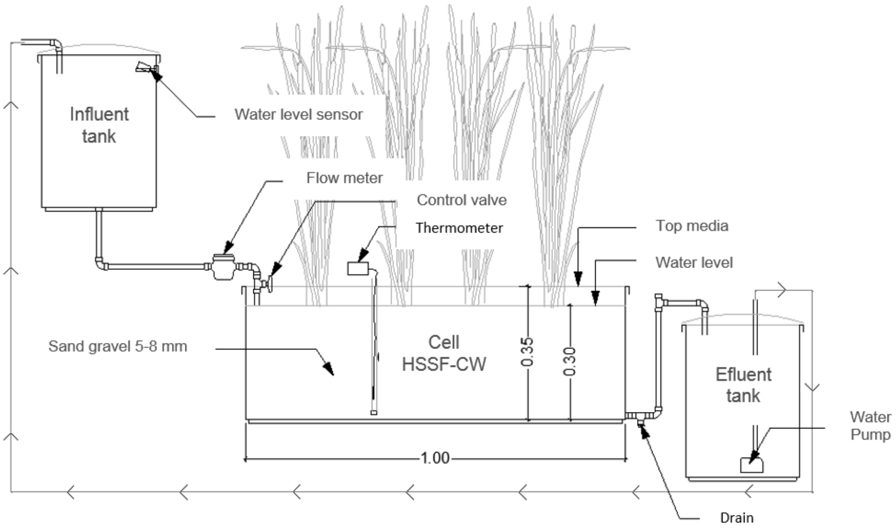

Figure 1. Schematic of pilot-scale HSSF-CW Unit Arrangement

2.5. Sampling and Sample Analysis

Effluent samples were taken from each HSSF-CW unit every day at 09.00 am for one week. Samples were taken and stored in 1000 ml plastic bottles for laboratory analysis of TSS and sterile 500 ml glass bottles for total coliform lab analysis. The TSS laboratory tests were carried out at the Laboratory of Analytical and Environmental Chemistry, Tadulako University, Palu. The total coliform laboratory test was carried out at the Biology Education Laboratory of PMIPA, Tadulako University, Palu.

The method for the Total Suspended Solid (TSS) test is gravimetrical. The homogeneous sample is filtered with weighed filter paper. The residue retained in the filter is dried to a constant weight at a temperature of 103°C to 105°C. The increase in filter weight represents total suspended solids (TSS). The method for the Total Coliform test uses the MPN (Most Probable Number) method. The Coliforms group used the microbiological quality test of water as an indicator. This group of bacteria has the characteristics: aerobic, facultatively anaerobic, gram-negative rods, and does not form spores-lactose ferments to form acids and gases within 48 hours at 35°C.

2.6. Performance Evaluation of HSSF-CW

The pollutant removal performance from HSSF-CW was calculated from Equation (3).

$$E = \frac{(C_{in} - C_{out})}{C_{in}}\, x\, 100\% \quad (3)$$

E: Efficiency of the HSSF-CW system; C_{in}: Parameters of wastewater before treatment, and; C_{out}: Parameters of wastewater after treatment.

3. RESULT AND DISCUSSION

3.1. Characteristics of Wastewater Used in Experiments

a. Total Suspended Solids

Laboratory test results showed that the TSS concentrations of wastewater used in this experiment were high, with 53 mg/L (Table 1). However, it was still lower than the average concentrations mean TSS in the previous period (Table 2). The current decrease in TSS concentrations was likely due to reduced hospital activities or patient visits due to the Covid-19 pandemic.

b. Total Coliform

Laboratory test results showed that the total coliform concentrations of wastewater used in this experiment were high, with 91000 MPN/100 ml (Table 1). However, it was still lower than the average concentrations mean total coliform in the previous period (Table 2). The current decrease in total coliform concentrations was likely due to reduced hospital activities or patient visits due to the Covid-19 pandemic.

Table 1. Concentration of TSS and Total Coliform of Wastewater Used in Experiments

Parameters	Concentration	Standard
Total Coliform (MPN/100ml)	91000	3000
TSS (mg/L)	53	30

Source: Laboratory Test Results September 2020

Table 2. Concentration of TSS and Total Coliform of Hospital Inlet Wastewater for the Period 2015-2019

Parameters	Average Concentration					Standard
	2015	2016	2017	2018	2019	
Total Coliform (MPN/100ml)	130808	140183	213333	45000	216375	3000
TSS (mg/L)	126	59	85	145	147	30

Sumber: Akhmad et al. (2020)

Table 3. Concentrations of BOD, COD, DO, and Ammonia in Hospital Wastewater Used in Experiments

Parameters	Concentration	Standard
BOD (mg/L)	22.70	30
COD (mg/L)	65.25	100
DO (mg/L)	3.77	
Ammonia (mg/L)	1.00	10

Source: Laboratory Analysis Results, September 2020

3.2. Another parameters.

- Temperature and pH

According to the standard, the required temperature is 38ºC, and the pH ranges from 6 - 9. Wastewater used in this experiment has a temperature of 30.8ºC and a pH of 7.7, still by the standard.

- BOD, COD, DO, and Ammonia

The concentrations of BOD, COD, ammonia, and DO from the hospital wastewater samples used in this experiment were 22.70 mg/L, 65.25 mg/L, 3.77 mg/L, and 1.00 mg/L, respectively (Table 3). The presence of organic components, nutrients, and dissolved oxygen is essential in the HSSF-CW system because plants and microorganisms need them.

The BOD/COD ratio of hospital wastewater used in this experiment was 0.35. According to Metcalf, Eddy and Tchobanoglous (2004), a BOD/COD ratio of 0.5 or greater indicates that organic is quickly degraded. A ratio below 0.3 indicates that available organic matter is difficult to degrade by microorganisms. Thus, the organic material from hospital wastewater used in this experiment tends to be difficult to degrade by microorganisms.

3.3. Performance of HSSF-CW on TSS and Total Coliform Removal

a. TSS Removal Efficiency

TSS removal for the three treatments generally showed a downward trend (Figure 2); this shows that fine sand-gravel with or without water plants in the HSSF-CW system is proven to remove TSS parameters. Reducing the TSS concentration to a standard 30 mg/L at CW1, CW2, and CW3 required hydraulic retention times of 2, 2, and 1 days, respectively (Figure 2). The performance of CW3 is still more efficient than CW1 and CW2.

According to Redder et al. (2010), the filtering process's effectiveness does not seem to depend on the type of media used. However, at small particle sizes. Tanner, Sukias, Headley, Yates, & Stott (2012) suggest that the filtration process is better with fine sand than coarser gravel. Watson, Reed, Kadlec, Knight, & Whitehouse (1989) suggested CW Subsurface Flow's performance on TSS removal, the percentage of TSS removal was 51% on gravel use and 94% on using sand media. However, media use with smaller particle sizes still needs to be studied about its susceptibility to clogging in the HSSF-CW system. Also, media with a smaller particle size has a small porosity value that affects the HSSF-CW system's capacity.

Karathanasis, Potter, and Coyne (2003) reported that plant roots provide a more effective filtration medium than gravel alone while increasing the attachment surface area and a food source for microorganism populations. Saeed and Sun (2011) also reported that plant tissue in water also acts as a filter media, releases oxygen, and reduces water velocity, thereby increasing sedimentation.

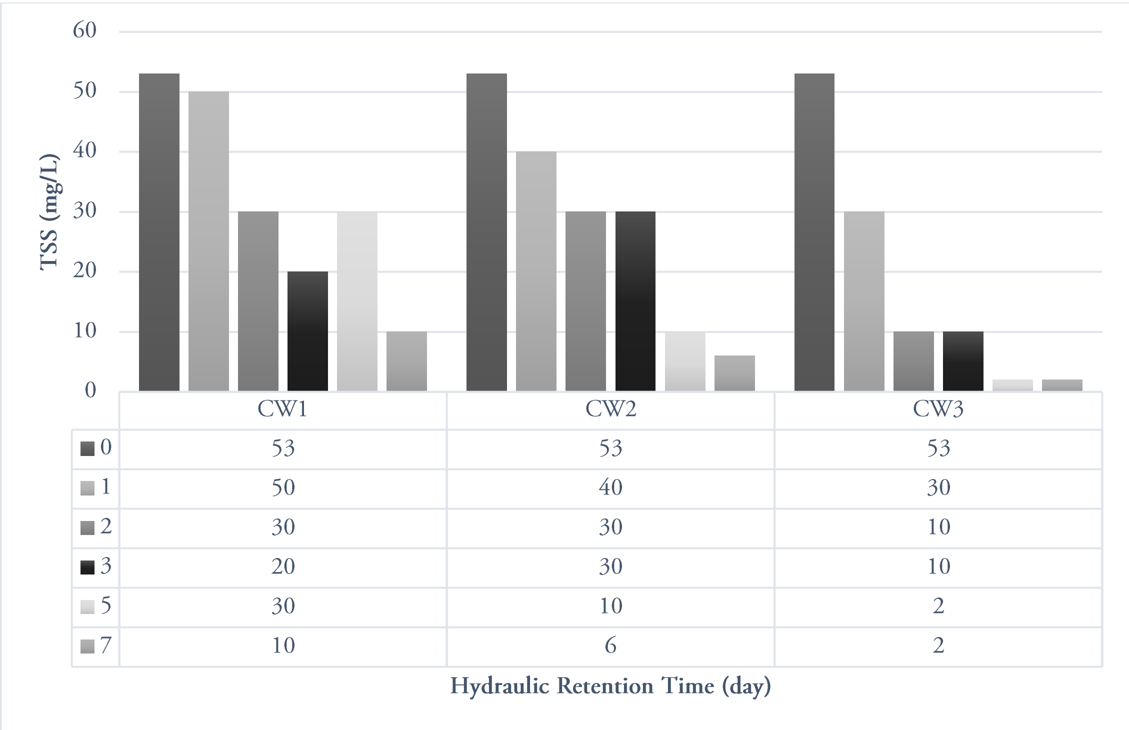

Figure 2. Value of TSS Removal on HSSF-CW According to Treatment and Hydraulic Retention Time

Table 4. Efficiency of TSS Removal on HSSF-CW According to Treatment and Hydraulic Retention Time

Treatment	Efficiency (%)				
	1 day	2 days	3 days	5 days	7 days
CW1	6	43	62	43	81
CW2	25	43	43	81	89
CW3	43	81	81	96	96

Source: TSS Removal Efficiency Analysis Results

Table 6. Temperature and pH of HSSF-CW Treated Water according to Treatment and Hydraulic Retention Time

Retention Time (day)	Temperature (°C)			pH		
	CW1	CW2	CW3	CW1	CW2	CW3
Initial	30.8	30.8	30.8	7.7	7.7	7.7
1	29.5	28.7	29.2	8.0	7.5	7.6
2	30.2	29.5	30.0	8.0	7.8	7.7
3	30.7	30.3	30.8	8.2	7.8	7.6
4	30.6	30.3	31.1	8.3	7.9	7.7
5	30.2	29.9	30.3	8.2	7.7	7.5
6	29,1	28.7	29.1	8.1	7.9	7.7
7	30.2	30.0	30.3	8.3	7.9	7.8
average	30.1	29.6	30.1	8.2	7.8	7.7

Source: On-site Measurement Results, September 2020

Table 7. DO and Ammonia Concentrations of HSSF-CW Treated Water According to Treatment and Hydraulic Retention Time

Retention Time (day)	DO (mg/L)			Amonia (mg/L)		
	CW1	CW2	CW3	CW1	CW2	CW3
Initial	3.77	3.77	3.77	1.00	1.00	1.00
1	5.15	5.39	5.09	1.10	1.10	1.20
2	4.93	5.04	5.00	1.20	1.20	1.20
3	4.91	5.00	4.81	1.30	1.20	1.20
5	5.21	5.22	5.24	1.30	1.30	1.20
7	4.45	4.87	5.00	1.20	1.20	1.20
Average	4.93	5.10	5.03	1.22	1.20	1.20

Source: Laboratory Analysis Results, September 2020

b. Total Coliform Removal Efficiency

Total coliform removal in the three treatments showed a downward trend (Figure 3). Either CW1, CW2, or CW3 required two days of hydraulic retention time to achieve a total coliform concentration less than the standard 3000 MPN/100 mg. However, the performance of CW3 is still more efficient than CW1 and CW2 because CW3 has a sharper downward trend (Figure 3).

The efficiency of total coliform removal at CW1 using fine sand-gravel media without plants, the percentage of total coliform removal on the first day was 53.85%. CW2 and CW3 with the treatment of using fine sand-gravel media with plants obtained the percentage of total coliform removal of 83.52% and 91.76%, respectively (Table 5), shows that using fine sand-gravel media with plants provides a more effective filtration medium than using sand-gravel alone. Karathanasis, Potter, and Coyne (2003) reported that plant roots provide a more effective filtration medium than gravel alone.

Several investigations have been carried out to evaluate the effect of plants on indicator bacteria removal in CW. In most of the investigations on HSSF-CW, water plants were shown to promote the removal performance of indicator bacteria positively. However, it was unclear whether this is due to the influence of the plant on the hydraulic system or other causes, such as increased surface area availability in plant roots (Kansiime & van Bruggen, 2001); or root exudates released by plant species that contain bactericidal activity (Tunçsiper, Ayaz, & Akça, 2012). The release of antimicrobial exudates may be toxic to pathogenic microorganisms and change the rhizosphere's physical and chemical environment and render it unsuitable for pathogen survival (Avelar, de Matos, de Matos, & Borges, 2014b).

c. Another parameters.

- Temperature and pH

In the wastewater treatment process, temperature and pH factors affect the performance of the HSSF-CW system. The temperature of the wastewater will affect the activity of microorganisms and plants. According to Suriawiria (1993), the temperature will influence the reaction, where every 10°C temperature increase will increase the reaction 2 - 3 times faster. Besides that, the temperature is also a limiting factor for the life of microorganisms. Considering that Indonesia's climate conditions generally have a tropical climate with a relatively small range of daily temperature differences (amplitudes), the temperature is not a limiting factor. During the experimental process, the water temperature conditions in the CW 1, CW2, and CW3 treatments tended to be stable in the average range of 29.6 - 30.1°C (Table 6).

Generally, nutrients are easily absorbed by plant roots at a neutral pH of 6-7 because at that pH, some nutrients, especially macronutrients, are readily soluble in water. At low pH (acid), many elements of aluminum (Al) are found, which are not only toxic but also bind to phosphorus (P) so that plants cannot absorb the phosphorus. Also, microelements such as Fe, Zn, Mn, Cu become easily dissolved, resulting in too large a quantity and are toxic to plants. In contrast, at high pH (alkaline), microelements Sodium (Na) and Molybdenum (Mo) are found, which are large and poisonous to plants. At a pH of 5.5 - 7, bacteria and fungi that decompose organic matter can thrive (Novizan, 2007).

During the experimental process, the water pH conditions differed between treatments CW1, CW2, and CW3. At CW1, there was an increase in the water's pH, an average of 8.2, CW2 an average of 7.8, and CW3 tended to be stable at pH 7.7 from the initial pH condition 7.7 (Table 6). The increase in the water's pH in the CW1 treatment was probably due to using sand-gravel media made of alkaline limestone. The pH values at CW2 and CW3, which tend to be stable at an initial pH of 7.7, maybe neutralized by plant roots because the partial test was carried out by submerging the roots of Typha angustifolia with the same water sample without sand-gravel media obtained a water pH of 7.4.

- DO and Ammonia

The results of laboratory analysis showed an increase in dissolved oxygen (DO) that was relatively the same at CW1, CW2, and CW3 with an average range of 4.93 - 5.03 mg/L (Table 7); this indicates that the increasing DO not only due to the influence of oxygen released by plant roots. However, it was likely caused more by the diffusion of atmospheric oxygen (Cooper, Job, & Green, 1996) due to wastewater recirculation factor in HSSF-CW.

The laboratory analysis results also showed an increase in ammonia concentrations relatively the same in the CW1, CW2, and CW3 treatments with an average range of 1.20 - 1.22 mg/L from the initial ammonia condition of 1.00 mg/L (Table 7). The increase in ammonia concentration indicates that CW1, CW2, and CW3 was low in ammonia removal. However, it was not an obstacle because the concentration is relatively low. The current literature shows that the performance of the HSSF-CW system often shows low nitrogen removal rates (Vymazal, Greenway, Tonderski, Brix, & Mander, 2005). Lack of biodegradable organics often hinders classical denitrification metabolism (due to dependence on organic carbon) in the CW system (Lavrova & Koumanova, 2010). Also, the sand-gravel media commonly applied at CW does not generate carbon, thus often limiting denitrification (Saeed & Sun, 2012).

4. CONCLUSION

The experimental results show that the performance of CW3 is more efficient than CW1 and CW2 in total coliform and TSS removal for hospital wastewater. The efficiency of pollutant removal at CW3 reached 97.69% for total coliform with two days hydraulic retention time and

43.00% for TSS with one day of hydraulic retention time. HSSF-CW planted with Typha angustifolia with a denser spacing (24 plants per 0.45 m2) using sand-gravel media with a 5 - 8 mm diameter with a submerged media depth of 0.30 m proved to be more efficient in removing total coliform and TSS from hospital wastewater. Apart from the influence of plant roots, there was an increasing DO due to atmospheric oxygen diffusion factors.

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REFERENCE

Abdulgani, H., M. Izzati, S. (2013). Pengolahan Limbah Cair Industri Kerupuk dengan Sistem Subsurface Flow Constructed Wetland Menggunakan Tanaman Typha Angustifolia. Prosiding Seminar Nasional Pengelolaan Sumberdaya Alam dan Lingkungan 2013.

Akhmad, A. G., Darman, S., Aiyen, & Hamsens, W. P. S. (2020). An Opportunity for Using Constructed Wetland Technology in Hospital Wastewater Treatment: A Preliminary Study. In *The 2020 International Conference on Science in Engineering and Technology*. Palu, Indonesia: IOP.

Avelar, F. F., de Matos, A. T., de Matos, M. P., & Borges, A. C. (2014a). Coliform bacteria removal from sewage in constructed wetlands planted with Mentha aquatica. *Environmental Technology*, *35*(16), 2095–2103. https://doi.org/10.1080/09593330.2014.893025

Avelar, F. F., de Matos, A. T., de Matos, M. P., & Borges, A. C. (2014b). Coliform bacteria removal from sewage in constructed wetlands planted with Mentha aquatica. *Environmental Technology*, *35*(16), 2095–2103. https://doi.org/10.1080/09593330.2014.893025

B., R., & Mallongi, A. (2018). Studi Karakteristik dan Kualitas BOD dan COD Limbah Cair Rumah Sakit Umum Daerah Lanto Dg. Pasewang Kabupaten Jeneponto. *Jurnal Nasional Ilmu Kesehatan*, *1*. Retrieved from http://journal.unhas.ac.id/index.php/jnik/article/view/4285

Cooper, P. F., Job, G. D., & Green, M. B. (1996). *Reed beds and constructed wetlands for wastewater treatment*. Swindon : WRc Swindon. Retrieved from https://library.wur.nl/WebQuery/titel/942402

Harlisty, B. F., Akili, R. H., & Kandou, G. D. (2016). Analisis Kandungan Amoniak dan Bakteri Coliform Total pada Limbah Cair Rumah Sakit Umum Daerah (RSUD) Kota Bitung Pada Tahun 2016. Retrieved from http://medkesfkm.unsrat.ac.id/wp-content/uploads/2016/10/JURNAL-Bima-Febrian-Harlisty.pdf

Headley, T., Nivala, J., Kassa, K., Olsson, L., Wallace, S., Brix, H., … Müller, R. (2013). Escherichia coli removal and internal dynamics in subsurface flow ecotechnologies: Effects of design and plants. *Ecological Engineering*, *61*, 564–574. https://doi.org/10.1016/j.ecoleng.2013.07.062

Kadlec, R. H., & Knight, R. L. (1996). *Treatment Wetlands*. New York: Lewis Publishers.

Kansiime, F., & van Bruggen, J. J. A. (2001). Distribution and retention of faecal coliforms in the Nakivubo wetland in Kampala, Uganda. *Water Science and Technology*, *44*(11–12), 199–206. https://doi.org/10.2166/wst.2001.0829

Karathanasis, A. D., Potter, C. L., & Coyne, M. S. (2003). Vegetation effects on fecal bacteria, BOD, and suspended solid removal in constructed wetlands treating domestic wastewater. *Ecological Engineering*, *20*(2), 157–169. https://doi.org/10.1016/S0925-8574(03)00011-9

Khiatuddin, M. (2003). *Melestarikan Sumber Daya Air dengan Teknologi Rawa Buatan*. Yogyakarta: Gadjah Mada University Press.

Kumar, S., & Dutta, V. (2019). Constructed wetland microcosms as sustainable technology for domestic wastewater treatment: an overview. *Environmental Science and Pollution Research*, *26*(12), 11662–11673. https://doi.org/10.1007/s11356-019-04816-9

Lavrova, S., & Koumanova, B. (2010). Influence of recirculation in a lab-scale vertical flow constructed wetland on the treatment efficiency of landfill leachate. *Bioresource Technology*, *101*(6), 1756–1761. https://doi.org/10.1016/j.biortech.2009.10.028

Leady, B. (1997). *Constructed Subsurface Flow Wetlands For Wastewater Treatment*. Purdue University.

Mara, D. D., & Johnson, M. L. (2006). Aerated Rock Filters for Enhanced Ammonia and Fecal Coliform Removal from Facultative Pond Effluents. *Journal of Environmental Engineering*, *132*(4), 574–577. https://doi.org/10.1061/(ASCE)0733-9372(2006)132:4(574)

Metcalf, L., Eddy, H. P., & Tchobanoglous, G. (2004). *Wastewater engineering : treatment, disposal, and reuse*. New York [etc.] : McGraw-Hill. Retrieved from https://library.wur.nl/WebQuery/titel/1979505

Morató, J., Codony, F., Sánchez, O., Pérez, L. M., García, J., & Mas, J. (2014). Key design factors affecting microbial community composition and pathogenic organism removal in horizontal subsurface flow constructed wetlands. *Science of The Total Environment*, *481*, 81–89. https://doi.org/10.1016/j.scitotenv.2014.01.068

Novizan. (2007). *Petunjuk pemupukan yang efektif*. Jakarta: Agromedia. Retrieved from http://cybex.pertanian.go.id/mobile/artikel/70521/Ph-Tanah-Dan-Ketersediaan-Unsur-Hara-Dalam-Tanah/

Pincam, T., & Jampeetong, A. (2020). Treatment of Anaerobic Digester Effluent Using *Typha angustifolia* L.: Growth Responses and Treatment Efficiency. *Journal of Water and Environment Technology*, *18*(2), 105–116. https://doi.org/10.2965/jwet.19-045

Prayitno, Kusuma, Z., Yanuwiadi, B., & Laksmono, R. W. (2013). Study of Hospital Wastewater Characteristic in Malang City. *Research Inventy: International Journal Of Engineering And Science Issn Www.Researchinventy.Com*, *2*(2), 13–16. Retrieved from https://s3.amazonaws.com/academia.edu.documents/31244050/C022013016.pdf?response-content-disposition=inline%3B filename%3DResearch_Inventy_International_Journal_o.pdf&X-Amz-Algorithm=AWS4-HMAC-SHA256&X-Amz-Credential=AKIAIWOWYYGZ2Y53UL3A%2F20191217%2Fus-e

Puspita, L., Ratnawati, E., Suryadiputra, I.N.N. dan Meutia, A. A. (2005). *Lahan Basah Buatan di Indonesia*. Bogor: Wetlands International Indonesia Programme dan Ditjen, PHKA.

Rahmawati, A. A., & Azizah, R. (2005). Perbedaan Kadar Bod, Cod, Tss, dan Mpn Coliform pada Air Limbah, Sebelum dan Sesudah Pengolahan di RSUD Nganjuk. *Jurnal Kesehatan Lingkungan Unair*, *2*(1), 97–110. Retrieved from http://www.journal.unair.ac.id/filerPDF/KESLING-2-1-10.pdf

Redder, A., Dürr, M., Daeschlein, G., Baeder-Bederski, O., Koch, C., Müller, R., … Borneff-Lipp, M. (2010). Constructed wetlands – Are they safe in reducing protozoan parasites? *International Journal of Hygiene and Environmental Health*, *213*(1), 72–77. https://doi.org/10.1016/j.ijheh.2009.12.001

Richter, A. Y., & Weaver, R. W. (2003). Ultraviolet disinfection of effluent from subsurface flow constructed wetlands. *Environmental Technology*, *24*(9), 1175–1182. https://doi.org/10.1080/09593330309385658

Saeed, T., & Sun, G. (2011). A comparative study on the removal of nutrients and organic matter in wetland reactors employing organic media. *Chemical Engineering Journal*, *171*(2), 439–447. https://doi.org/10.1016/j.cej.2011.03.101

Saeed, T., & Sun, G. (2012). A review on nitrogen and organics removal mechanisms in subsurface flow constructed wetlands: Dependency on environmental parameters, operating conditions and supporting media. *Journal of Environmental Management*, *112*, 429–448. https://doi.org/10.1016/j.jenvman.2012.08.011

Suriawiria, U. (1993). *Mikrobiologi Air*. Bandung: Alumni.

Tangahu, B. V., & Warmadewanthi, I. D. A. A. (2001). Pengelolaan limbah rumah tangga dengan memanfaatkan tanaman cattail (typha angustifolia) dalam sistem constructed wetland. *Purifikasi*, *3*(3), 127–132.

Tanner, C. C., Sukias, J. P. S., Headley, T. R., Yates, C. R., & Stott, R. (2012). Constructed wetlands and denitrifying bioreactors for on-site and decentralised wastewater treatment: Comparison of five alternative configurations. *Ecological Engineering*, *42*, 112–123. https://doi.org/10.1016/j.ecoleng.2012.01.022

Toscano, A., Hellio, C., Marzo, A., Milani, M., Lebret, K., Cirelli, G. L., & Langergraber, G. (2013). Removal efficiency of a constructed wetland combined with ultrasound and UV devices for wastewater reuse in agriculture. *Environmental Technology*, *34*(15), 2327–2336. https://doi.org/10.1080/09593330.2013.767284

Tunçsiper, B., Ayaz, S. Ç., & Akça, L. (2012). Coliform Bacteria Removal from Septic Wastewater in A Pilot-Scale Combined Constructed Wetland System. *Environmental Engineering and Management Journal*, *11*(10), 1873–1879. Retrieved from https://www.researchgate.net/profile/Bilal_Tuncsiper2/publication/287773645_Coliform_bacteria_removal_from_septic_wastewater_in_a_pilot-scale_combined_constructed_wetland_system/links/5910090aaca2722d1860547d/Coliform-bacteria-removal-from-septic-wastewat

Vymazal, J., Greenway, M., Tonderski, K., Brix, H., & Mander, Ü. (2005). Constructed Wetlands for Wastewater Treatment. In *Wetlands and Natural Resource Management* (pp. 69–96). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-33187-2_5

Watson, J. T., Reed, S. C., Kadlec, R. H., Knight, R. L., & Whitehouse, A. E. (1989). Performance expectations and loading rates for constructed wetlands. In: Hammer, D.A. (Ed.),. In D. A. Hammer (Ed.), *Constructed Wetlands for Wastewater Treatment. Municipal, Industrial and Agricultura* (pp. 319–358). Lewis Publishers.

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Potential Activated Carbon of Theobroma cacao Shell for Pool Water Purification

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ABSTRACT

Research has been carried out to improve the quality of the yellow pool water. The water is used as a source of clean water for the academics of the Politeknik Negeri Padang, so it needs to be improved in accordance with the quality standards of clean water and is suitable for daily use. The adsorption process was carried out using activated carbon of Theobroma cacao shells which was carbonated at 400oC for 1 hour and activated with H3PO4. Characterization of functional groups using Frontier Transform Infra Red, and morphology of surface using Scanning Electron Microscopy. The quality of clean water standard analyzed is turbidity, Total Dissolved Solids, color, Total Suspended Solids, and Fe and Mn content. Functional group analysis exhibits that the activated carbon produced has a pattern of absorption with O-H, C-H, and C-O bond types. At the optimum condition of the activation process, a good adsorbent is absorbed in pool water purification at a flow rate of 5 mL/min with a mass of 2 grams. The efficiency value after the adsorption process showed 67% for turbidity, 71% for TDS, 97% for color, 86% for TSS, 38% for Fe content, and 66% for Mn content. The surface morphology of activated carbon showed the presence of pore cavities, and after the adsorption process, the cavities became saturated. This shows that there has been an absorption by activated carbon so that the water becomes clear. Cacao shell activated carbon is very effective in the process of purifying pool water into clean water and fulfilling clean water standards according to Permenkes 416/MENKES/PER/IX/1990, so it is suitable for being used.

1. INTRODUCTION

Water is one of the most important elements of human life. However, water pollution is still a serious problem in Indonesia at this time. Water pollution can be caused by human activities and by nature itself, such as the presence of organic and inorganic substances in water. One of the efforts to solve water pollution is by using the adsorption method (Rahmawati & Yuanita, 2013), (Yetri, Marantika, Alamsyah, Alif, & Zein, 2020). Clean water that meets health requirements must be free from pollution and meet the quality standards (Siti Munfiah & Anbariawan, 2015; Amin, et al., 2005). The pool water used by the Politeknik Negeri Padang academic community is slightly yellowish, so the quality is doubtful. This yellowish color is possible because of the large amount of Iron (Fe) dan Mangan (Mn) in it, or if this water is collected in the tub, it will give yellowish sediment and stains on the walls. For more details, the standard of clean water quality can be seen in Table 1. Fe in drinking water will accumulate in the body and attack organs such as damage to the intestinal wall and other organs (Amin, et al., 2005). In addition, the presence of suspended substances in the pool

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Table 1. Clean Water Quality Standards According Permenkes RI No.416 / MENKES / PER / IX / 1990

Parametes	Units	Quality Standards	Method Standards
pH	-	6.5 – 8.5	-
Color	TCU	15	SNI 3554:2015
BOD	mg/L	2	SNI 06-6989. 14-2004
COD	mg/L	10	-
TSS	mg/L	50	SNI 06-6989.3-2004
TDS	mg/L	500	SNI 3554:2015
Turbidity	NTU	5	SNI 3554:2015
Fe	mg/L	1	-
Mn	mg/L	0.5	-

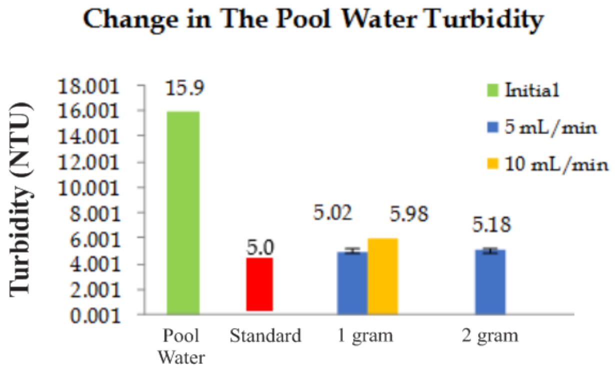


Figure 1. The Influence of Flow Rate and Mass of Activated Carbon on Turbidity Value Changes After Adsorption

water also causes color changes in the water. Therefore, a process is needed to improve the quality of pool water so that it can be used to meet daily needs.

Previous research has carried out water purification methods using activated carbon from coconut shells (Budiono, Suhartana, & Gunawan, 2008; Surest, Kasih, & Wisanti, 2008), super activated carbon from coal and coconut shells (Surest et al., 2008). In this research, the use of cacao shells activated carbon will be carried out for purifying pool water at Politeknik Negeri Padang. Activated carbon was chosen because it has a large surface area, large adsorption ability, is easy to apply, and the cost required is relatively cheap (Dąbrowski, Podkościelny, Hubicki, & Barczak, 2005; Gupta, Sharma, Yadav, & Mohan, 1998). Previous research suggested that functional group analysis and surface morphology of activated carbon from cacao shells had better absorption processes than coconut shells (Mozammel, H.M., Masahiro, O., Bhattacharya SC, 2002). The activation process is carried out using H3PO4. Previous research, when compared to the activation process of coconut shell charcoal with sulfuric acid and phosphoric acid for phenol adsorption, showed better results when activated using phosphoric acid (Budiono et al., 2008). The activated carbon consists of 87%-97% carbon and the rest in the form of hydrogen, oxygen, sulfur, nitrogen and other compounds shaped from the manufacturing process (Arsad, 2010; France, 1991, Lelifajri, 2010). A required material for making activated carbon is the presence of cellulose or hemicellulose in the material. The content of cacao shells consists of 21.06% hemicellulose, 20.15% cellulose, and 55.11% lignin, and coconut shells containing 34% cellulose, 21% hemicellulose, and 27% lignin (Mozammel, H.M., et al, 2002, Yetri Y et al, 2017). The high lignin content in the skin of the cacao is very promising for a higher percentage of efficiency. (Bledzki, A.K., Mamuna, A.A., Volk, J, 2010). So it has the potential to be used as an adsorbent in the adsorption process (Wijaya.M & Wiharto, 2017). The parameters analyzed were pH, color, TSS, TDS, turbidity and iron by using AAS and looking for the optimum flow rate and mass conditions (Gupta et al., 1998; Misran, 2009; Siti Munfiah, 2015).

2. METHODS

2.1. Materials and Tools

The materials used were pool water, cacao shells, paper of filter, glass woll, aquadest, concentrated H_3PO_4 (Merck), K_2PtCl_6 (Merck), $CoCl_2.6H_2O$ (Merck), pH 4.7 and 9 buffer solutions (Merck).

The tools used were a column of glass with a length of 25 cm and diameter of 1.5 cm, standard, clamp, container of well water, Front Lab peristaltic pump, Analytical Balance (Kern & Sohn GmbH), Miyako Blender, Furnace Carbolite CWF 1200, pH meter (HANNA HI 98127), mortar and pestle, Frontier Transform Infra Red (FTIR) (Unican Mattson Mod 7000 FTIR), Scanning Electron Microscopy by HITACHI S-3400 N, UV-Vis Spectrophotometer with

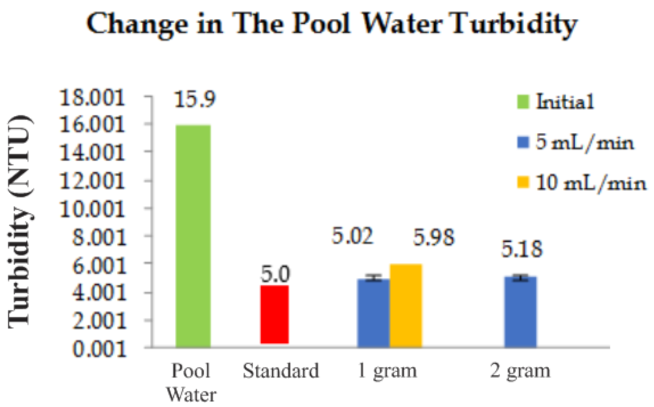


Figure 1. The Influence of Flow Rate and Mass of Activated Carbon on Turbidity Value Changes After Adsorption

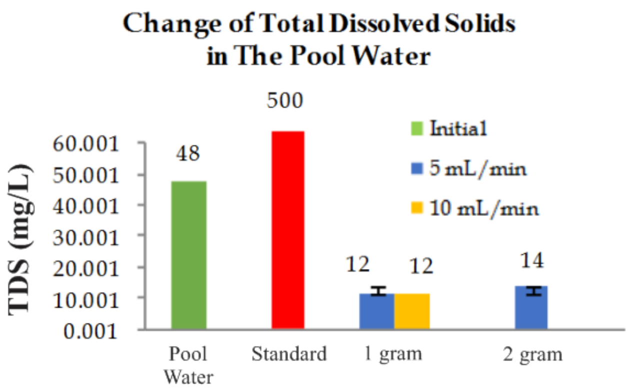


Figure 2. The Influence of Flow Rate and Mass of Activated Carbon on the Change in the Value of Total Disolved Solids (TDS) after Adsorption

Thermo Scientific GENESYS 10S Series, sieve with size particles ≤ 160 µm.

2.2. Activated Carbon Preparation

The cacao shells were washed with water, dried, and then carbonized at 400 oC for 1 hour to form charcoal. The charcoal was then mixed with 50% H3PO4 in a ratio of 1:4 and left for 24 hours. Then the mixture was washed with distilled water until the pH was neutral, then oven at 105 ^{o}C for 3 hours. The resulting activated carbon was sieved to produce a particle size of ≤ 160 µm to be used. SEM and FTIR are used to characterize the activated carbon produced (Purnamawati & Utami, 2014; Wijaya.M & Wiharto, 2017).

2.3. Treatment of Samples

The method of purifying pool water uses a glass column measuring 1.5 cm in diameter and 25 cm in height. Activated carbon was put into the column as much as 1 gram with a variation of flow rate of 5 mL/minute and 10 mL/minute using a pump of peristaltic. After obtaining the best flow rate, 2 grams of adsorbent was treated. The resulting filtrate was analyzed for color, pH, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), turbidity and metal content of Fe and Mn.

Determination of the water color was carried out by a spectrophotometer using the method of spectrophotometric at 456 nm of wavelength with the standard solution used was platinum-cobalt. Quotation of turbidity values using a turbidimeter. TDS is carried out by SNI 01-3554-2015. Determination of TSS value according to SNI 19-7119.3-2005 with gravimetric method, and determination of iron content according to SNI 6989.4: 2009. Meanwhile, for the characterization of activated carbon produced, were used SEM and FTIR.

3. RESULT AND DISCUSSION

Turbidity in pool water samples possibly caused by the presence of suspended and dissolved organic and inorganic materials, such as mud, fine sand, and soil. Turbidity can also be caused by the presence of plankton and microorganisms that are present in large quantities in water. The turbidity value is directly proportional to suspended solids, however, the high dissolved solids turbidity does not always occur (Arsad, 2010; Siti Munfiah, 2015). The results of the initial turbidity analysis of pool water were 15.9 NTU. The value of turbidity in pool water after adsorption can be seen in Figure 1.

Figure 1 tends the effect of the mass of activated carbon on the pool water turbidity. Based on these data, it can be shown that the turbidity of the pond water has decreased after passing through the activated carbon of the cocoa shells. This decrease in turbidity value occurred because the number of particles is well adsorbed by the activated carbon used. The activation process can enlarge carbon pores by breaking hydrocarbon bonds or by oxidizing surface molecules so that the surface area increases and affects the adsorption power (Arsad, 2010; Guo et al., 2007). Adsorption occurs because of the weak Vander Waals forces between particles (Edward Tandy, Ismail Fahmi Hasibuan, & Hamidah Harahap, 2012; Siti Munfiah, 2015).

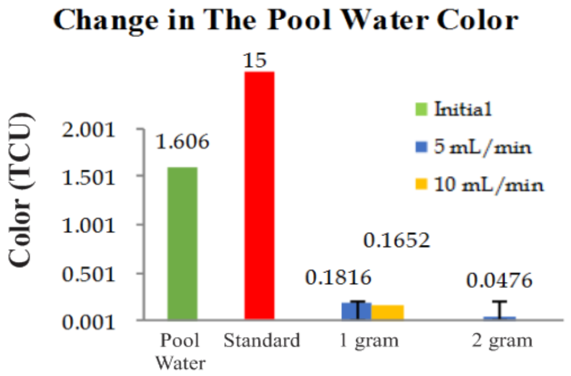


Figure 3. The Influence of Flow Rate and Mass of Activated Carbon on Changes in the Value of Color After Adsorption

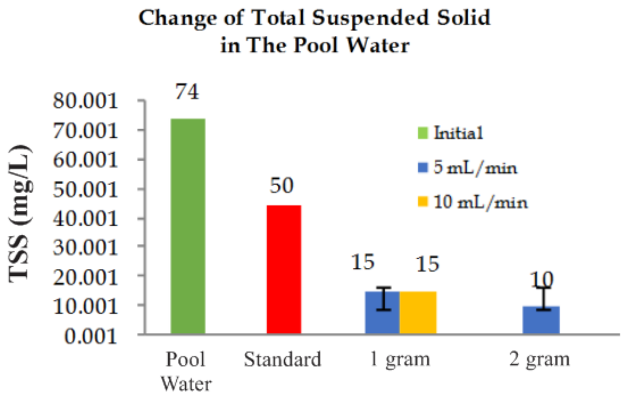


Figure 4. The Influence of Flow Rate and Mass of Cacao Shell Activated Carbon on Changes in Total Suspended Solids (TSS) Value After Adsorption

The efficiency of reducing the turbidity value using 1 gram of activated carbon with flow rates of 5 mL/minute and 10 mL/minute was 68% and 62%. Meanwhile, using the mass of 2 grams of activated carbon, the reduction efficiency was 67%. The results above indicate that the turbidity value of pool water after surpassing activated carbon is according to the clean water quality standards Permenkes 416/MENKES/PER/IX/ 1990.

Total Disolved Solids (TDS) contains various solutes (organic, inorganic, or other materials) in a solution (Guo et al., 2007). The TDS value is one of the chemical parameters in determining the quality of a water, because it represents the number of ions in the water.

Based on Figure 2, it can be seen that the TDS value of the pond water has decreased after surpassing the activated carbon. The efficiency of reducing the TDS value on the mass of 1 gram activated carbon with a flow rate of 5 mL/minute and 10 mL/minute was 75%, and with a mass of 2 grams was 71%. The large percentage of TDS indicates that the solid particles dissolved in the pool water have been adsorbed into the pores of cocoa activated carbon so that the pool water becomes colorless.

Color can be one of the parameters for determining water quality. The water color possibly caused by the presence of organic and inorganic materials, plankton, ions, humus, and other materials in water (Surest et al., 2008; Effendi & Hefni, 2003).

Drinking water must be clear and colorless. Previous research has carried out a reduction in color content analysis using activated carbon from wood and coconut shell of 69.21% and 93.57%, respectively (Budiono et al., 2008). While the analysis of results of pool water after adsorption by activated carbon from cacao shells showed better results, where the color change from yellow to colorless with a reduction in mass efficiency of 1 gram, flow rate of 5 mL/minute and 10 mL/minute was 89% and 90%, while the mass of 2 grams was 97%, as shown in Figure 3. It means that the more mass of activated carbon, the surface area becomes larger so that its absorption capacity will increase. The pool water that has passed through the activated carbon of cacao shells has met the quality of clean water. The yellow color in the water is also caused by the presence of Fe metal, which was 0.842 mg/L in the initial sample of pool water. After the adsorption process, the Fe concentration decreased from 0.842 mg/L to 0.522 mg/L for a flow rate of 5 mL/minute and a mass of 2 grams by 38% efficiency. Meanwhile, Mn decreased from 0.375 mg/L to 0.127 mg/L after adsorption, as shown in Figure 5. This is because the smaller flow rate gives the more dissolved Fe ions in the pool water are adsorbed into the activated carbon (Wieber, J. F., Kuick, B., Zuman, P. 1988).

Water quality is also influenced by the amount of suspended substances in the water. Water quality standards based on PP. 82 of 2001, the TSS threshold is 50 mg/L as measured by the gravimetric method. This regulation was issued to strengthen the Republic of Indonesia Minister of Permenkes No. 416/MENKES/PER/IX/1990 concerning the importance of clean water management for the benefit of the public, as well as to prevent people from hazardous substances

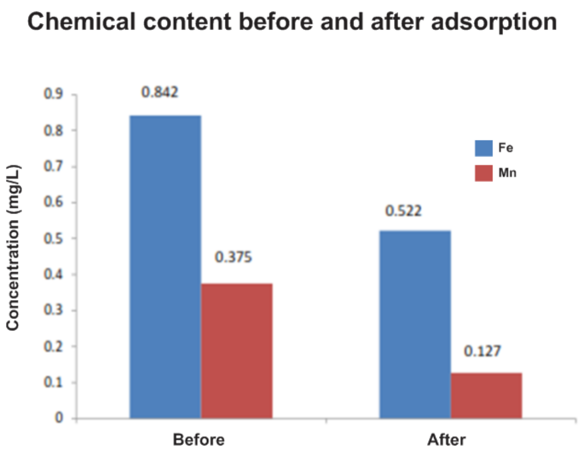


Figure 5. Chemical Content Before and After Adsorption

Table 2. Quality standard of each parameter

Parametes	Units	Quality Standards	Method Standards
pH	-	6.5 – 8.5	-
Color	TCU	15	SNI 3554:2015
BOD	mg/L	2	SNI 06-6989. 14-2004
COD	mg/L	10	-
TSS	mg/L	50	SNI 06-6989.3-2004
TDS	mg/L	500	SNI 3554:2015
Turbidity	NTU	5	SNI 3554:2015
Fe	mg/L	1	-
Mn	mg/L	0.5	-

contained in water. Suspended material consists of mud and microorganisms originating from soil erosion or erosion that is carried into the water (Hendra & Darmawan, 2007; Siti Munfiah, 2015).

The efficiency of TSS reduction on the mass of 1 gram of cacao shell activated carbon with a flow rate of 5 mL/minute and 10 mL/minute was 80%, while 2 grams of activated carbon was 86%. The TSS value after adsorption can be seen in Figure 4. When the flow rate of 5 mL/minute and a mass of 2 grams, the optimum absorption conditions are where the adsorbent contact with water is longer. The longer the contact time, the more chance the activated carbon particles will come into contact with the ions that are bound to the pores of the activated carbon (Lu & Chung, 2001; Misran, 2009). For more details, the comparison between initial, quality standard, and adsorption results can be seen in Table 2.

3.1 Characterization of Activated Carbon

The results of characterization by FTIR are shown in Figure 6 to see the absorption of functional groups contained in the sample.

There was a change in the absorption band on the carbon of the cacao shells before and after adsorption. The main components of it are cellulose, hemicellulose and lignin (Purnamawati & Utami, 2014; Rahmadani & Kurniawati, 2017). Figure 6 shows the cellulose content in the presence of O-H hydroxyl bonds at wave number 3347.13 cm^{-1} and experiencing a shift to wave number 3232.33 cm^{-1} after processing of adsorption. The functional group of –OH on the adsorbent undergoes deprotonation, so that the group of functional becomes negatively charged, which is very reactive in adsorbing ions of Ca^{2+}, and other cations of metal (Rahmadani & Kurniawati, 2017). This Ca^{2+} ion will bind with OH^- from the adsorbent to form a base. This condition will accelerate the adsorption by the adsorbent. At the initial activated carbon, a peak was seen around the wavelength of 2346.79 cm-1 which indicates the appearance of the group of C≡N. The surface containing the group of nitrogen on the surface of the activated carbon increases the ability to adsorb acid gases. The functional group of carboxyl (Aliphatic C-O stretching) at wavenumber 1235.96 cm^{-1} shows the presence of hemicellulose content and after adsorption, there is a shift to wavenumber 1236.01 cm^{-1}. The wavenumber 1916.18 cm^{-1} shows the lignin content and undergoes a shift to the wavenumber 1935.37 cm^{-1} which is indicated by the presence of aromatic C-H groups (Wijaya.M & Wiharto, 2017). Carboxyl and hydroxyl groups play a role in adsorbing cations of metal. The resulting activated carbon has an adsorption pattern with the types of C-H, C-O, and O-H bonds (Rahmadani & Kurniawati, 2017).

The results of surface analysis by SEM at 400°C can be seen in Figure 7. Cacao shells activated carbon with H_3PO_4 has a porous surface because the activator used is water-binding. Water will be firmly bound to the carbon pore and then the activator will enter the pore and open the active surface which is still closed so that its adsorption capacity will

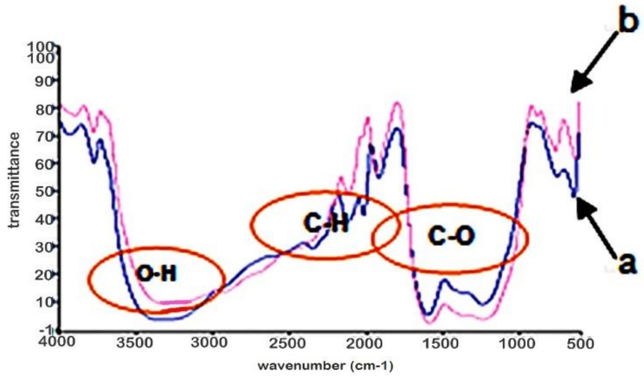
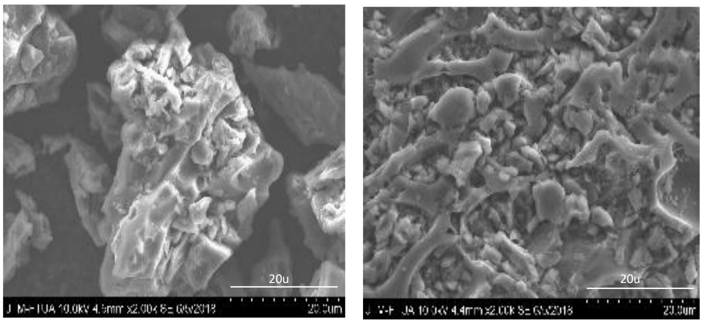


Figure 6. FTIR Spectrum of Cacao Shell Activated Carbon Absorption, (a) Before and (b) After



(a) (b)

Figure 7. Morphology of surface of activated carbon adsorption with magnification 2000X, (a). before, (b). after

be better (Dąbrowski et al., 2005). The more activators used will increase pore formation on activated carbon (Rahmadani & Kurniawati, 2017). In Figure 6a, the pores are clean, clear and still open, because adsorption has not occurred. Meanwhile, Figure 6b shows that adsorption of activated carbon has occurred, the pores have closed and become denser. This is because the interaction between the adsorbate and the adsorbent only occurs on the surface of the adsorbent (Edward Tandy et al., 2012).

CONCLUSION

Activated carbon of cacao shells obtained from carbonation at 400°C for 1 hour which was activated with H_3PO_4 showed good adsorption in pond water purification. The optimum condition is obtained at a mass of 2 grams with a flow rate of 5 mL / minute. The analysis showed that the efficiency of decreasing the turbidity value was 67%, TDS 71%, color 97%, TSS 86%, Fe 38%, and Mn 66%. Characterization of surface and groups of functional shows that the morphology of activated carbon greatly influences the adsorption process. These results indicate that the activated carbon of cacao shells is very effective in the process of purifying pool water into clean water and meets the requirements of Permenkes 416/MENKES/PER/IX/1990.

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REFERENCE

Arsad, E. (2010). Teknologi Pengolahan Dan Pemanfaatan Karbon Aktif Untuk Industri. *Jurnal Riset Industri Hasil Hutan*, *2*(2), 43. https://doi.org/10.24111/jrihh.v2i2.1146

Bledzki, A.K., Mamuna, A.A., Volk, J. (2010). Barley husk and coconut shell reinforced polypropylene composites: The effectof fibre physical, chemical and surface properties. *Composites Science and Technology*. 70. 840–846.

Budiono, A., Suhartana, & Gunawan. (2008). Pengaruh Aktivasi Arang Tempurung Kelapa dengan Asam Sulfat dan Asam Fosfat untuk Adsorpsi Fenol. *E-Universitas Diponegoro*, *4*(1), 1–12.

Dąbrowski, A., Podkościelny, P., Hubicki, Z., & Barczak, M. (2005). Adsorption of phenolic compounds by activated carbon - A critical review. *Chemosphere*, *58*(8), 1049–1070. https://doi.org/10.1016/j.chemosphere.2004.09.067

Edward Tandy, Ismail Fahmi Hasibuan, & Hamidah Harahap. (2012). Kemampuan Adsorben Limbah Lateks Karet Alam Terhadap Minyak Pelumas Dalam Air. *Jurnal Teknik Kimia USU*, *1*(2), 34–38. https://doi.org/10.32734/jtk.v1i2.1416

Effendi & Hefni. (2003). Telaah Kualitas Air: Bagi Pengelolaan Sumber Daya dan Lingkungan Perairan. Yogyakarta. Penerbit: Kanisius.

France, E. De. (1991).**血清及尿液特定蛋白**检测在糖尿病肾病早期诊断中的意义, *6*(4), 1380–1385.

Guo, J., Luo, Y., Lua, A. C., Chi, R. an, Chen, Y. lin, Bao, X. ting, & Xiang, S. xin. (2007). Adsorption of hydrogen sulphide (H2S) by activated carbons derived from oil-palm shell. *Carbon*, *45*(2), 330–336. https://doi.org/10.1016/j.carbon.2006.09.016

Gupta, V. K., Sharma, S., Yadav, I. S., & Mohan, D. (1998). Utilization of bagasse fly ash generated in the sugar industry for the removal and recovery of phenol and p-nitrophenol from wastewater. *Journal of Chemical Technology and Biotechnology*, *71*(2), 180–186. https://doi.org/10.1002/(SICI)1097-4660(199802)71:2 <180::AID-JCTB798>3.0.CO;2-I

Hendra, D., & Darmawan, S., (2007). Sifat Arang Aktif dari Tempurung Kemiri. *Jurnal Penelitian Hasil hutan, 25(4), 291-302.*

Lelifajri. (2010). Adsorpsi Ion Logam Cu(II) Menggunakan Lignin dari Limbah Serbuk Kayu Gergaji, *Jurnal Rekayasa Kimia dan Lingkungan*.7 (3), 126-129.

Lu, W., & Chung, D. D. L. (2001). Preparation of conductive carbons with high surface area. *Carbon*, *39*(1), 39–44. https://doi.org/10.1016/S0008-6223(00)00077-4

Misran, E. (2009). Pemanfaatan kulit coklat dan kulit kopi sebagai adsorben ion Pb dalam larutan. *Jurnal Sigma*, *12*(1), 1–7.

Mozammel, H.M., Masahiro, O., Bhattacharya SC. (2002). Activated charcoal from coconut shell using ZnCl2 activation. *Biomass and Bioenergy*, 22. 397 – 400.

Purnamawati, H., & Utami, B. (2014). Pemanfaatan Limbah Kulit Buah Kakao (*Theobroma cocoa L*) Sebagai Adsorben Zat Warna Rhodamin B. *Prosiding Seminar Nasional Fisika Dan Pendidikan Fisika (SNFPF)*, *5*(1), 12.

Rahmadani, N., & Kurniawati, P. (2017). Sintesis dan Karakterisasi Karbon Teraktivasi Asam dan Basa Berbasis Mahkota Nanas. *Prosiding Seminar Nasoinal Kimia Dan Pembelajarannya 2017*, (November), 154–161.

Siti Munfiah, R. M. P. A. (2015). Kemampuan Karbon Aktif Tongkol Jagung dalam Menurunkan Kekeruhan Air. *Medsains*.

Surabaya, U. N., & Ketintang, J. (2013). Adsorpsi Pb^{2+} oleh Arang Aktif Sabut Siwalan (*Borassus flabellifer*). Jurusan Kimia FMIPA, Fakultas Matematika dan Ilmu Pengetahuan Alam, *2*(3), 82–87.

Surest, A. H., Kasih, J. A. F., & Wisanti, A. (2008). Pengaruh suhu, konsentrasi zat aktivator dan waktu aktivasi terhadap daya serap karbon aktif dari tempurung kemiri. *Jurnal Teknik Kimia*, *15*(2), 18. Retrieved from http://jtk.unsri.ac.id/index.php/jtk/article/view/49/50

Wieber, J. F., Kuick, B., Zuman, P. (1988) Sorption of lignin, wood celluloses, copper (II) and zinc (II) ions, *Colloid and Surface* 33, 141-152.

Wijaya.M, M., & Wiharto, M. (2017). Characterization of Cacao Fruit Skin for Active Carbon and Green Chemicals. *JKPK (Jurnal Kimia Dan Pendidikan Kimia)*, *2*(1), 66. https://doi.org/10.20961/jkpk.v2i1.8520

Yetri, Y., Marantika, D. A., Alamsyah, T., Alif, M. F., & Zein, R. (2020). Contribution of Activated Carbon Based on Cacao Peels (*Theobroma cacao L.*) to Improve the Well Water Quality (COLOR, BOD, and COD). *IOP Conference Series: Materials Science and Engineering*, *846*(1). https://doi.org/10.1088/1757-899X/846/1/012003

Yetri, Y., Sukatik. (2017). Green Inhibitor for Mild Steel in Acidic Solution by Using Crude Extract and Polar Extract of *Theobroma cacao* Peels, *Oriental Journal of Chemistry*, 33(4), 2071-2079. http://dx.doi.org/10.13005/ojc/330456

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Modelling Green Production Process in the Natural Dyes Batik Industry Using Cleaner Production Options

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ABSTRACT

Sustainable production policy has encouraged batik industry to switch synthetic dyes to natural dyes. However, the production process still brings negative impacts on the environment and humans. To solve this problem, the batik industry needs to develop green production process model using cleaner production options. The purpose of this research is to identify opportunities for implementing cleaner production, to select clean production options, and to present a green production process model of the natural dyes batik industry. The research was conducted in the natural dyes batik industry "Mbah Guru". Mbah Guru Industry is located in Lamongan, East Java. The research used Bayes method to assess and determine cleaner production options based on technical, economical, and environmental aspects. The last decision making of the options was used a feasibility study by using Pay Back Period (PBP). The Bayes method was used to make conclusions quickly. The results showed that Mbah Guru Industry produces waste per year as much as 72 kg of wax waste, 648 kg of ginger and natural dyes material waste, and 42.075 m^3 of wastewater. The wastewater contains BOD of 343.71 mg/L, COD of 1352 mg/L, TSS of 2828.57 mg/L, oil and fat of 5.97 mg/L, and pH of 3.65. The best option is "natural dyes wastewater reusing". it becomes the most priority of the options and has the best feasibility value with a payback period of 0.11. The batik industry will be more profitable if it is able to implement the recommended process improvements so that the negative impacts, both on the environment and humans, can be minimized. The model would give a clear guidance to existing entrepreneurs and aspiring entrepreneurs on how to green the natural dyes batik industry.

1. INTRODUCTION

Batik is a patterned cloth with coloring by traditional techniques using wax (Syahputra & Soesanti, 2016) that is globally known as Indonesian heritage. Batik has good potentials in economy and social. The Industrial Ministry of Republik Indonesia (2019) reported that batik export in the first semester of 2019 reached US $ 17.99 million. Batik industry also has a role in empowering women's welfare because most of the workers are women (Al Rasyid & Asri, 2017).

Recently, the increased environmental awareness and pollution control have encouraged the use of natural dyes. They were considered non-allergenic, less toxic, non-carcinogenic, and more biodegradable than synthetic dyes (Maulik, Bhowmik, & Agarwal, 2014). And also today mostly, batik craftsmen have realized the importance of this. However, natural dyes batik industry still gives negative impacts on the environment and humans. It uses water excessively and the wastewater contains total suspended solids (TSS), chemical oxygen demand (COD), biological

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oxygen demand (BOD), and color in high value, so has certainly contributed to pollution (Handayani, Kristijanto, & Hunga, 2018a). It also still causes several diseases like respiratory disorders, skin diseases, kidney problems, low back pain (Hunga, 2014).

For the solution of this case, in Indonesia, sustainable policy production encouraged businesses to move to cleaner production (Handayani, Kristijanto, & Hunga, 2018b). Nevertheless, there are several problems in batik SMEs for the application due to the lack of information on the characteristics and hazard levels of batik waste, the lack of information on appropriate technology for batik waste, and there is no information about waste management models that are easily understood by them.

Many researches have been carried out related to study and application of cleaner production in batik industry, including research conducted by Nurdalia (2006), Suhardi, Laksono, & Fadhilah (2017), Hasibuan & Hidayati (2018), Sirait (2018), Fauzi & Defianisa (2019), and Riyanto, Subaderi, & Nafi (2019). Nurdalia (2006) investigated at three stamped batik SMEs with synthetic dyes in Pekalongan (Clarasita, Fayza, Ismi). The research showed that each operating unit was inefficient, the saving measures taken were not significant, the waste discharge and pollution load were greater than the maximum threshold. The conducted research by Suhardi, Laksono, & Fadhilah (2017) at Batik Puspa Kencana SME in Surakarta City (batik with synthetic dyes) found that cleaner production can be implemented by purchasing raw materials as needed and at the right time.

Hasibuan & Hidayati (2018) researched in Batik Bogor (written batik, stamped batik, combination batik, and printing batik with synthetic and natural dyes). Cleaner production innovations that have been successfully applied are substitution of toxic dyes to non-toxic dyes, the use intensity of non-renewable energy reducing, solid waste reusing, and solid waste recycling. "Mosaic Batik" is one of the innovations of the solid waste batik utilization. Sirait (2018) ran the research at Batik Celaket SME in Malang (written batik industry with synthetic dyes). It resulted that the application of cleaner production can significantly reduce environmental impacts in terms of reducing COD of 89%, BOD of 85%, and TSS of 98%.

Fauzi & Defianisa (2019) researched at batik SMEs in Bogor, Batik Bumiku (natural dyes), and Batik Tradisiku (synthetic dyes). The quick scan results showed that the process of coloring, soaking, and rinsing are the main contributor to dyes waste. The use of natural dyes is considered the best strategy for realizing an environmentally friendly and sustainable batik industry, and the use of a bucket under the drying cloth to resist falling water is recommended as the best option. The conducted research by Riyanto, Subaderi, & Nafi (2019) at written batik SMEs with synthetic dyes in Jetis Village, Sidoarjo (Namiroh, Dahlia, Azizah) found that the most feasible alternative technology applied to the Batik SMEs Sidoarjo is the application of appropriate technology for coloring process which can improve eco-efficiency in the production process of the batik-writing UKM in Jetis Village, Sidoarjo.

Table 1. Characteristics of Natural Dyes Batik Waste, Synthetic Dyes Batik Waste, and Quality Standards

Parameter	**Natural Dyes**		**Synthetic Dyes**		**Quality Standards (Regulation of Environmental Ministry Number 5 of 2014)**
	Dyeing (Handayani, Kristijanto, & Hunga, 2018a)	**Wax Removal and washing (Handayani, Kristijanto, & Hunga, 2018a)**	**Dyeing (Handayani, Kristijanto, & Hunga, 2018a)**	**Wax Removal and washing (Handayani, Kristijanto, & Hunga, 2018a)**	
pH	6.7	7.4	9.2	9.8	6.0-9.0
TSS (mg/L)	1470	16900	300	4200	50
Warna (PtCo)	15270	51500	204500	43800	-
COD (mg/L)	4000	16800	986.70	71200	150
BOD (mg/L)	209	380	185	237.82	60

Based on all findings, until now there has been no research related to designing a model for implementing cleaner production in the batik industry in Indonesia, specifically in the natural batik industry. Therefore, it is very important to conduct a research related to designing a Green Production Model using cleaner production options in the natural dyes batik industry.

This paper aims to identify opportunities for implementing cleaner production, to select clean production options for better management of batik waste based on feasibility study using payback period and determination of priority using Bayes Method, as well as to present a green production process model of natural dyes batik industry based on cleaner production options. The model was developed after a field research that conducted at one of the popular batik heritage tourist destination in Lamongan, known as Mbah Guru batik industry. Mbah Guru batik industry is a Small-Medium Enterprise (SME) that has applied natural dying process.

In this work, an ideal model of batik production process was developed based on cleaner production options. The model would give clear guidance to existing entrepreneurs and aspiring entrepreneurs on how to green the natural dyes batik industry by actualizing cleaner production options upon the whole production process which is the novelty of this research. The formulated model would make the cleaner production becomes more practical, therefore it could ease the batik industrial players to understand and adopt the cleaner production options into their production process.

2. METHOD

2.1. Subject of research

The research was conducted at Mbah Guru batik industry, Jugo Village, Sekaran, Lamongan, East Java. Mbah Guru batik industry is a natural dyes batik small-medium enterprise (SME) that was founded in 2016 and has become a tourist site for Lamongan culture advancement. It has marketed its batik fabric in the local and national markets and the production capacity is around 1500m /year. For measurement of wastewater quality was carried out at Surabaya Standardization Research Center (Baristand of Surabaya).

2.2. Data collection

The data collection process was carried out using several methods. Identification of materials, energy, and waste used descriptive analysis (literature study, observation, survey, questionnaire, and interview), priority determination of options used Bayes Method, and strategy formulation used a feasibility study. The Bayes method was selected to determine the options priority because it can be used to make conclusions quickly on cases with multiple sources of measurement that cannot be handled by other methods such as complex hierarchical models.

2.3. *Stages of the Research*

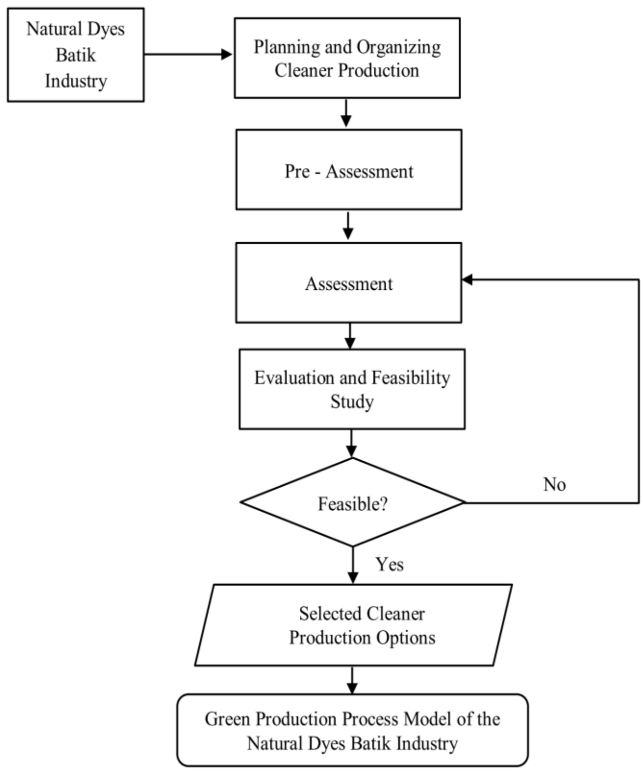

Figure 1. Flowchart of the research

2.3.1. Planning and Organizing Cleaner Production

At this stage, it focuses on obtaining the commitment of all members in the company, forming a competent team in the application of clean production, making environmental policies, setting goals and targets for implementing clean production, and preparing a study on the application of cleaner production (Gurbuz, Kiran-Ciliz, & Yenigun, 2004).

2.3.2. Pre – Assessment

At this stage, information searches are carried out regarding company profile data and process flow diagrams, an inspection of the batik production process, emphasizing at which points of cleaner production aspects must be applied (Gurbuz et al., 2004).

2.3.3. Assessment

The most important thing in this step is the collection of data related to the amount of resources used, the products, the waste, and the emissions produced. By conducting the material balance assessment, it will be known the amount of input components used and the resulting output components, where the total input must be the same as the total output. The waste minimization could be attempted after observing the mass balance calculation (Gurbuz et al., 2004).

2.3.4. Evaluation and Feasibility Study

This step is an evaluation of the options in the previous stage to find out which options are feasible to be implemented from the priority list of options for implementing cleaner production (Gurbuz et al., 2004).

2.3.5. Modelling Green Production Process

After determining the selected cleaner production options in the stage of Evaluation and Feasibility Study, a green production process model was designed. This model integrated the production process and the selected cleaner production options and also integrated several elements related to the batik industry. The formulated model would make the batik industrial players easy to understand the description of cleaner production implementation.

2.4. Data Analysis

The data analysis consisted of priority scale analysis and feasibility study to assess and determine the selected cleaner production options.

2.4.1. Priority Scale Analysis

Expert systems are to learn how to adopt an expert in thinking and reasoning to make decisions and conclude a number of facts (Apriani, Perwira, & Daulay, 2020). Bayes method is a method used to calculate the probability of an event (Perbawawati, Sugiharti, & Muslim, 2019 and Susanti & Manahan, 2020). Bayes probability is how to conquer data uncertainty (Sihotang, Riandari, Simanjorang, Simangunsong, & Hasugian, 2019).

The study began with a questionnaire on the selection of cleaner production options. The questionnaire was given to experts in batik and environment. Here used three aspects consist of technical aspect, economical aspect, and environmental aspect. The expert respondents filled out the questionnaire using a Likert scale from 1 to 5. The numbers show the low impact to high impact of criterion. Furthermore, the data was processed using Bayes method. According to Wardani, Aulady, Frido, & Hendri (2021), the calculation of the score in Bayes method for each criterion is:

$$\text{The total value } \mathrm{I} = \sum_{i=1}^{m} \mathrm{ij}\ (Criteria[\mathrm{ij}])$$

Note:

The total value of i		= The total value of the final value of the i- option
The value of ij		= The value of the i- option in the j-criteria
Critical j		= Level of importance (weight) the j criterion
i = 1,2,3, .. n;	n	= Number of options
j = 1,2,3, .. m;	m	= Number of criteria

Calculations to find the weight value per criterion, total weight, and probability value per criterion can be done in the following ways (Sibagariang & Riandari, 2019):

a. Weight Per Criterion is calculated by adding up the value of the options on each question for each criterion.
b. Total weight is calculated by adding up all of the weight values for each criterion.

c. Probability Per Criterion is calculated by calculating the weight per criterion divided by the total weight.
d. Total Probability, obtained by adding the overall probability value of each criterion with the total must be 1.

2.4.2. Feasibility Study of the Proposed Cleaner Production Options

Cleaner production options can save some money on the costs involved in production process and provide a new revenue source. Many Cleaner production options have a little cost, and can be very lucrative but others must be carefully analyzed to weigh their profitability. Economic feasibility analysis is carried out to determine whether cleaner production options are feasible or not. If the selected cleaner production options need costs for equipment installation or operation, a feasibility study is needed. Payback period is a quick method for comparing the options (Anonymous, 2005).

According to Anonymous (2005), the pay back period measures the ability to return on investment in terms of time. According to Anonymous (2016), the pay back period formula is:

Pay back period formula when the cash flow per year is the same

$$\text{Pay back period (in years)} = \frac{\text{Initial investment Cost}}{\text{Annual Operating Savings}}$$

Pay back period formula when the cash flow per year is different.

$$\text{Pay back period} = n + \frac{(a - b)}{(c - b)} \times 1 \text{ year}$$

Note:

n = The last year the amount of cash flow has not been able to cover the initial investment cost
a = The initial investment amount
b = The cumulative amount of cash flows in year n
c = The cumulative amount of cash flows in year (n + 1)

If an investment option has a faster payback period than the economic life, the option is feasible. If an investment option has a longer payback period than the economic life, the option is not feasible. If there are more than one proposed investment options, the earlier payback period will be selected.

3. RESULTS AND DISCUSSION

3.1. Planning and Organizing Cleaner Production

Mbah Guru Batik Industry has a policy to take actions that lead to the creation of an environmentally friendly industry, one of which is by switching from synthetic dyes to natural dyes, utilizing the extraction wastewater to water dyes plants, providing gardens so as not to buy dyes from outside so that it can save energy and avoid damaging the material due to excess supply caused it has expired, the use of sack waste for safety from wax droplets when chanting process, providing infiltration wells for waste treatment, and utilization of extraction dregs for making compost but composting is done only by adding rice washing wastewater to the dregs.

According to Sirait (2018), material input substitution by switching chemical dyes to natural dyes indicated that significantly improved the environmental performance by reducing BOD of 85%, COD of 89%, and TSS of 98%. The application of cleaner production is intended to increase productivity, reduce costs, and can become a pilot batik industry, especially in waste management. The target of implementing cleaner production is directed at materials, water, energy, occupational health and safety, waste, and pollution.

3.2. Pre-Assessment

3.2.1. Natural Dyes Batik Making Process

Before batik making process, we should make mordant solution and natural dyes solution first. For mordant solution preparation, here using alum, soda ash, chopped ginger, and water. Chopped ginger is covered using a small piece of cloth so that its dregs do not contaminate the solution. Furthermore, alum, soda ash, chopped ginger, and water are boiled together. For natural dyes solution preparation, here used natural dyes material which is cut and mashed. After that, it is extracted by cooking it in table salt solution. Let it cool and filter it using sieve.

In the initial step of natural dyes batik making process is the fabric providing by soaking it in Turkish Red Oil (TRO) solution or concentrate detergent solution to remove starch that effects the quality of coloring. After that, the fabric is washed and let it dry naturally in air drying. Then continued drawing pattern using pencil. Drawing pattern can be directly or by copying the pattern behind the fabric. After it, followed by pattern framing, pattern frame filling, pattern frame copying on the back surface, and the certain parts covering processes by applying hot wax using canting. After applying wax, the fabric is washed by soaking in TRO solution, washed using water, and dried using air drying.

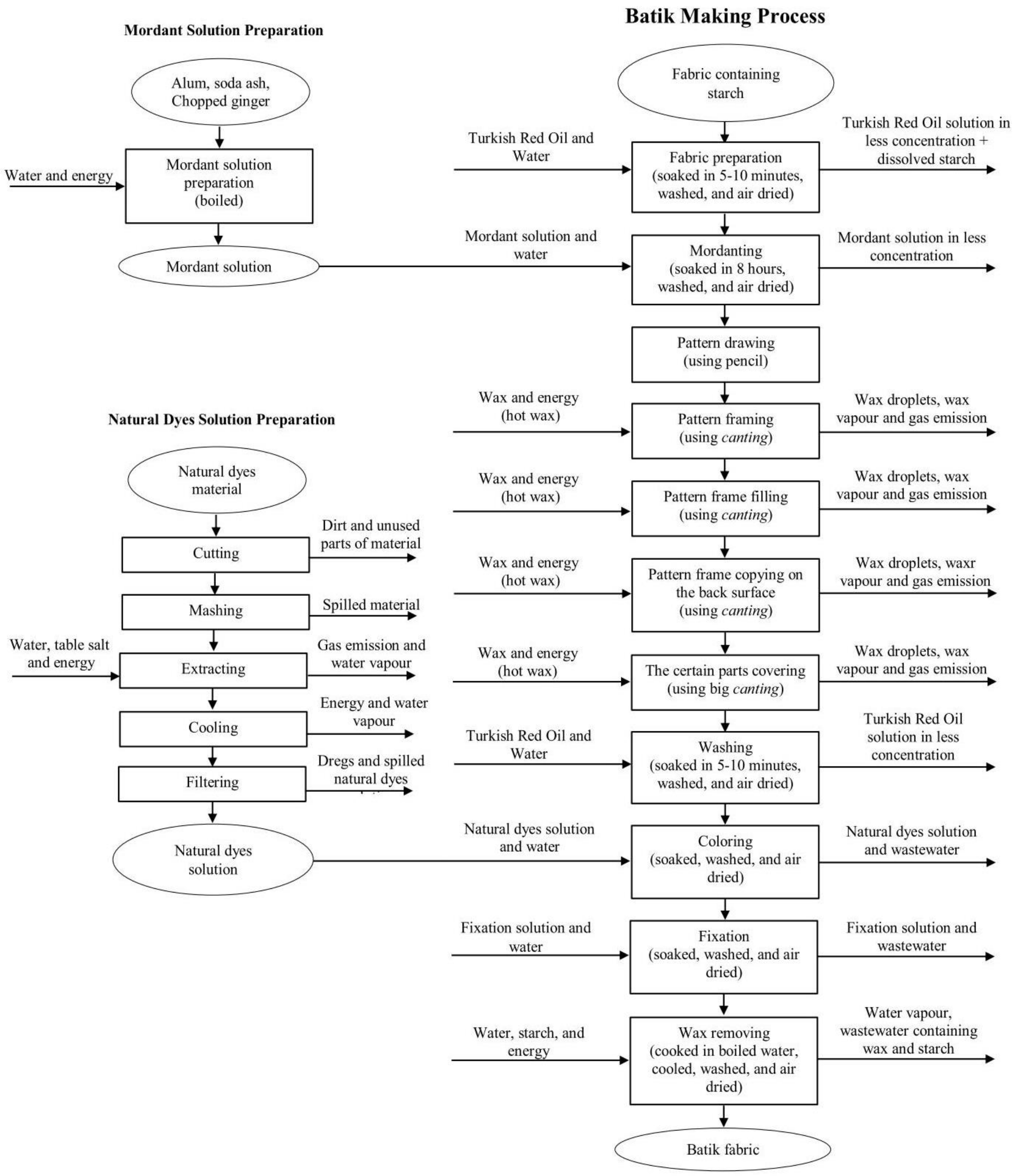

Figure 2. Flowchart of Batik Making Process

Table 2. The Requirement Structure of Material, Water and Energy Per Meter of Output with the Benchmark Data Structure

No.	Materials Requirement	Unit	Benchmark Data (Nurdalia, 2006)	Mbah Guru
1	Dyes	gram	0.5-6**)	3.52
2	Wax	gram	100-150*)	100
3	Water	liter	25-50	33
4	Electricity	kWh	5-15	178
5	Kerosene	ml	25-50	150
6	Firewood	gram	100-150	450

*) depending on the motive

**) the requirement per color

Table 3. Comparation of Quality Mbah Guru Wastewater and Quality Standards

Parameter	Wastewater Quality of Mbah Guru *)	Quality Standards	
		Regulation of Environmental Ministry Number 5 of 2014	East Java governor Regulation No. 72 of 2013
BOD (mg/L)	343.71	60	60
COD (mg/l)	1352	150	150
TSS (mg/L)	2828.57	50	50
Minyak dan lemak (mg/L)	5.97	3.0	3.0
pH	3.65	6.0-9.0	-

*) test results in Baristand of Surabaya

Furthermore continued by coloring, fixation, and wax removing processes. In coloring process, the fabric is soaked in natural dyes solution, washed using water, and air dried. In fixation process, the fabric is soaked in the fixation solution, washed using water, and air dried. In wax removal, add starch to water and boiled. Enter the fabric into the water. After all the wax is removed, take the fabric and cool it. And then it is washed using water and dried using air drying.

3.2.2. Input Requirement and Produced Output

From 1500 m of batik cloth produced, approximately are needed 52.78 kg of natural dyes, 150 kg of wax, 49.5 m^3 of water, 266.27 kWh of electricity, 225 liters of kerosene, 168.75 kg of firewood, and 120 kg of gas. Kerosene is used for chanting process, firewood is used for wax removing process and gas is used for mordant solution preparation, extraction, and sometimes for wax removing. If the price of gas is converted to the price of firewood, it is equivalent to about 506.25 kg of firewood. Firewood is selected as comparation because the price is cheaper than kerosene. To find out whether the requirement structure of material, water, and energy per meter of product is efficient or not, it is necessary to compare it with the benchmark data structure as in Nurdalia (2006) as follows.

Based on **Table 2**, can be seen that the use of electricity, kerosene, and firewood is above the benchmark. This indicates that there are inefficiencies in the use of electricity, kerosene, and firewood. The waste of electricity use because the volume of production is still below production capacity. The waste of kerosene occurs because of the waiting time and the insufficient amount of the cloth in one chanting process. Likewise with firewood, there is waste due to the waiting time and the amount of the cloth is still below the capacity in every wax removing process. The use of dyes and water is actually quite efficient, but efforts can still be made to increase efficiency.

Mbah Guru Batik Industry produces 72 kg of wax waste per year, 648 kg of ginger and natural dyes material waste per year, and 42,075 m^3 of wastewater per year. The resulted wastewater is 85% of the water requirement as according to Indrayani (2018). So far, the wax waste is partially reused, the extraction dregs for making compost, and the wastewater is disposed of into infiltration wells. The main problem of environment in the batik industry is the wastewater in high pollutant levels (Dasgupta, Sikder, Chakraborty, Curcio, & Drioli, 2015). To determine wastewater quality, a laboratory wastewater assessment was carried out and the results as in **Table 3**.

Based on **Table 3**, it can be seen that the quality of the wastewater produced in Mbah Guru for all parameters still does not meet the quality standards so that it needs treatment. The high concentrations of BOD, COD, and TSS in wastewater are caused by the high content of organic materials and chemicals. The characteristics of the wastewater occur because the raw materials used are organic materials. The organic material is broken down by microorganisms so that the BOD and COD concentrations of wastewater are high (Sirait, 2018). Both pollution and water inefficiency cause water scarcity. Efforts are needed to prevent scarcity (Handayani, Kristijanto, & Hunga, 2018a).

Table 4. Proposed Cleaner Production Options

Operation Units	Proposed Cleaner Production Options in Each Operation Unit	**Proposed Cleaner Production Options for Selected**
Fabric preparation	1. The washing process should not be carried out in water flow but carried out in 2 stages of washing using washtub 2. Use of the washing wastewater for fertilizer	1. Two steps washing for all washing processes 2. Fertilizer making from natural dyes wastewater 3. Wastewater treatment from mordanting, fixation, and wax removing processes 4. Utilization of ginger waste and natural dyes material waste for composting 5. Natural dyes wastewater reusing 6. Wax recycling 7. Masks and gloves using
Mordanting	1. Treatment of the mordanting wastewater 2. Utilization of solid waste for composting	
Waxing	1. Use of gloves 2. Use of masks	
Natural dyes preparation	1. Utilization of dirt or unused parts of material for composting 2. The spilled material for composting 3. Use of dregs from the extraction process for composting	
Washing	1. The washing process should not be carried out in water flow but carried out in 2 stages of washing using washtub 2. Use the washing wastewater for fertilizer	
Coloring	1. Reuse of the wastewater for the next day's coloring processes 2. The wastewater that can not be used for the coloring process again is used for making fertilizer	
Fixation	1. Utilization of the calcium oxide waste for wastewater treatment 2. Treatment of the fixation solution wastewater	
Wax removing	1. Treatment of wax removing wastewater after the wastewater can not be used again 2. Wax recycling 3. Use of masks 4. Use of gloves	

Table 5. Criteria Weighting by Experts

No.	Criteria	Score			Total	Bayes Weight
		R1	R2	R3		
1	Technical Aspect	2	3	3	8	8/34 = 0.24
2	Economical Aspect	5	3	4	12	12/34 = 0.35
3	Environmental Aspect	5	4	5	14	14/34 = 0.41
Total weight					34	1

3.2.3. Identification of Cleaner Production Options

The cleaner production implementation contributes significantly in improving the performance of environment during the batik production (Sirait, 2018). The production process was observed to discover where cleaner production opportunities can be run. The production process consists of several operation units. A walking-through process was carried out at each operation unit to analyze what cleaner production options can be proposed. After making several suggestions for cleaner production options, they were summarized for analysis. The proposed cleaner production options can be seen in **Table 4**.

There are several processes that should be carried out on a large scale to save on the use of water, kerosene, dyes, fixation solutions, or firewood which will provide benefits if done. However, this option cannot be proposed because the company is still producing according to order and the orders are still limited, so the number of batik produced per day cannot be determined. In order to save the electricity usage, the production volume should be increased. However, this cannot be done because it has to adjust to market demand. Therefore, this option was not proposed. Initially, the use of wax waste was only partial. In this option, it is proposed to recycle all wax waste and reuse it for the purposes of the production process. Initially, the extraction liquid waste was only used for watering the plants, here it is proposed to make liquid fertilizer.

Extraction dregs are used for composting. From the proposed options, not only extraction dregs which are used for composting but also ginger waste from the mordanting process and waste of unused dyes material from the cutting process and spilled dyes material from the mashing process. In addition, the compost that was made not only used rice washing water but also added bioactivators. This is because the rice washing water only lasts for one day and after that, it will stale and the microbes in it will die so it is necessary to add a bioactivator as a decomposer material.

For the waste that enters the infiltration wells, the option proposes decrease in volume by proposing "two-stage washing" option which can reduce the volume of washing wastewater by almost 50%. In addition, activated charcoal is added as an ingredient for wastewater treatment where initially it only uses palm fiber, sand, gravel, and bricks. Activated carbon is very important to add, especially to absorb chemicals used during the batik-making process.

3.4. Selection of Cleaner Production Options

The implementation of cleaner production is based on three aspects, namely technology, policy, and finance (payback period) (A. M. Fauzi, Rahmawakhida, & Hidetoshi, 2008). Policy priorities or option priorities were analyzed using the Bayes method.

3.4.1. Priority Determination Using Bayes Method

After determining what the cleaner production options would be analyzed, we determined the priority scale of them using Bayes Method to sort out which the cleaner production options should take precedence.

3.4.1.1. Criteria Weighting

Based on information obtained from several literatures, 3 criteria for selecting cleaner production options were used. They are technical aspect, economic aspect, and environmental aspect. The technical aspect relates to the time of production process is not too long, the high resulted yield, the convenience of the option implementation, either in terms of equipment procurement or operation. The economic aspect relates to the significance of added value provided by the option and considers the costs required and the benefits obtained. The environmental aspect relates to the given effect significance of the option implementation to the environment based on reducing waste and improving environmental performance. The weighting criteria were carried out by experts which would be the basic in determining the Bayes weight.

In **Table 5** can be seen that the highest criterion weight is the environmental aspect of 0.41 and followed by the economical aspect of 0.35. This shows that the environmental aspect and economical aspect are priorities taken into consideration in selecting cleaner production options. As in study of Ulya & Hidayat (2018), these criteria are expected to have an effect on reducing the generation of waste both solid waste and liquid waste around the industry without neglecting the production costs that will become a burden to the industry. In contrast to the research results of Suhardi, Laksono, & Fadhilah (2017) where after environmental criteria, technical criteria are the priority for consideration. This is due to the different characteristics of the proposed options where they do not really need economic considerations because they do not require costs or are very affordable.

Table 6. Options Weighting to the Criteria

No.	Cleaner Production Options	Criteria			Option Weight	Priority Scale
		Technical Aspect	Economical Aspect	Environmental Aspect		
1	Two steps washing for all washing processes	4.3	4	4.3	4.195	3
2	Fertilizer making from natural dyes wastewater	4	4.3	4.7	4.392	2
3	Wastewater treatment from mordanting, fixation, and wax removing processes	3	3.3	4	3.515	6
4	Utilization of ginger waste and natural dyes material waste for composting	4	3.7	4.3	4.018	5
5	Natural dyes wastewater reusing	4.7	5	5	4.928	1
6	Wax recycling	3	4.3	4.7	4.152	4
7	Masks and gloves using	3.7	3.3	2.3	2.986	7
	Bayes Weight	0.24	0.35	0.41		

Table 7. Economic Feasibility Analysis of the Cleaner Production Options

No.	Cleaner Production Options	Investment Cost	Annual Operating Saving	Payback Period	Feasibility
1	Two steps washing for all washing processes	60,000 rupiahs	65,160 rupiahs	0.92 years	Feasible
2	Fertilizer making from natural dyes wastewater	224,000 rupiahs	3,940,000 rupiahs	0.057 years	Feasible
3	Wastewater treatment from mordanting, fixation, and wax removing processes	300,000 rupiahs	336,180 rupiahs	0.89 years	Feasible
4	Utilization of ginger waste and natural dyes material waste for composting	150,000 rupiahs	624,000 rupiahs	0.24 years	Feasible
5	Natural dyes wastewater reusing	1,300,000 rupiahs	11,591,017.5 rupiahs	0.11 years	Feasible
6	Wax recycling	200,000 rupiahs	1,632,960 rupiahs	0.12 years	Feasible
7	Masks and gloves using	120,000 rupiahs	70,000 rupiahs	0.58 years	Feasible

3.4.1.2. Options Weighting to the Criteria

The next step is options weighting to the criteria. Results of the each options weighting to several criteria were determined by the experts and can be seen in **Table 6**.

From the data in **Table 6** we can see that the most priority of the cleaner production options is "natural dyes wastewater reusing" and followed by "fertilizer making from natural dyes wastewater", "two steps washing for all washing processes", "wax recycling", "utilization of ginger waste and natural dyes material waste for composting", "wastewater treatment from mordanting, fixation, and wax removing processes", and "masks and gloves using". "Natural dyes wastewater reusing" is the most important to be implemented, reviewed based on technical, economic, and environmental criteria. Based on technical criteria, it is very easy to implement because it has no process before reusing process. Based on economic and environmental criteria, this option become the best option because a large initial cost is only for providing refrigerator, the operating costs are very little, and it provides significant economic and environmental benefits. By reusing dyes waste as a coloring agent can reduce the cost of procuring dyes and indirectly reduce the negative impact on the environment because the amount of waste generated can be reduced. Production operators have to really maximalize in using dyes before 3 days so that they can save more on the use of dyes and can also reduce dyes that become waste.

On the other hand, "masks and gloves using" is the least priority. Based on technical criteria, "masks and gloves using" is clear that it is very easy to do because it is just a matter of procuring or purchasing masks and gloves. However, from an economic point of view, it requires routine costs with the same expenditure in each period, while the benefits that are obtained are only benefits related to worker health and safety, namely improving the health of workers because workers are protected from inhaling gas pollution and also protecting their hands from being exposed to chemicals during processes that use chemicals and hot steam during the processes of boiling water or hot wax when chanting processes.

3.5. Feasibility Study

After we knew whether the cleaner production options are feasible or not, we conducted Economic Feasibility Analysis on them. If they are feasible, the cleaner production options would be selected to be implemented or for making green production process model.

Based on **Table 7** we can see that the payback period of each option is under one year and all of the cleaner production options are feasible. It means that they can be implemented in this industry. "Fertilizer making from natural dyes" has the shortest payback period with significant profit but requires total of the operational cost more than twice of total of the profit. "Two steps washing for all washing processes" has the longest payback period, almost one year but does not require operational cost at all and the equipment procurement costs are quite little (only 60,000 rupiahs) even though the annual profit is the same (65,160 rupiahs). "Natural dyes wastewater reusing" has the second shortest payback period with a large equipment procurement cost, but the benefit is very significant.

The feasible options that have a high priority are is a priority to implement because according to Sirait (2018), they would be effective for improving environmental performance. In this research, the option of "Natural dyes wastewater reusing" becomes the best option to implement because besides having the highest priority, it also has the best feasibility value with a payback period value of 0,11. Another reason that the option is easy to do because it can be done even though there is a limited time or a lack of knowledge of either the owner or the workers.

3.6. Green Production Process Model

The last step is green production process model making. According to Yaacob & Zain (2016), a green batik industry model resulted from green options is proposed to give benefit to the planet, profits and people. Because all of the cleaner production options are feasible, so they are all selected for making green production process model. In modeling, to avoid a confusion, different line colors were used for each option. The model of green batik production process can be seen in **Figure 3**.

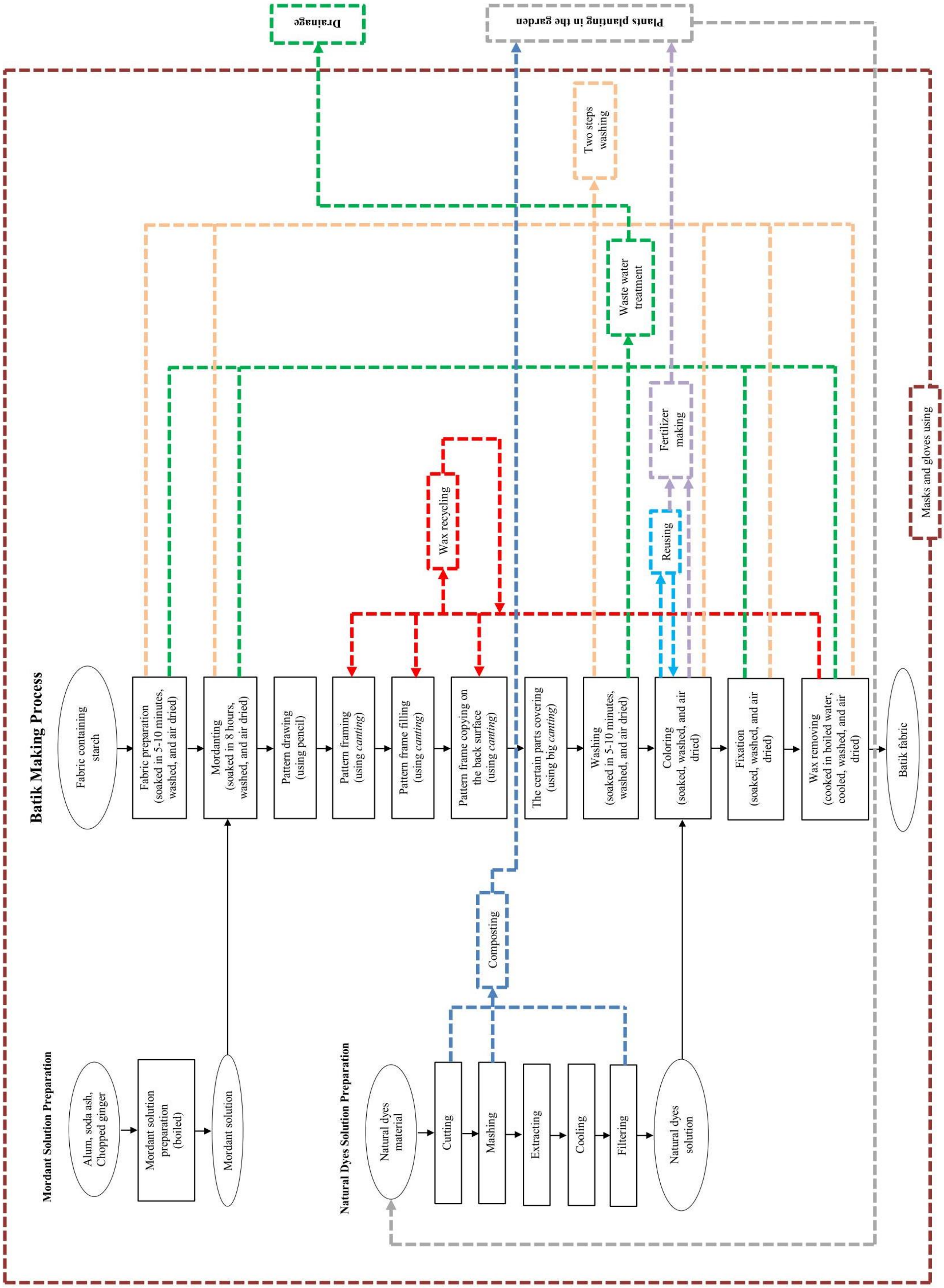

Figure 3. Green Batik Production

The produced solid waste in the preparation of the natural dye, from the cutting, mashing, and filtering processes goes into the composting process where the produced compost will be used for planting dye plants in the garden. All of the washing processes in the fabric preparation, mordanting, washing, coloring, fixation, and wax removing processes use "two steps washing". The wastewater from the fabric preparation, mordanting, washing, fixation, and wax removing processes goes into "wastewater treatment" process where the treated water will be discharged to drainage.

The natural dyes solution (after used) from the coloring process is stored to go into the reusing process in the next day. However, after the natural dyes solution can no longer be used, it and the wastewater from washing in coloring process will enter the fertilizer making process and the produced fertilizer will be used to fertilize the natural dye plants in the garden. All waste waxes from the waxing processes and from the wax removing process goes into the wax recycling process. The recycled wax is reused for the waxing process. During the production process, all workers are required to wear masks and gloves for occupational health and safety.

Mbah Guru Batik Industry has a large area for planting natural dye plants. The various types of plants are planted there. Mbah Guru Batik Industry also has a waste treatment facility, in the form of infiltration wells. The taken action plan on the waste is adjusted to the availability of the owned facilities. It is the reason why the produced fertilizers are not sold but used for internal purposes and the wastewater treatment uses infiltration wells.

In contrast to the results of research by Malaysian Department of Environment (2013) in Yaacob & Zain (2016) where model was built from options consisting of good ventilation, reusable wax produced for patterning batik, sell off excess wax, prepare a sealed dye container and labeled, soaking the fabric in bulk, recycling of surplus raw materials, provide proper drainage system to be channeled directly into the treatment system, and provide an appropriate water treatment system. This is because the conditions that occur in each company, the types of dyes used, and the policies in each company are different.

At Mbah Guru batik industry, there is no need to improve ventilation because the production site is designed to be open, no sales of wax are carried out because it is not excessive, it is not recommended to provide tightly closed containers and labeling because of no dyes stocking. The storage of dyes is carried out for dyes that have been used which will be reused the next day and the storage and labeling processes have been carried out properly. There is also no option for providing a wastewater treatment system because it is already available and no option to connect between the drainage system and the wastewater treatment system because they have been well connected. Raw material surplus is related to company policy in raw material procurement. Here it is not proposed to recycle the surplus raw materials because the material procurement arrangements are well organized. it also does not recommend the soaking in bulk because the orders are still limited.

In the research of the Malaysian Department of Environment (2013) in Yaacob & Zain (2016), it is not recommended to reuse dyes wastewater, make compost, make liquid fertilizer because the dyes used are synthetic dyes. It is also not recommended to use masks and gloves because safety and health protection to the workers have been carried out properly.

4. CONCLUSION

Based on the results, the best cleaner production option is "natural dyes wastewater reusing". It has the highest priority and the best feasibility value with a payback period of 0.11. The results of this study could be explicitly implemented to Mbah Guru Batik Industry and other similar industries by using several adjustment variables for financial calculations. The Lamongan Regency Government can provide funding to help Mbah Guru Batik Industry initiate the implementation of cleaner production options to become a pilot batik industry for other batik industries.

Among the cleaner production options identified for upgrading Mbah Guru Batik industry to a green batik industry such as "natural dyes wastewater reusing", "fertilizer making from natural dyes wastewater", "two steps washing for all washing processes", "wax recycling", "utilization of ginger waste and natural dyes material waste for composting", "wastewater treatment from mordanting, fixation, and wax removing processes", and "masks and gloves using" which should be applied in the industry for greening the batik industry to prevent the negative impacts on humans and the environment. The model would give a clear guidance to existing entrepreneurs and aspiring entrepreneurs on how to green the natural dyes batik industry using cleaner production options upon the whole production process. For the future research can be made a research related to modelling in natural dyes batik industry but without having empty land for gardening and infiltration wells for water treatment so that can give different analysis.

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REFERENCE

Al Rasyid, M. R., & Asri, R. W. P. (2017). Waste Prevention Effectiveness of Batik Production in Yogyakarta, Indonesia. *ICoSI 2014*, 473–481. https://doi.org/10.1007/978-981-287-661-4_46

Anonymous. (2005). *Cost Analysis for Pollution Prevention. Hazardous Waste and Toxics Reduction Program, Department of Ecology, Washington State*.

Anonymous. (2016). *Engineering Economics*. Sam Ratulangi Manado University.

Apriani, W., Perwira, Y., & Daulay, S. (2020). Expert System of Pest Diagnosis in Passion Fruit Plants using the Bayes Theorem Method. *International Journal of Innovative Technology and Exploring Engineering*, *9*(4), 503–508. https://doi.org/10.35940/ijitee.d1312.029420

Dasgupta, J., Sikder, J., Chakraborty, S., Curcio, S., & Drioli, E. (2015). Remediation of Textile Effluents by Membrane Based Treatment Techniques: A State of the Art Review. *Journal of Environmental Management*, *147*, 55–72. https://doi.org/10.1016/j.jenvman.2014.08.008

East Java governor Regulation No. 72 of 2013 about Wastewater Quality Standards.

Fauzi, A., & Defianisa, R. (2019). Analysis for cleaner production implementation strategy in batik industry in Bogor Analysis for cleaner production implementation strategy in batik industry in Bogor. *IOP Conf. Series: Earth and Environmental Science*, *325: 01200*. https://doi.org/10.1088/1755-1315/325/1/012005

Fauzi, A. M., Rahmawakhida, A., & Hidetoshi, Y. (2008). Study on Cleaner Production Strategy in The Small Scale Tapioca Industry: A Case Study in Kelurahan Ciluar, North Bogor Sub-District. *Jurnal Teknologi Industri Pertanian*, *18*(2), 60–65.

Gurbuz, S., Kiran-Ciliz, N., & Yenigun, O. (2004). Cleaner production implementation through process modifications for selected SMEs in Turkish olive oil production. *Journal of Cleaner Production*, *12*(6), 613–621. https://doi.org/10.1016/S0959-6526(03)00121-5

Handayani, W., Kristijanto, A., & Hunga, A. (2018). A water footprint case study in Jarum village, Klaten, Indonesia: The production of natural-colored batik. *Environment, Development and Sustainability*, *21*(4), 1919–1932. https://doi.org/10.1007/s10668-018-0111-5

Handayani, W., Kristijanto, A., & Hunga, A. (2018). Behind the eco-friendliness of " batik warna alam ." *Wacana*, *19*(1), 235–256. https://doi.org/10.17510/wacana.v19i1.673.Downloaded

Hasibuan, S., & Hidayati, J. (2018). The Integration of Cleaner Production Innovation and Creativity for Supply Chain Sustainability of Bogor Batik SMEs. *International Scholarly and Scientific Research & Innovation*, *12*(5), 679–684. Retrieved from scholar.waset.org/1307-6892/10009386

Hunga, A. I. R. (2014). Threat of Ecological Destruction in Home-Based Batik Production: a Narrative of Protecting Domestic Sphere. *Jurnal Perempuan: Untuk Pencerahan Dan Kesetaraan*, *19*(1).

Indrayani, L. (2018). Batik Industry Wastewater Processing As One Pilot IPAL Batik in Yogyakarta. *ECOTROPHIC*, *12*(2), 173–184.

Maulik, S. R., Bhowmik, L., & Agarwal, K. (2014). Batik on handloom cotton fabric with natural dye. *Indian Journal of Traditional Knowledge*, *13*(4), 788–794.

Nurdalia, I. (2006). *Study and Analysis of Cleaner Production Opportunities in Stamped Batik Small Entreprise*. Universitas Diponegoro.

Perbawawati, A. A., Sugiharti, E., & Muslim, M. A. (2019). Bayes Theorem and Forward Chaining Method On Expert System for Determine Hypercholesterolemia Drugs. *Scientific Journal of Informatics*, *6*(1), 116–124. https://doi.org/10.15294/sji.v6i1.14149

Regulation of Environmental Ministry Number 5 of 2014 about Wastewater Quality Standards

Riyanto, O. A. W., Subaderi, & Nafi, A. S. (2019). Penerapan Produksi Ramah Lingkungan Pada Proses Produksi UKM Batik Tulis. *Prosiding PKM-CSR*, *2*.

Sibagariang, R., & Riandari, F. (2019). Decision Support System for Determining the Best Wood For the Production Cabinet in PT.Tanjung Timberindo Using Bayes Method. *Jurnal Mantik*, *3*(3), 99–103. Retrieved from https://iocscience.org/ejournal/index.php/mantik/index

Sihotang, H. T., Riandari, F., Simanjorang, R. M., Simangunsong, A., & Hasugian, P. S. (2019). Expert System for Diagnosis Chicken Disease using Bayes Theorem. *Journal of Physics: Conference Series*, *1230*(1). https://doi.org/10.1088/1742-6596/1230/1/012066

Sirait, M. (2018). Cleaner production options for reducing industrial waste : the case of batik industry in Malang , East Java-Indonesia. *The 4th International Seminar on Sustainable Urban Development. IOP Conf. Series: Earth and Environmental Science, 106: 01206.* https://doi.org/doi :10.1088/1755-1315/106/1/012069

Suhardi, B., Laksono, P. W., & Fadhilah, N. N. (2017). Analysis of Cleaner Production Implementation in Printed Batik at Batik Puspa Kencana SME In Laweyan Surakarta. *Jurnal Teknologi Industri Pertanian*, *27*(2), 182–191. https://doi.org/10.24961/j.tek.ind.pert.2017.27.2.182

Susanti, S., & Manahan, O. (2020). Disease Diagnosis Expert System At Chili Plants Using Bayes Method. *Journal Of Computer Networks, Architecture and High Performance Computing*, *2*(2), 292–296. https://doi.org/10.47709/cnapc.v2i2.432

Syahputra, R., & Soesanti, I. (2016). Application of Green Energy For Batik Production Process. *Journal of Theoretical and Applied Information Technology*, *91*(2), 249–256.

The Industrial Ministry of Republik Indonesia. (2019). Interested in the global market, batik export is targeted to increase by 8 percent. Retrieved August 10, 2020, from https://kemenperin.go.id/artikel/20650/Diminati-Pasar-Global,-Ekspor-Batik-Dibidik-Naik-8-Persen

Ulya, M., & Hidayat, K. (2018). Selection of the Best Alternative for Cleaner Production in the Cassava Chips Industry in Support of Sustainable Manufacturing. *Rekayasa*, *11*(2), 110–117. https://doi.org/10.21107/rekayasa.v11i2.4417

Wardani, M. K., Aulady, M. F. N., Frido, W., & Hendri, S. (2021). Determining the weight of the hammer based on expert experience for estimating load-carrying capacity. *IOP Conference Series: Materials Science and Engineering*, *1010*(1). https://doi.org/10.1088/1757-899X/1010/1/012041

Yaacob, M. R., & Zain, N. M. (2016). Modelling Green Batik Industry – A Strategy for Sustainability in the Craft Industry in Malaysia. *International Journal of Development and Sustainability*, *5*(2), 87–97. Retrieved from https://isdsnet.com/ijds-v5n2-4.pdf

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9 772087 096504