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Removal of Pollutants in Wastewater using Plastic-Based Media Biofiltration: A Meta-Analysis

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ABSTRACT

The use of plastics as a biofilter medium is an environment-friendly and effective technology for reducing pollutants in liquid waste. The main objective is to analyze the ability of biofilters with plastic media to remove pollutants in wastewater by looking at several parameters. Various types of data were developed and analyzed to answer specific goals set through the search engines EBSCO, Scopus, and ProQuest by examining several parameters, including wastewater source, research scale, research period, temperature, media type, media thickness, and pollutant removal. The obtained data were processed to determine the distribution of the descriptions. Data related to biofiltration using plastic media was obtained from 152 articles, with only 14 articles in the search category. These findings show that all types of plastic media are effective for biofilm attachment and bacterial growth, resulting in a very large removal of pollutants present in liquid waste. Biofilters with plastic media are also known to be able to remove contaminants such *as Chemical Oxygen Demand, biological oxygen demand, total organic carbon, nitrogen, phosphorus, ammonia nitrogen, hydrogen sulfide, toluene, ammonia, diethanolami, phenol, total suspended solids, and Escherichia coli.* Synthetic wastewater (35.71%) was the most common wastewater source. Research related to biofiltration using plastic as the medium is mostly carried out on a laboratory scale with a total of 64.30% and using units of the day as an indicator of changes in a total of 71.42%, with an average experimental temperature of 29.1 °C.

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INTRODUCTION

Plastic waste is a global pollution problem that occurs on land and at sea (Enders et al., 2015)(Horton, Walton, et al., 2017)(Guerrera et al., 2021)(Ivar Do Sul & Costa, 2014)(Rocha-Santos & Duarte, 2015). The amount of plastic waste floating in high seas is predicted to be approximately 250,000 tons (Eriksen et al., 2014)(Jambeck Jenna R et al., 2015). The amount of plastic waste has increased annually since the 1950s. This is because plastic waste cannot be decomposed by the environment, resulting in an unnatural build-up in one area. Plastics that have been released into the environment for a long time will become microplastics and not decompose. Microplastics are plastic particles < 5 mm in length (Arthur et al., 2009). Plastics in the form

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of microplastics are of special concern because of their resistance to the environment and their potential to act as carriers and releasers of chemical compounds present in the plastic element itself (Teuten et al., 2009). Currently, plastics are found in various conditions of both water bodies (Dris et al., 2018)(Wang et al., 2017)(F. Liu et al., 2019), soils, and sediments (Scheurer & Bigalke, 2018)(Horton, Svendsen, et al., 2017)(P. H. Liu, 2019), and more worryingly recently, are also found in freshwater and deep-sea organisms (Taylor et al., 2016)(Windsor et al., 2019)(Savoca et al., 2019)(Valente et al., 2019), which give rise to concern is this indicates that the human food chain is under risk of plastic contamination (CONTAM, 2016)(Toussaint et al., 2019).

The main source of plastics is human activities in households, offices, and industries. Plastic waste that is not properly managed is a major source of plastic pollution in aquatic, atmospheric, and terrestrial environments (Windsor et al., 2019). Many paths can carry plastics to become waste, including rainwater, municipal and industrial wastewater, and wind (F. Liu et al., 2019)(Jambeck Jenna R et al., 2015)(Lebreton et al., 2017). Wastewater passing through a city route plays an important role because it carries plastic waste from residential, industrial, agricultural, and other commercial activities. Several studies have also proven that WWTPs can be designed in such a way as to remove pollutant substances present in wastewater, either with plastic media in the biofilter or with other more conventional media with reported efficiencies generally above 90% (Carr et al., 2016)(Talvitie, Mikola, Setälä, et al., 2017)(Simon et al., 2018)(Sun et al., 2019). Decentralized wastewater treatment systems (DEWATS), which are usually low-cost, have been successfully adopted in developing countries, including India, Nepal, and Indonesia, and the resulting wastewater meets the national waste disposal standards of each country (Bright-Davies et al., 2015)(Kerstens et al., 2012)(Singh et al., 2019).

More than 90% of domestic waste in developing countries is disposed directly into the environment without undergoing treatment, which poses a potential hazard to the environment and the people who are directly connected to the wastewater (Sato et al., 2013). Recently, many wastewater treatment techniques have been developed, including the contact flocculation filtration technique, which uses a filter with a floating medium. In small-scale waste treatment, this method can be a substitute for conventional methods such as flocculation and sedimentation. Several advanced technologies have been developed to remove contaminants from wastewaters. Some of these are membrane bioreactors, fast sand filters, and disk filters (Gatidou et al., 2019)(Talvitie, Mikola, Koistinen, et al., 2017)(Simon et al., 2019). One technology that can be used to remove pollutants from wastewater is the biofilter technique, which is designed to degrade certain dissolved pollutants such as drugs and other chemicals (Zhang et al., 2019). It has also been noted that hundreds of millions of households worldwide rely on on-site wastewater treatment systems (ON-SITE Systems) to treat waste before disposal into the environment. (Amador, J. A., & Loomis, 2019)(Petitjean et al., 2016). Domestic wastewater contains a variety of contaminants, including organic matter, nutrients (nitrogen [N] and phosphorus [P]), pharmaceutical and personal care products (PPCPs), and pathogens (i.e., bacteria and viruses). (Farkas et al., 2020) (Guruge et al., 2019) (Martikainen et al., 2018). A conventional septic tank without a biofilter consisting of a septic tank followed by a sewer or infiltration pond (United State Environmental Protection Agency, 2003) , can provide limited levels of nutrients and pathogen removal, depending on soil characteristics (Amador, J. A., & Loomis, 2019)

Plastics used as media in biofilters are widely available; however, researchers in developing countries are often constrained by the cost of providing them, particularly in large quantities. Apart from the effectiveness of commercial biofilters, the application of various low-cost biofilter media has been studied and evaluated in several studies (Kaetzl et al., 2018); however, the use of media with local materials is one way to reduce costs. (de Oliveira Cruz et al., 2019). One of these uses plastic, which is not used. In Indonesia, waste management, especially that of wastewater, remains a challenge for large cities. Generally, waste is generated through residential

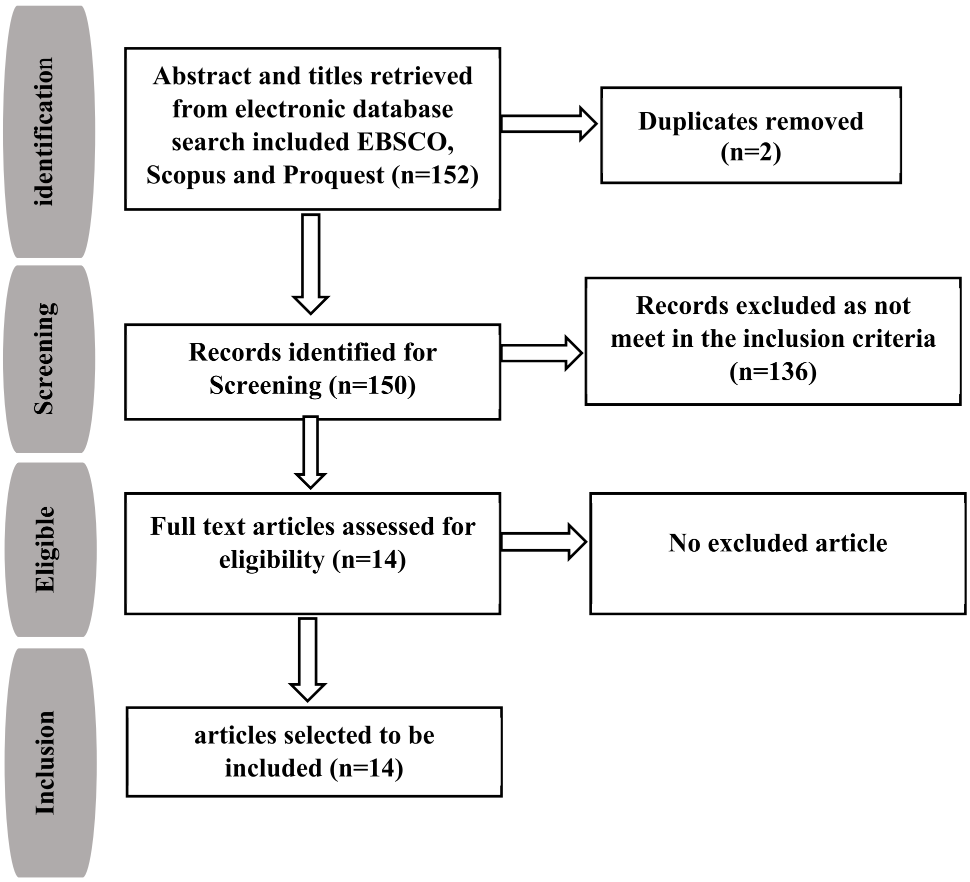

Fig. 1. Research Flow Chart

activities such as laundry waste, washing water, and human waste (Aulia Sari & Pamadi, 2019).

Several studies that discuss the ability of plastics as biofilter media are also shown in this paper, among others, showing that artificial wastewater with plastic packaging media can reduce COD, BOD nitrogen, phosphorus (Rebah et al., 2010), pH, and H2S (Su et al., 2014). This shows that plastic media can be used as biofilter media, but there has been no research that has attempted to reveal how effective it is and what types of plastics can be used as biofilter media. This study is the first to combine and identify pollutants that can be removed in biofilters using plastic media.

The main objective was to answer the following questions: First, what contaminants can be removed using a plastic biofilter, and what is the percentage of removal, both aerobically and anaerobically, by including the source studied? Several databases were used, including thickness of the media, type of plastic media used, research scale, research period, and temperature. They were then evaluated in two ways:1) critical review of studies using biofilters with plastic media and their effect on each parameter, and 2) meta-analysis of data across all studies. The novelty of this study is that there has never been no study has attempted to combine and determine the overall benefits of using plastic as a biofilter medium in the biofiltration process.

MATERIALS AND METHODS

Several databases were developed to address specific objectives, including peer review reports, original articles, and case studies, and were sourced from journals that had been published in their entirety in academic databases or search engines, such as EBSCO, SCOPUS, and ProQuest. In the EBSCO database, there were one of three results related to the topic you wanted to search for with the selected keywords, while in the ProQuest database, there were four out of 71 articles. In the Scopus database, nine out of 78 articles were selected in a structured manner by considering keywords. for the wastewater, biofiltration, and plastics, respectively. The data obtained were then combined, reviewed, and analyzed by examining the cause and effect between the influential variables by considering the frequency distribution of the data obtained. The data were also collected and studied in depth to determine the effectiveness of plastic as a biofilter medium to reduce the pollutant load in wastewater on a laboratory, pilot, and full scale. The initial data obtained from the search showed as many as 14 articles that entered the search category, and the data were then sorted based on predetermined parameters such as the ability to reduce organic pollutant loads, temperature, media type, media thickness, research period, and research scale.

RESULTS AND DISCUSSION

According to several studies, synthetic wastewater (35.71 %) is the most common source of wastewater. Research related to biofiltration using plastic as the medium is mostly carried out on a laboratory scale with a total of 64.30% and using units of the day as an indicator of changes in a total of 71.42%, with an average experimental temperature of 29.1 °C. The types of plastic media used varied with thickness. The ability of biofilters with plastic media to reduce pollutant loads in wastewater is categorized as very good, whereas the parameters that can be removed from biofilters with plastic media are COD, BOD, *nitrogen phosphorus, methane, nitrate*, *toluene*, diethanolamine, TOC, TSS, E. coli, and phenol. More details can be found in Table below.

Biofilters with plastic media were able to reduce COD levels up to 90%, and BOD up to 98% using plastic-packed material (from EKokan) with an experimental time of up to 142 days, with a media thickness of 200 mm by 1.4 mm. not only that, it turns out that with any plastic media as a biofilter, plastic can reduce the COD content by 90-95% at an optimal temperature of 25 C in just 19 hours (Güneş, 2013). Plastic bottles, one of which is made of PET or PP, are known to be able to be used as a biofilter media in wastewater treatment systems, where it is known that the plastic can remove 29-72% COD and 60-90% BOD on the Pilot scale with a working time of 262 days at 23°C. ,4 °C, with the amount of 200-500 litres of plastic placed in the biofilter system(Dorji et al., 2022). Plastic balf media are also known to reduce COD by 80% at temperature of 17-23 °C with an experimental time of 109 days (LIU). Surprisingly, a biofilter using an interlaced plastic disc made from Plexiglas can reduce COD in just 4.4 hours at an optimal temperature of 35°C (Shokoohi et al., 2017). Biofilter with plastic waste media is very effective in reducing BOD (84.85%).(Juniarta et al., 2018)

The removal of TOC is also an interesting finding, where a lab-scale study using synthetic wastewater and plastic ring media could remove 60% to 80% of TOC in both 72 and 7 days (Zeng, Soric, Ferrasse, et al., 2013). This shows that time was not a barrier for the removal of TOC from wastewater by the plastic ring media. Basically, it is known that TOC removal efficiency is the interaction between hydrodynamic behaviour and biological kinetics (Méndez-Romero et al., 2011). It is known that total organic compounds are an indicator of carbon behavior in polluted water (Costa et al., 2013)(He et al., 2016)(Yang & Hur, 2014); therefore, the hydrodynamic behavior of carbon interacting with biological kinetics can cause the drastic reduction in TOC. TOC removal will be effective over the normal temperature range of, 10-20 ^{0}C, after which the system will operate under normal conditions unless there are changes in the quality of the influent water, for example, temperature, or operating conditions such as the flow rate(Terry & Summers, 2018).

Ammonia gas is known to be present in various sources, such as carcass processing factories, sewage, composting work, livestock, and wastewater treatment plants (Kavyashree et al., 2015);

Table 1. Summary of studies which systematically evaluated related to plastic media for biofiltration on wastewater

No	Source Water	Scale	Time Period	Temp	Media Type	Thickness Of Media	Pollutants Removal	References
1	Synthetic wastewater	Lab	142 H	34 °C	plastic packed (from EKokan)	200 mm by 1.4 m	1. COD = 90% 2. BOD= 91 to 98% 3. *Nitrogen* = 60 and 70% 4. *Phosphorus* = 70%	(Rebah et al., 2010)
2	Piggery wastewater	Pilot	120 Days	15–38 °C	plastic Raschig ring	0·2 × 1·0 m	1. pH = 1·6 ± 1·0 2. H_2S= 79·2%	(Su et al., 2014)
3	Wastewater storage tank	Lab	NA	NA	Plastic media (Sweetwater SWX bio-media, Pentair) high-density polyethylene	40 cm x 5.08 cm	1. Nitrat= 92.57 %	(Paul & Hall, 2021)
4	Isfahan Water and Wastewater Co	bench	10 days and 17 days respectively	30°C	shredded high density plastics	1.0×0.5 cm	NH_3= 9.85 g-NH_3 /m3 h	(Taghipour et al., 2006)
5	Valadolid wastewater treatment plant (Spain)	full	60 days	NA	Kaldnes K2 plastic rings (BTF-K)	950 kg/m3	H_2S, *toluene*, and methylmercaptan =80%	(Lebrero et al., 2021)
6	Municipal wastewater	Lab	40 days	40°C and 30°C	HDPE Shredded Plastic Hose	0.5cm	Diethanolamine< 170 ppm	(Moshrefzadeh & Sabour, 2014)
7	Wastewater lift stations	Pilot	107 days	NA	plastic hollow spherical balls	0.9 m	1. *Toluene* = 91% 2. H_2S= 74%	(Martinez et al., 2008)

Continiued Table 1. Summary of studies which systematically evaluated related to plastic media for biofiltration on wastewater

No	Source Water	Scale	Time Period	Temp	Media Type	Thickness Of Media	Pollutants Removal	References
8	Synthetic wastewater	Lab	72 days	15–25 °C	plastic rings Anox Kaldnes	NA	TOC=60%	(Zeng, Soric, & Roche, 2013)
9	Synthetic wastewater	Lab	6-19 hours	25◦C	random plastic material	2.5 L	COD= 90–95%	(Güneş, 2013)
10	Synthetic wastewater	Lab	7 days	15–22◦C	Plastic Ring	1.5 to 10.1 g/L	TOC=60%-80%	(Zeng, Soric, Ferrasse, et al., 2013)
11	On-Site Wastewate r in Bhutan	Pilot	262 days	23.4◦C	Plastic Bottles (PET and PP)	200-500 L	1. TSS = 80% 2. *Escherichia coli* =84.6–92.4 % 3. BOD =60-90% 4. COD = 29–72 %	(Dorji et al., 2022)
12	Swine wastewater	Lab	75 days	30°C	hollow plastic balls	71 kg /m3	H_2S and NOx–N= 60%	(Deng et al., 2009)
13	Municipal wastewater	Lab	109 days	17.3 °C to 23 °C	plastic ball BAF	95,6 kg/m3	1. COD=80% 2. *ammonia nitrogen* (NH_3-N)= 93.7%	(Y. X. Liu et al., 2010)
14	Synthetic wastewater	Lab	4,4 Hours	21 to 35°C	interlace d plastic disc made from Plexiglas	NA	1. phenol = 500 mg/L 2 COD = 4–4.5 kg COD/m3 d	(Shokoohi et al., 2017)

Source: Ebsco, Proquest, and Scopus

therefore, knowledge of media that can reduce ammonia gas in biofilters will be an innovation. The removal of *nitrogen* and *phosphorus* by a biofilter using a plastic material is a very important finding, where a laboratory scale study using a sample of synthetic wastewater for 142 h at a temperature of 34 °C using plastic packed (from EKokan) succeeded in removing *nitrogen* and *phosphorus* up to 70 % (fall). in a laboratory scale experiment using samples from municipal wastewater for 109 days at a maximum temperature of 23 °C, and plastic ball baff media was able to remove 93.7% *ammonia nitrogen* (NH_3-N) (Y. X. Liu et al., 2010). Excessive accumulation of *ammonium* discharged into water can cause serious ecological problems (Seruga et al., 2019); therefore, it is important to find a solution for its removal using plastic media.

Another important finding was that Raschig ring plastic medium, which was used as a pilot-

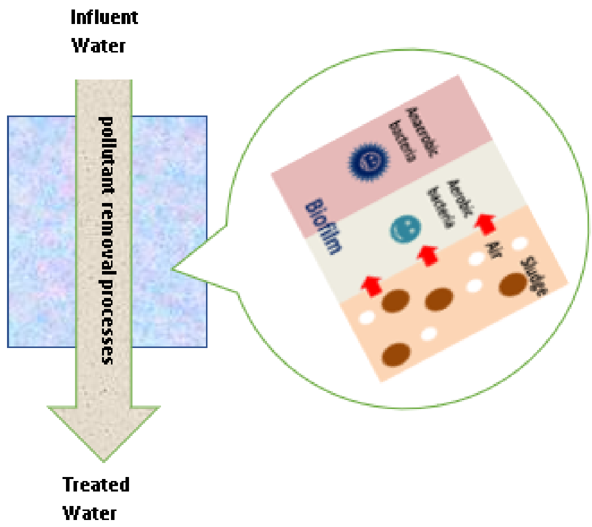

Fig. 2. Role of Biofilm in wastewater treatment

scale biofilter medium for 120 days at a temperature of up to 38 °C, was able to remove 79.2% of H_2S (Su et al., 2014). In addition, another full-scale study using Valadolid wastewater as a sample for 60 days with plastic ring media was able to remove H_2S and 80% *toluene* (Lebrero et al., 2021). The same phenomenon also occurred in synthetic wastewater, which was tested on a laboratory scale for 107 d using hollow plastic spherical balls to remove 91% *toluene* and 74% H_2S (Martinez et al., 2008). Similarly, what happened in a laboratory-scale study using wastewater samples for 75 d at a temperature of 30°C using hollow plastic ball media was able to remove 60% H_2S (Deng et al., 2009). Approximately 9% of the methane released into the environment originates from wastewater treatment (Karakurt et al., 2012)(Hu et al., 2017)(Short et al., 2017). The source of this methane must be determined for alternative removal using plastic media. The process of methane removal in biofilters can be shortened to methane, resulting from decomposition, which is transferred from the gas to the biofilm and then biologically transformed into biomass and final products. Generally, these gases are converted into water (H2O), CO2, and biomass(Ferdowsi, Avalos Ramirez, et al., 2017)(Ferdowsi, Ramirez, et al., 2017)(Zamir et al., 2015).

Plastic media (Sweetwater SWX Bio-media, Pentair) high-density polyethene, which is used as a biofilter, is also known to remove nitrate from wastewater with a removal percentage of 92.57% (Paul & Hall, 2021). The ability of shredded high-density plastics to operate as a biofilter medium for 17 days on a bench scale enabled the removal of NH_3= 9.85 g (Taghipour et al., 2006). The Shredded Plastic hose, which is used as a biofilter medium for 40 days at a lab scale at a temperature of 30-40°C can remove 170 ppm diethanolamine (Moshrefzadeh & Sabour, 2014). Phenol was removed using an interlaced plastic disc made from Plexiglas at a temperature of 21-35°C with a removal success of 500 mg/L.

Another interesting finding is that the plastic media in the biofilter can also be a destroyer and a means of removing total suspended solids (TSS), after a pilot-scale study was carried out for 262 days at an average temperature of 23.4◦C using plastic bottles (PET and PP), where the total suspended solid content was lost up to 80%. In addition, the same study showed that plastic media could remove *up to 92.4% of E. coli* (Dorji et al., 2022). Total suspended solids can also be a good source of heavy metals (C. Liu et al., 2016)(Gao et al., 2015). This is certainly very dangerous for water if these substances are present in liquid waste. E. coli removal performance decreases after a dry period from the biofilter, but increases significantly as the biofilter system matures (Chandrasena et al., 2014).

CONCLUSION

Whole plastic media can be used as biofilter media at various temperatures, and not only on a laboratory scale, but also bench, pilot, and full plastic media have proven to be effective in removing various contaminants from liquid waste. However, from the many studies that have been conducted and related to biofiltration with plastic media, it takes days, although one study explained that in a matter of hours, it can also reduce pollutants. This is evidence that the use of plastic as a biofilter medium can reduce pollutants for a short to a long time. The optimal temperature for biofilters with plastic media follows a temperature that is suitable for bacterial growth, allowing bacteria to adhere to the media and form biofilms. The size of the medium did not appear to have a significant effect on the bacterial growth in the biofilm. The findings show that The parameters that can be removed from the biofilter with plastic media are COD, BOD, *nitrogen phosphorus, methane, nitrate*, *toluene*, diethanolamine, TOC, TSS, E. coli, and phenol. In this study, we did not analyze the causal relationship data for each variable because there were too many polluting variables and the recorded media could not be processed because they were in the form of words. Therefore, it will be better in the future if other researchers consider one parameter with the dependent variable so that it can be analyzed. test the data of time, temperature, and pollutant variables, such as TSS or *Escherichia coli*, so that the causal relationship of each variable can be seen.

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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