

Immobilization of resin photocatalyst

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CASE STUDY

Immobilization of resin photocatalyst in removal of soluble effluent organic matter and potential for disinfection by-products

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ABSTRACT

BACKGROUND AND OBJECTIVES: The existence of organic matter is one of the main issues for wastewater reclamation since chlorination is applied most frequently before use wastewater reclamation for many purposes. One of the eco-friendly and effective methods is using innovative material through resin immobilized heterogeneous photocatalyst, which is based on the principle of advanced oxidation processes. Resin immobilized photocatalyst has been using for pollutant reduction, however lack of studies focused on dissolved effluent organic matter and its impact on the formation carcinogenic as by-product of water or wastewater treatment. This study aims to characterize organic matter by resin immobilized photocatalyzed titanium dioxide and zinc oxide and to determine its effectiveness in removing organic matter and potential for disinfection by-products in treated wastewater compare with resin only.

METHODS: The bulk parameters, including total organic carbon, aromatic organic carbon as ultraviolet at 254 nm wavelength and specific ultraviolet absorbance value, and disinfection by-products formation potential, including trihalomethanes and haloacetic acids concentration was measured.

FINDINGS: The results present that all materials could remove organic carbon in the range 58.18% - 93.45%, aromatic organic carbon removal 48.77% - 76.51%, and specific ultraviolet absorbance value decreased into less than 2 L/mg-m after longer contact time. Disinfection by-products formation potential concentration removal decreased and indicated the consistency results with bulk parameters removal. Resin immobilized photocatalyzed zinc oxide performed a higher efficiency removal than resin immobilized photocatalyzed titanium dioxide and resin only.

CONCLUSION: This study exhibited the performance of resin immobilized photocatalyst with titanium dioxide and zinc oxide in removing dissolved organic matter and to control formation of disinfection by-products. A combination between bulk parameters and disinfection by-products formation potential removal concluded that the aromatic structure, was mainly haloacetic acids precursors, while the non-aromatic organic fraction was probably trihalomethanes precursors.

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INTRODUCTION

Wastewater reclamation has been an alternative way for conserving water resources for sustainable usage. It will continue to be the advantage of industries since it will reduce operational costs and decrease wastewater discharge quantity. Several methods have been designed for wastewater reclamation to remove organic matter using membrane filtration, adsorption onto activated carbon, chemical oxidation, removing suspended solids by filtration, removing nutrients by biological process, and removing pathogen disinfection processes (Englande et al., 2015). However, the usage of cost-effective, eco-friendly, and sustainable agents such as electrons, microorganisms, sunlight, and enzyme has been applied to degrade pollutants in the most effective ways to completely resolve the requirements for the quality of effluent wastewater reclamation (Yadav et al., 2019). The chlorination method, wastewater disinfection which is regarded as costly processes, is most frequently applied before use wastewater reclamation for many purposes. It is applied to protect humans against exposure to waterborne pathogenic microorganisms (Nieuwenhuijsen et al., 2009). However, the reaction between the existence of organic matter in treated water/wastewater and chlorine or the other chemical disinfection can rise the formation of carcinogenic and disinfection by-products (DBPs) that are positively detrimental to human and aquatic organisms (Liang and Singer, 2003; Bond et al., 2012; Hidayah et al., 2016). Even tertiary-treated wastewater can contain high total nitrogen (TN), and it lead to the other species of DBPs formation which caused by nitrogen, such as nitrosodimethylamine or NDMA (Najm and Trussell, 2001), and a high organic carbon concentration can conduct to the formation of numerous chlorinated DBPs species after exposure to chlorine (McBean et al., 2010). Although chlorine toxicity can be anticipated by dechlorinating the effluent before its usage, it does not reduce DBPs concentration (Verdugo et al., 2020). Therefore, it is necessary to consider the selected technology that could simultaneously reduce organic matter and remove pathogens during wastewater reclamation treatment. The alternatives of the greenness and efficiencies processes are an integration of nanotechnology with the conventional technique to enhance the quality of

effluent wastewater treatment. Ion exchange using resin technology is one of the promising physical treatment process to remove pollutant (Cornellisen et al., 2008). Resin is mainly used as ion exchange materials which are high molecular weight insoluble polyelectrolytes that can release counter ions to trap equally charged ions from surrounding liquid. Less information about harmful effect of resin has been reported, probably due to the usage of resin has been managed well. At the same time, it is unable to remove or break out the pollutants when solely utilized thoroughly. Using a new innovative material through resin immobilized heterogeneous photocatalyst with ultraviolet (UV) light or sunlight is based on the principle of advanced oxidation processes (AOPs) for wastewater treatment is an alternative material that could be applied in advanced technologies (Pachwarya and Meena, 2011; Bethi et al., 2016). The developed photocatalyst Methylene Blue Immobilized Resin Dowex-11 (MBIRD11) has been studied as an alternative process to remove high pollutants. However, it has not yet been opportunely implemented because of the economic issues and problems related to separating photocatalyst particles from the suspension after treatment (Pachwarya and Meena, 2011). The oxide semiconductor photocatalysts, such as titanium dioxide (TiO₂), have performed to be the most widely implemented due to their strong oxidizing power, long-term photostability, and non-toxicity (Uyguner et al., 2017). Recently, zinc oxide (ZnO) has been applied as an alternative photocatalyst to TiO₂ as it has the same bandgap energy and suitable highest quality of electrical, optical and mechanical properties but shows a higher efficiency of absorption across a significant compound of the solar spectra when compared to TiO₂ (Ong et al., 2018). In this study, the removal of bulk parameters of organic matter from tofu wastewater used for reclaimed water was investigated on resin only and resin immobilized with two different photocatalysts, namely TiO₂ and ZnO. Bulk parameters includes organic matter parameters through quantitative analysis, and qualitatively analysis through high performance size exclusion chromatography, which is fractionated organic matter based on its molecular weight. Fluorescence spectroscopy could assess organic matter based on its fluorophores organic matter (Sillanpää et al., 2015; Hidayah et al.,

2016). The results will be related to DBPs formation potential (DBPFP), including haloacetic acids (HAAs) and trihalomethanes (THMs). Roughly, this study exhibited characterization of organic matter and its impact on the possibility of the formation halogenated organic carbon through resin treatment. The aims of the current study is to characterize organic matter by resin immobilized photocatalyzed TiO_2 and ZnO and determine the effectiveness of resin immobilized photocatalyst TiO_2 and ZnO in removing organic matter and in reducing DBPFP of treated wastewater. This study has been carried out in Water Laboratory of University Pembangunan Nasional Veteran Jawa Timur Indonesia in 2021.

MATERIALS AND METHODS

This study used source water from the effluent of the settling tank after the activated sludge process in the tofu wastewater treatment plant in Surabaya, Indonesia, which was collected in July 2021. The first step was preparing resin-immobilized photocatalyst TiO_2 (RIP- TiO_2) and ZnO (RIP-ZnO) with ratio photocatalyst over Dowex-11 resin 1:10 in 1000 mL distilled water and shake well in the dark place for three days in order to complete immobilization. Further, filter both ZnO and TiO_2 immobilized resin from the solution, cleanse the resin with deionized water twice and utilize it as a photocatalyst (Pachwarya and Meena, 2009). The second step was experimenting with a simple photocatalytic reactor. Source water samples 1500 mL were put on the reactor mixer with three samples tested at a time, and 15 gram (g) of original Dowex-11 resin, 15 g of RIP- TiO_2 , and 15 g of RIP-ZnO was added and mixing at 50 rpm. Treated samples were collected twice every 30 – 60 minutes for 15 hours and filtered through a 0.45 μm cellulose acetate filter (Toyo Roshi, Japan) before further analysis. All samples have to be filtered in order to remove particulate organic matter, since this study focus on dissolved organic matter. The raw sample and treated sample were quantified for bulk parameter quantitative parameters to measure dissolved organic matter, such as total organic carbon (TOC), ultraviolet absorbance for aromatic carbon as detected at 254 nm (UV_{254}), according to protocol Standard Methods (APHA, 2012), and specific UV absorbance (SUVA) value with regard to the UV_{254} concentration over TOC concentration (Edzwald and Tobiason, 2011).

Measurement of aromatic organic matter has been well known at wavelength 254 nm, TOC quantified the dissolved organic carbon concentration, while SUVA value identified hydrophobicity and hydrophilicity organic matter (Sillanpää *et al.*, 2015). TOC was measured by using TOC Analyzer 5000A, Shimadzu. UV_{254} was quantified by using a UV/visible (UV/vis) spectrophotometer (Cary 100 Bio UV-Visible Spectrophotometer). Analysis of DBPs formation was initiated by adding sodium hydroxide (NaOH) or sulfuric acid (H_2SO_4) solution (Merck, Germany), then adding an amount of phosphate buffer solution (0.8 M, Merck, Germany), for keeping the pH value of samples at 7.0 ± 0.2 . In order to ensure free residual chlorine existed 1 mg/L at 25 °C incubation period in the 4th day of a seven days, then an adequate amount of 30 mg Cl_2/mL sodium hypochlorite solution (Merck, Germany) was spiked into the samples. the DPD ferrous method was applied to measure residual chlorine (APHA, 2012), then 0.04 M sodium thiosulfate solution (Merck, Germany) was added to dechlorinated samples. The purge and trap module (Model LCS-2000, Tekmar USA) and an electron capture detector (ECD) was installed with packed-column gas chromatographic (GC) method using a Model 3400 GC, Varian, USA was conducted to analyze trihalomethanes (THMs) concentration. In addition, haloacetic acids (HAAs) involved liquid-liquid extraction with methyl tertiary butyl ether (MTBE) and esterification with diazomethane before GC-ECD analysis. The percentage efficiency removal of TOC, UV_{254} , THMs, and HAAs was calculated according to the initial concentration minus the effluent concentration and the result was divided by the initial concentration. Further, those percentage data were plotted into the graph, while the SUVA value was plotted on the graph directly without percentage removal because the value is used to indicate the hydrophobicity and hydrophilicity properties of dissolved organic matter.

RESULTS AND DISCUSSION

Bulk parameters of dissolved organic matter removal by resin immobilized photocatalyst

Characteristic effluent organic matter of the settling tank after activated sludge process in the tofu wastewater treatment plant has a high TOC concentration (17.24 mg/L), high UV_{254} concentration (0.5514/cm), and SUVA value 3.1984 L/mg.m. The

initial concentration of bulk parameters indicates that tofu wastewater has high dissolved organic matter and content of mixture aromatic humic substances-like, mixture hydrophobicity, and a mixture of molecular weight. This study measured the organic content in terms of BOD and COD, though it does not the main parameters in this study. BOD and COD concentration is 710 mg/L and 1550 mg/L, respectively. The waste from tofu processing usually has a high amount of organic substances, in term of BOD is about 600-1000 mg/L and COD is about 1500-3000 mg/L, or approximate TOC 15-30 mg/L (Hidayah *et al.*, 2016). Figs. 1 and 2 show the removal of TOC and UV_{254} of tofu wastewater after treatment by using resin, RIP-TiO₂, and RIP-ZnO. Those data were collected from dosage 15 gram of each treatment and the process was at indoor room and under room temperature. Firstly, the results show that resin, RIP-TiO₂, and RIP-ZnO could remove dissolved organic matter and aromatic organic matter, as compared at the same time sampling. All materials have performed their efficiency in removing organic matter in higher percentage removal than aromatic organic carbon. TOC has been removed with percentage value 58.18% - 93.45%, while UV_{254} has been occupied with percentage removal 48.77% - 76.51%. The percentage reduction was quite significant although the effluent quality standard for TOC and UV_{254} has not being provided in the national regulation. TOC indicates total dissolved organic carbon, which included aromatic and aliphatic compounds, hydrophobic and hydrophilic compounds, humic substances-like and non-humic substances-like. Meanwhile, UV_{254} indicates organic matter that contains aromatic rings or unsaturated double bonds in their molecular structures. Most organic matter has been composed of aromatic carbon double bonds (Sillanpää *et al.*, 2015; Hidayah *et al.*, 2016). It is reasonable that TOC has been removed in a higher percentage than UV_{254} because TOC represents whole dissolved organic carbon. Comparison between percentage removal of TOC and UV_{254} has pointed out the removal amount of aliphatic compound. It seems that an aliphatic compound has a lower removal than aromatic compound in the resin and resin immobilized. In some cases, low resin and resin immobilized photocatalyst removal might be due to competition with non-targeted ions (Finkbeiner *et al.*, 2018).

Secondly, resin and resin immobilized photocatalyst showed better performance during a longer contact time. TOC removal up to 50% after longer contact time and depends on the material used, such as RIP-ZnO took about 2.5 hours, RIP-TiO₂ needed a longer time about 3.5 hours, and resin only spent about 9 hours. UV_{254} removal took about 6 hours, 8 hours, and more than 15 hours by using RIP-ZnO, RIP-TiO₂, and resin only, respectively. A longer contact time resulted in a better removal and found the optimal time of contact between resin immobilized photocatalyst and raw samples were more than 10 hours. In comparison, resin without photocatalyst seems to have a longer contact time than u¹⁹ and lower efficiency. Photocatalyst technology was initiated by the generation of electron/hole pairs through excitation by photons. Further, it was able to conduct with oxygen and water to produce reactive oxidative species (ROS), highly reactive with many pollutants, including organic matter (Ye *et al.*, 2019).

Third, TOC removal seems a state that reached a stable condition after 10 hours of processing time. It means that resin and resin immobilized photocatalyst have almost its capacity in removing dissolved organic matter. Meanwhile, resin and resin immobilized photocatalyst indicates a higher capacity to remove UV_{254} than TOC because the graph line does not exhibit equilibrium conditions at a contact time of more than 10 hours. Previous studies suggested that an increase of organic matter reduction through resins was affected by the structure of resin, because the larger organic matter species is easier to entry due to open structures (Bolto *et al.*, 2002). In addition, the selectivity of the resins increased with an increase in the number of carbon atoms and in the number of aromatic rings in the organic anion around the exchange site (Graf *et al.*, 2014). Fourth, a comparison between resin and resin immobilized photocatalyst revealed that resin immobilized has a higher removal than resin only, and even RIP-ZnO performed a slightly higher removal of TOC and UV_{254} than RIP-TiO₂. The high photocatalytic efficiency of ZnO and TiO₂ has been well known because both photocatalytic exhibit an appropriate band gap of about 3.2 eV. However, the ZnO photocatalyst performed slightly higher than TiO₂ photocatalyst because of the better crystallinity of the ZnO, which leads to better photocatalytic degradation. ZnO has a hexagonal

crystalline structure, and it is favorable to the electron and hole transport in the resin material. On the other hand, TiO_2 has an amorphous structure, and it's less favorable for the charge carrier diffusion (Ishchenko *et al.*, 2016). Fig. 3 shows the SUVA value

of source water over time during treatment using resin, RIP- TiO_2 , and RIP-ZnO. The SUVA value of tofu wastewater decreased gradually to 2.182, 1.818, 1.566 L/mg/m under treatment processes by using resin, RIP- TiO_2 , RIP-ZnO, respectively. It indicates

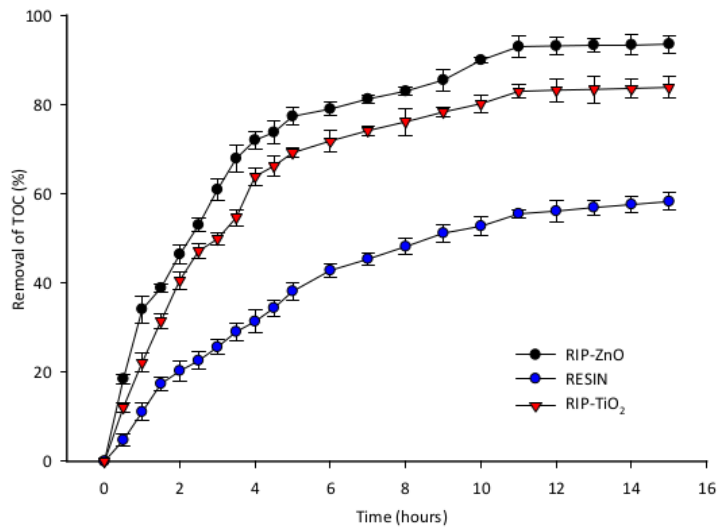


Fig. 1: Performance of resin, RIP- TiO_2 , and RIP-ZnO in removing TOC and (b) UV_{254} in tofu wastewater.

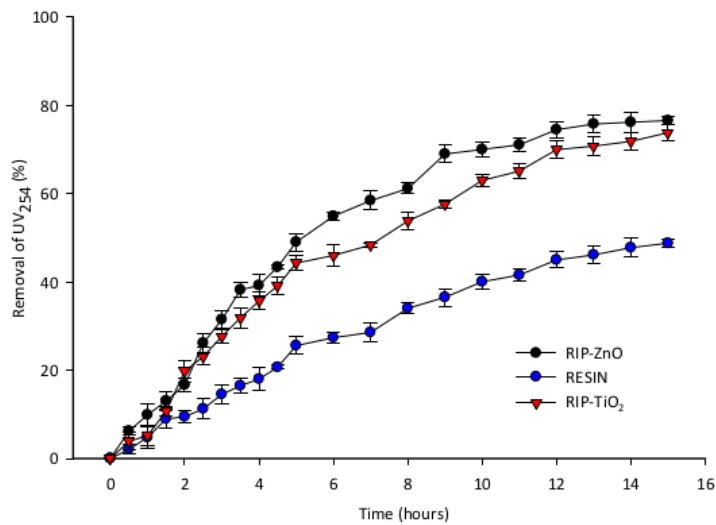


Fig. 2: Performance of resin, RIP- TiO_2 , and RIP-ZnO in removing UV_{254} in tofu wastewater

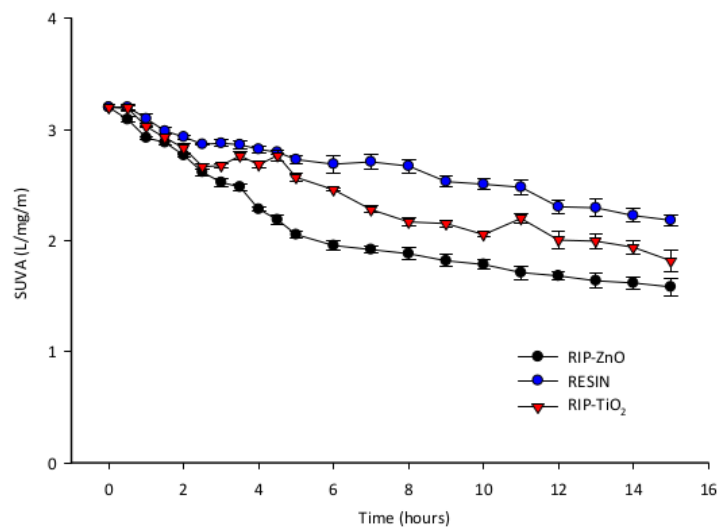


Fig. 3: The changing of SUVA value in tofu wastewater under various processes of resin, RIP-TiO₂, and RIP-ZnO

the changing of organic properties from a mixture of humic-like, mixture hydrophobicity, and mixture molecular weight into mostly low hydrophobicity, non-humic and low molecular weight. As Fig. 1 indicates the removal of total organic carbon in terms of aromatic and aliphatic compounds, and Fig. 2 shows the removal of unsaturated double bonds, it means that the amount of aliphatic compound or less aromatic compound existed in the treated samples. The result of SUVA value, which presents low aromatic, non-humic substances, and low molecular weight organics, has been supported by TOC and UV₂₅₄ analysis, which means that there is a consistency among all parameters of organic matter. The SUVA value of treated samples, which is below the initial value, confirmed the preferential removal humic, a high molecular weight and hydrophobic of organic matter. In addition, the competition between various properties of organic matter components might occur in the systems at a different time process. Overall, the removal of organic matter through resin and resin immobilized photocatalyst suggested the mechanism of entropy sorption, releasing free water molecules because of the dehydration of hydrophobic moieties (Li and Sengupta, 2004). In addition, the increasing hydrophobic character could increase the reduction affinity because of their weak interactivity with

water molecules. Resin could be applied to reduce a naturally harmful charged organic matter, and the addition of photocatalyst will improve the performance of resin in oxidizing the organic matter (Ye et al., 2019).

Effect of Resin Immobilized Photocatalyst on the Formation Potential of DBPs

Figs. 4 and 5 show the removal concentration of trihalomethanes (THMs) and haloacetic acids (HAAs), respectively. The reduction of THMs compared to the raw water is in the percentage 51.30 – 75.23 %, while HAAs removal exhibits a higher removal than THMs, in the range 64.89 – 84.94 %. The percentage reduction was quite significant although the effluent quality standard for THMs and HAAs has not being provided in the national regulation. THMs and HAAs is a chlorinated by-product, which are carcinogenic. Dissolved organic matter is known as a precursor for the formation of those products, therefore removal THMs and HAAs could indicated the presence of dissolved organic matter in treated water. Resin and resin immobilized photocatalyst showed a better performance removal of DBPs during a longer contact time. Performance of resin and resin immobilized photocatalyst in removing DBPs indicates the consistency performance in removing bulk parameters of organic matter. Firstly,

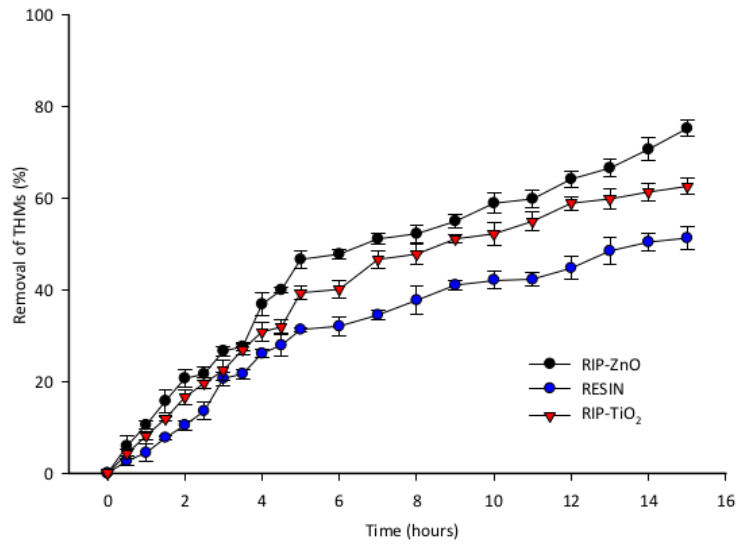


Fig. 4: The changing of THMs concentration in tofu wastewater under various processes of resin, RIP-TiO₂, and RIP-ZnO

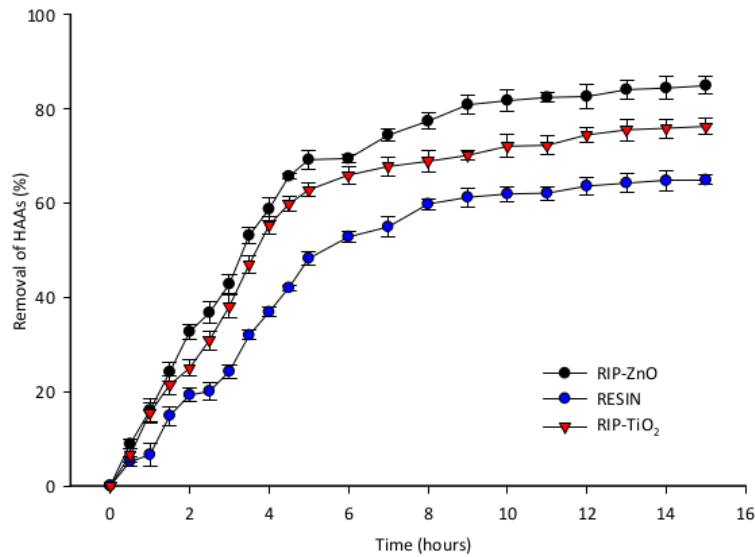


Fig. 5: The changing of HAAs concentration in tofu wastewater under various processes of resin, RIP-TiO₂, and RIP-ZnO

the removal of THMs has a similar percentage with UV₂₅₄ removal. Resin and resin immobilized photocatalyst could gain a higher capacity to remove THMs more than 15 hours contact time, as Fig. 5 has not shown the equilibrium state of line removal THMs. Resin immobilized photocatalyst

with ZnO has a higher removal of THMs than resin immobilized photocatalyst with TiO₂ and resin only. Secondly, the removal HAAs seems by TOC removal. HAAs removal performed an almost equilibrium state after 10 hours of contacting time. The resin and resin immobilized photocatalyst almost

Table 1: Resumed of comparison between this study and the previous study regarding the characteristic of dissolved organic matters through resin ion exchange

Component	This study	Previous studies
Aliphatic and aromatic compound	Aliphatic compound has a lower removal than aromatic compound in the resin and resin immobilized	Low resin and resin immobilized photocatalyst removal might be due to competition with non-targeted ions (Finkbeiner <i>et al.</i> , 2018)
Removal UV ₂₅₄ and TOC	Removal UV ₂₅₄ is higher than removal TOC	High molecular weight organic matter is easier to be removed than lower molecular weight (Graf <i>et al.</i> , 2014)
SUVA value	Decreasing SUVA value indicated less hydrophobic organic matter	Dehydration of hydrophobic moieties (Li and Sengupta, 2004)
DBPFP	Aromatic and hydrophobic compound were THMs precursors and total organic carbon was HAAs precursors	aromatic and hydrophobic fractions were HAAs precursors (Liang and Singer, 2003); hydrophobic fractions of organic matter were THMFP precursors (Lamsal <i>et al.</i> , 2012)
Resin immobilized photocatalyst and resin only	Resin immobilized photocatalyst ZnO is better than TiO ₂ and resin only in tofu wastewater	Resin immobilized photocatalyst ZnO is better than TiO ₂ in textile wastewater (Pachwarya and Meena, 2011)

obtained its capacity in removing HAAs. However, comparison among these resins represented that resin immobilized photocatalyst with ZnO is much better than resin material in this study. It has been well known that dissolved organic matter is a precursor for DBPs formation, as the higher DOC concentration is accompanied by a higher DBPFP (Liang and Singer, 2003; Bond *et al.*, 2012; Hidayah *et al.*, 2016). This research led to the conjecture that conjugated C=C double bonds and aromatic structure and, which UV₂₅₄ represents, were mainly HAAs precursors, while the non-aromatic organic fraction was probably THMs precursors. Previous studies found that hydrophobicity and hydrophilicity properties of organic matter had influenced the DBPFP, such as hydrophobic fractions of organic matter were THMFP precursors (Lamsal *et al.*, 2012), hydrophilic organics had a higher HAAFP concentration (Wang *et al.*, 2013). However, different studies obtained different conclusions, that aromatic and hydrophobic fractions were HAAs precursors than THMs precursors (Liang and Singer, 2003) and THMFP was triggered due to hydrophilic fractions (Hwang *et al.*, 2000). According to the humic and non-humic compounds, it was concluded that the fraction of the humic substance was the precursors for HAAs, while the biopolymer fraction was the precursors for THMs (Hidayah *et al.*, 2016).

Table 1 resumed the comparison between this study and the previous study regarding the characteristic of dissolved organic matters under

different treatment process, and its formation of DBPs concentration. Aromatic organic matter is mainly consist of high molecular weight and has hydrophobic properties. The molecular weight of organic matter influences the resin performance due to the size exclusion effect (Bazri and Mohseni, 2016). Low molecular weight diffuses more easily into the resin pores and is not restricted to exchange sites outside, whereas larger molecules are rejected due to size exclusion (Winter *et al.*, 2018). In addition, the resin has limited capacity, and larger molecules blocked the possibility of the resin surface at high TOC concentration (Levchuk *et al.*, 2018). Hydrophobicity considered, the hydrophobic compounds lack an affinity for water, insoluble in water, which results in reduction of the compound from the solution, or called by therefore entropy-assisted sorption (Li and Sengupta, 2004). The reduction of organic matter by using resin is driven primarily by charge. More highly charged molecules of organics are preferentially reduced because of the stronger affinity to the resin (Liu *et al.*, 2017). Overall, the removal of DBPFP is strongly related to the reduction of bulk parameters of organic matter, including TOC, UV₂₅₄, and SUVA value because bulk parameters represented the properties of organic matters. Therefore, controlling bulk parameters removal leads to the monitoring and removing DBPFP concentration. Further, it is necessary to identify the characteristic of organic matter in the source water to know the appropriate treatment

process in removing organic matter. This study shows that resin immobilized photocatalyst has a better performance than resin only, and the used resin should be regenerated for further usage until the resin has lower exchange capacity. An example of the treatment train for reclaimed water, which is applied ¹⁶ technology, will be conventional treatment such as coagulation, flocculation, sedimentation, filtration, resin technology, disinfection and collected water. Therefore, the following treatment processes are needed to obtain the criteria standard for reclaimed water as regulated by the government, primarily related to the concentration of dissolved organic matter, THMs, and HAAs.

CONCLUSION

This study observed the usage of resin, RIP-TiO₂, and RIP-ZnO for treating tofu wastewater into reclaimed water with a focus on the bulk parameters, including TOC, UV₂₅₄, SUVA value, and DBPs concentration, including THMs and HAAs concentration. It was characterized that tofu wastewater has high dissolved organic matter and content of mixture aromatic humic substances-like, mixture hydrophobicity, and a mixture of molecular weight. After treatment, it was confirmed that all materials preferentially reduce bulk parameters and DBPs concentration under different percentage removal, about 48%-93% of bulk parameters concentration removal, and 51%-85% of DBPs concentration removal. RIP-ZnO performed a slightly higher removal of TOC, UV₂₅₄, THMs, and HAAs concentration than RIP-TiO₂, while resin exhibited the lowest capacity removal. TOC has been removed in a higher percentage than UV₂₅₄ since TOC represents whole dissolved organic carbon. Comparison between percentage removal of TOC and UV₂₅₄ has pointed out the removal amount of aliphatic compound. It seems that an aliphatic compound has a lower removal than aromatic compound in the resin and resin immobilized. Decreasing SUVA value indicated changing of organic properties from a mixture of humic-like, mixture hydrophobicity, and mixture molecular weight into mostly low hydrophobicity, non-humic, and low molecular weight. Performance of resin and resin immobilized photocatalyst in removing DBPs indicates the consistency performance in

removing bulk parameters of organic matter. Removal of THMs has a similar percentage with UV₂₅₄ removal, while the removal HAAs seems by TOC removal. Controlling bulk parameters removal, such as TOC, UV₂₅₄, and SUVA value, is one of the efforts to monitor and control the formation of DBPs. Identify the characteristic of organic matter in the raw water is one of the strategies to know the appropriate treatment process. Further treatment processes are needed to obtain the criteria standard ¹⁷ for reclaimed water because the proposed process does not always directly reduce DBPs reactivity, but it facilitates a better removal of DBPs precursors.

AUTHOR CONTRIBUTIONS

E.N. Hidayah performed the experimental work, analyzed the data, and wrote the manuscript and reviewed the literatures. R.B. Pachwarya analyzed the data, interpreted the results, and reviewed the manuscripts. O.H. Cahyonugroho performed the experimental, presented the data, and wrote the manuscript.

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² CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. Also, ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and submission, as well as redundancy, have been entirely witnessed by the authors.

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ABBREVIATIONS

AOPs	Advanced oxidation processes
BOD	Biological oxygen demand
COD	Chemical oxygen demand
cm	Centimeter
°C	Degree celcius
DBPFP	Disinfection by-products formation potential
DBPs	Disinfection by-products
C=C	Double bond carbon
ECD	Electron capture detector
GC	Gas chromatographic
GC-ECD	Gas chromatographic- electron capture detector
HAAs	Haloacetic acids
L/mg/m	Liter milligram meter
MBIRD11	Methylene blue immobilized resin dowex-11
MTBE	Methyl tertiary butyl ether
µm	Micrometer
mg	Miligram
mg Cl ₂ /mL	Miligram Chlorine per milliliter
mg/L	Miligram per liter
M	Molar
NaOH	Natrium hydroxide
NDMA	Nitrosodimethylamine

DPD	N,N-diethyl-p-phenylene diamine
%	Percent
RIP	Resin immobilized photocatalyzed
RIP-TiO ₂	Resin immobilized photocatalyzed-titanium dioxide
RIP-ZnO	Resin immobilized photocatalyzed - zinc oxide
rpm	Radian per minutes
ROS	Reactive oxidative species
SUVA	Specific ultraviolet absorbance
H ₂ SO ₄	Sulfuric acid
TiO ₂	Titanium dioxide
THMs	Trihalomethanes
TN	Total nitrogen
TOC	Total organic carbon
UV	Ultraviolet
UV ₂₅₄	Ultraviolet at 254 nm wavelength
UV/vis	Ultraviolet visible
ZnO	Zinc oxide

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