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Treatment of Domestic Wastewater on Fixed-Bed Reactor Using Plastic Supporting Media – A Review

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ABSTRACT

Biofilm processes are increasingly being recognized for the removal of organics and nutrients in domestic wastewater treatment. One system that is often used is the Fixed-Bed Reactor (FBR). This review aimed to analyze wastewater treatment using anoxic-aerobic FBR system with various supporting media. The method used was the descriptive analysis of articles obtained from Google Scholar, ScienceDirect, and Springer. The results of the review showed that wastewater treatment with a growth system is able to remove organics and nutrients quite high. The types of polymers used as supporting media for attaching biofilms consisted of PET, PS, HDPE, and LDPE. However, when viewed from the removal efficiency, the supporting media with polymers is superior to PET compared to other types. This is because PET has hydrophobic physicochemical properties which have good adhesion in the initial attachment of microorganisms. In addition, this type of PS polymer also has fairly high organic and nutrient removal efficiency, similarly to other types of polymers such as HDPE, and LDPE.

Keywords: domestic wastewater, FBR, plastic supporting media, review, treatment.

INTRODUCTION

Domestic wastewater is the water that has been used by society and contains all the materials added to the water during its use. The wastewater consists of human body waste (feces and urine are included in the black water category) along with the water used to flush toilets (Mara, 2004). In contrast, domestic wastewater that comes from water used for washing dishes, washing clothes, bathing activities, and handwashing tubs is called gray water (Ytreberg, 2020). Gray water contributes around 50%-80% of domestic wastewater which has a composition of nitrogen, phosphorus, and potassium (Al-Joyoussi, 2002).

In recent years, biofilm-based wastewater treatment such as the fixed-bed biofilm reactor (FBBR) or moving bed biofilm reactor (MBBR) is a promising treatment alternative for organic and nutrient removal (Al-Amshawee et al., 2020; Saltnes et al., 2017; Shao et al., 2017). Biological treatment using the biofilm process has many advantages when compared to conventional activated sludge processes such as having a large active biomass concentration, small space requirements, reduced hydraulic retention time, more stable performance, and low sludge production (Huang et al., 2017; Mannina et al., 2018; Sriwiriyarat and Randall, 2005; Zhao et al., 2018). Microbial colonies in biofilms tend to be more diverse than activated sludge systems, allowing better degradation of various organic pollutants in biofilm systems (Al-Amshawee et al., 2020; Zhao et al., 2019).

The use of supporting media in attached growth reactors or biofilm technology in biological processing has been widely applied. The development of biofilm technology in wastewater treatment globally is quite rapid with various materials, shapes, and sizes with the aim of obtaining a large specific surface area and cavity volume, so that it can attach large numbers of microorganisms and affect reactor performance. Tchobanoglous et al. (2003) established design criteria for a specific surface area of 100–820 m^2/m^3 and a void ratio of 15–98%. Even the physical properties of a supporting medium affect the rate of biofilm formation (Dias et al., 2018).

METHODS

The method used was literature review, by searching for relevant articles in journal databases such as ScienceDirect, google scholar, and Springer. There were 38 articles found with the keywords attached growth system, domestic wastewater treatment, supporting media, biofilm formation, biofilm development, and influence of carrier media. The articles that have been collected were reviewed and analyzed to become a literature review, with a discussion of the types of polymers as supporting media in FBR.

PLASTIC WASTE AS A SUPPORTING MEDIUM IN WASTEWATER TREATMENT

Biofilter technology is a supporting media which is one of the alternative technologies that is often applied to people's homes or for domestic wastewater treatment (McNevin & Barford, 2000). Research on plastic bottle waste as a supporting media in Indonesia has been widely studied, both on a laboratory scale and on a pilot scale, since 2014. The used plastics such as PET plastic bottles waste (Effendi et al., 2014; Salas, 2016; Radityaningrum and Kusuma, 2017, Purnangtias et al., 2018), Polystyrene (PS) (Hikmawati, 2013; Putra et al., 2016 and Radityaningrum and Kusuma, 2017) and a combination of PET and Polypropylene (PP) (Putri et al., 2015; Juniarta et al., 2018) have been studied at the laboratory scale and PET plastic bottles waste on a pilot scale for 5 families (Komala et al., 2017). Even the use of PET as a supporting media has been applied to communal WWTPs (capacity of up to 75 households) in several regions in Indonesia since 2014. PET/PETE type bottles with code 1 are recommended for single use only. The estimated time for plastic bottles to decompose naturally is 450 years, causing used plastic bottles to accumulate in the environment. The concept of a waste-treats-waste approach (Carrasco et al., 2016), involves treating two types of waste at once, e.g reducing PET plastic bottle waste while treating wastewater by using PET as a supporting media. The PET used as a supporting media is generally in the form of used mineral bottles in previous studies.

These forms are (1) used plastic bottles are assembled using cable ties (Effendi et al., 2014); (2) arrangements such as wasp nests and flowers (Radityaningrum and Kusuma, 2017); (3) cut lengthwise, folded lengthwise and the folds are placed into bottles which have been cut at the top and bottom (Komala et al., 2017); (4) Used plastic bottles are cut to a size of 2×10 cm and rolled up to form a cylinder with several layers (Punaningtias et al., 2018); (5) cut crosswise like a rubber band (Lapo et al., 2018). The shape of the PET, PP, and PS series as supporting media affect their arrangement in the reactor, namely in the form of a fixed (fixed bed) or moving bed (moving bed) according to the space in the reactor. Among these polymer types, fixed bed PET is superior in removing organics and solids (TSS, BOD, and COD) in wastewater (Radityaningrum and Kusuma, 2017). However, the design criteria, the ability of micro-organisms to stick to the supporting media for used plastic bottles, have not been discussed further. More details can be seen in Table 1.

It can be seen in Table 1 that the type of PET polymer has the efficiency of organic and nutrient removal in treating domestic wastewater. Another thing that causes the high removal efficiency is the shape of the series of plastic bottles which is closely related to the specific surface area produced. On the basis of Tchobanoglous, et al. (2003), the design criteria for a specific surface area are 100–820 m^2/m^3 with a void ratio of 15–98%, whereas according to Grady (2011) the surface area for bacterial growth is 100 m^2/m^3 with a void fraction of 90–95%. In addition, the filling ratio of supporting media also affects the resulting removal efficiency. Other polymer types can also remove organics and nutrients; based on Table 1, the resulting removal efficiency is not much different from PET media. Not only can it remove

Table 1. Previous research on the use of plastic as a supporting media

No.	Polymer	Type	Form of supporting media arrangement	Process	Wastewater type	Flow/ volume	HRT	Removal	Sources
1	PET	Fixed-bed	Used plastic bottles were strung using Cable Ties and filled with 11 pieces of 2 cm (L) × 12 cm (L) plastic pieces. The number of series of plastic bottles is 9 series, 6 series are put into 2 anaerobic biofilter reactors, and 3 series into aerobic biofilter reactors. One series of used plastic consists of 60 plastic bottles	Anaerobic-aerobic biofilter	Wastewater of tofu	360 L	-	BOD = 85,58 - 92,96 % COD = 84,80 - 92,54 %	Effendi et al., 2014
2	PET	Fixed-bed	Arranged in flower shape	Anaerobic biofilter	Domestics wastewater (*grey water*)	0,348 m^3/ day	9 hours	TSS = 84% BOD = 79% COD = 57%	Radityaningrum and Kusuma, 2017
3	PET	Fixed-bed	The biofilter is filled with plastic bottle media containing pieces of plastic, and the biofilter is filled with pipette circuit media	Combination of the anaerobic-aerobic biofilter and aquatic plant phytoremediation emergency	Wastewater of rubber	190 L	-	BOD5 = 80%-98%, COD = 85%-98%	Putri et al., 2015
4	PET	Fixed-bed	Used plastic bottles are cut with a size of 2 × 10 cm and rolled in several layers to form a cylinder	Aerobic biofilter	Domestics wastewater of health laboratorium	75 Liter	3, 6, 9 hours	COD = 86,89%, BOD = 75,18%, Fosfat = 9,1 mg/L	Purnaningtias Et al, 2018
5	PP and PET	Fixed-bed	PET was cut into segments 5 cm long and 2 cm wide, PP was cut into 80 cm long and 5 cm wide	Aerobic submerged fixed biofilm reactors (AFRB)	Domestics wastewater	2,8 L	-	COD = 70-80%	Lapo et al., 2018
6	PET, HDPE, LDPE	Fixed-Bed	60% of reactor volume @ PET, HDPE and LDPE	Aerobic biofilter	Domestics wastewater	12 L	-	COD > 80% (LDPE and PET) COD < (HDPE)	Epinoza et al, 2019
7	LDPE, PET, HDPE	Fixed-Bed	Arranged in 3 reactors, each reactor containing different materials, 1 reactor for LDPE, 1 reactor for PET and 1 reactor for HDPE	Aerobic biofilter	Domestics wastewater	12 L	Phase 1 = 9,6±0,03 hours Phase II = 6,8±0,36 hours Phase III 5±0,26 hours	COD = 80% (LDPE and PET) COD << (HDPE)	Espinoza et al., 2019
8	PS	Fixed-Bed	Arranged in honeycomb shape	Anaerobic biofilter	Domestics wastewater (*greywater*)	0,348 m^3 /day	9 hours	TSS = 68% BOD = 64% COD = 31%	Radityaningrum and Kusuma, 2017
9	PP dan PET	Fixed-Bed	The 600 ml PET bottle is perforated on the bottom, sides, and top. Waste from snack wrappers (PP) is put into each used PET bottle so that the weight of each bottle becomes 25 grams. Mineral water bottles that already contain plastic bag waste are arranged in such a way.	Aerobic biofilter	Domestics wastewater of hospital	150 Liter	36 hours	BOD = 84,85% COD = 31,73% Ammonia = 50,60%	Juniarta et al., 2018
10	PET		Pieces of used plastic bottles are divided into 3 parts, with the height of each piece measuring 2.5 cm and a diameter of 5.5 cm. The surface area of the cut media used for drinking water bottles is 86.35 cm^2	Aerobic biofilter (downflow and upflow)	River	21 L	1-4 hours	COD = 59% (downflow) COD = 43% (upflow)	Salas, 2016
11	PS	Fixed-Bed	Bottles are arranged in such a way with perforated plate buffer media	Anaerobic biofilter	River	72 mL/ minutes	-	COD = 73,24% - 80,53%, DO = 95% - 98%, Turbidity= 47,15% - 56,10%.	Putra and Karnaningroem, 2011
12	PS	-	-	Anaerobic-aerobic biofilter	-	-	-	BOD = 67%-91% COD = 42%-95%	Hikmawati, 2013

organics and nutrients from domestic wastewater, this supporting medium can also be used in water bodies to remove pollutants. PET is a group of chemically stable polyesters in the form of thermoplastic polymer resins. The use of this polymer is diverse, ranging from in food and beverage containers to the manufacture of electronic components (Hui, 2006). Polymerization of ethylene terephthalate monomer units with repeating units ($C_{10}H_8O_4$) is a constituent of PET material. PET functional groups and properties can be seen in Figure 1 and Table 2. The use of PET as drinking bottle packaging will lead to the growth of plastic bottle waste. However, if PET plastic bottle waste is used in wastewater treatment, this will reduce plastic bottle waste. This is beneficial for Indonesia as the 4th largest waste producer in the world (PT. Chandra Asri Petrochemical, 2017). Plastic bottles are assembled to have a specific surface area that fits the design criteria. An example of a

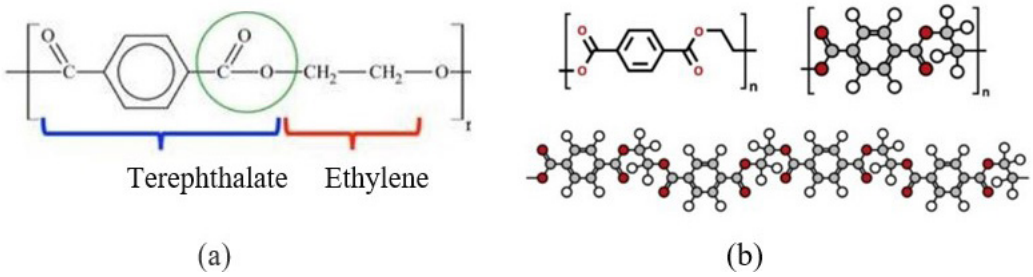

Figure 1. Polyethylene terephthalate (PET) Sources (a) Andrady, 2017; (b) Crawford and Quinn, 2017

Table 2. PET properties

Chemical formula	$(C_{10}H_8O_4)_n$
Classification	Thermoplastic
Molecular orientation in a solid phase	Semi-crystalline
Monomer	Terephthalic acid, Ethylene glycol
Density	± 1.29–1.40 g/cm^3
Glass transition	+ 69
Crystallinity	10–30 %
Strength	7.000–10.500 Psi
Surface energy	45.1 MJ/m^2
Temperature glass (Tg)	75 °C
Melting point	260 °C
Thermal conductivity	0,24 W/(m.K)
General properties	Transparent to visible light and microwaves. Highly resistant to aging, wear and heat. Lightweight, impact and shatter resistant. Good gas and moisture barrier properties.

Note: Sources – Andrady (2017), Crawford and Quinn (2017).

Figure 2. Supporting media from plastic bottle waste

series of used plastic bottles as supporting media which has a specific surface area of 444 m^2/m^3 can be seen in Figure 2. This type of PET polymer was proven to be able to attach large numbers of microorganisms (Setiyawan et al., 2023). Microorganisms grow covering the entire surface of the supporting medium to form a microbiological film (biofilm) (Chudoba et al., 1998). Selection

of biofilter system media must consider specific gravity, hardness, abrasion resistance, surface roughness, uniformity coefficient and availability in large quantities. Biofilter media can function as a place for biomass growth and retain solids. In addition, the media must also have easy washing and release of trapped solids. Due to the expected properties and properties of used plastic bottles, such as high inertia, high void volume fraction, large surface area, and hydrophilic nature, used plastic bottles have been utilized as supporting media in wastewater treatment. Even the properties and properties of plastic that can be shaped as desired, are easy to clean, resistant to change, resistant to abrasion, resistant to corrosives, strong, and persistent make it superior in operation and maintenance. Furthermore, being one of the world's leading manufacturers of plastic bottle waste, Indonesia will benefit greatly from this in terms of reducing plastic waste to landfill. Plastic bottles are produced not only in the home (Fauzi et al., 2022a), but also in hotels (Dewilda et al., 2022), restaurants (Dewilda et al., 2019), and the food industry (Dewilda et al., 2023), and other non domestics (Fauzi et al., 2022b). This plastic bottle waste can be used as a supporting medium in wastewater treatment.

CONCLUSIONS

Domestic wastewater treatment using attached systems biofilm is very popular for removing organics and nutrients. In this system, a supporting media is needed as a place for the attachment of microorganisms that will degrade pollutants. The supporting media that are often used are PET, PS, HDPE, and LDPE polymers. This media has been proven to remove organics and nutrients which are quite high. PET has relatively higher removal efficiency when compared to other media.

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