Applied Environmental Research
- RESEARCH FOR SUSTAINABLE PLANET -

Review Article

The Role of Bacteria and Factors Affecting the Biodegradation of Pollutants in the Biofilter Reactor: A Review

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Abstract

The findings showed that several types of bacteria can help biodegrade organic pollutants, such as *Comamonadacea*, which can biodegrade volatile fatty acids and aromatic compounds. *Proteobacteria*, *Bacteroidetes*, and *Actinobacteria* can biodegrade ammonium. Burkholderiales can biodegrade ferric ions and hydrogen. *Comamonas testosteroni* is able to biodegrade nitrates. Pseudomonas taiwanensis, *Acinetobacter guillouiae*, and Klebsiella pneumoniae can reduce copper, chromium and zinc levels. Azolla biomass reduces strontium. Rhodospirillum sp. can biodegrade cadmium, mercury, lead, and nickel. *Gallionella ferruginea* and Leptothrix sp. can biodegrade arsenic and manganese. *Gracilaria sp.* can biodegrade aluminum, chromium, and zinc. *Desulfovibrio sp.* can biodegrade copper, zinc, nickel, iron, and arsenic. *Thiomonas sp.* can biodegrade arsenic and iron. *Thauera selenatis* can biodegrade copper, zinc, cadmium, nickel, lead, cobalt, chromium, and mercury. *Thiobacillus thiooxidans* can degrade both zinc and copper. *Sargassum filipendula* biodegrades copper and nickel. Meanwhile, in the findings of the factors that affected biofiltration, it was identified that there were four that played a significant role such as temperature, dissolved oxygen, hydraulic retention time, organic loading rate, biological organisms, and supply nutrients. In conclusion, several types of bacteria grow and help biodegrade in biofilter reactors. This is inseparable from the supporting factors that increase the efficiency of pollutant reduction in biofilter reactors.

ARTICLE HISTORY
Received: 14 Jan. 2023
Accepted: 21 Sep. 2023
Published: 24 Oct. 2023

KEYWORDS
Biofiltration;
Microorganisms;
Biodegradation of Pollutants;
Wastewater;
Heavy metal and organic pollutants removal

Introduction

Water scarcity that occurs throughout the world is caused by the depletion of freshwater sources due to liquid waste pollution, which mostly occurs in poor and developing countries. However, several developed countries have reported similar problems [1–2]. Many recent cases of eutrophication have had detrimental impacts on the environment and have received tremendous attention worldwide [3]. The increasing problem of lack of clean water and polluted sources has increased the paradigm of renewable water treatment by attempting to treat water directly from the source [4], reuse [5], and decentralization [6]. Therefore, it does not pollute the environment. Wastewater treatment techniques, both physical, chemical, and biological, have been introduced to prevent damage to clean water sources from harmful pollutant contamination. Physicochemical treatments include coagulation-flocculation, aeration, chemical oxidation, filtration, and biofiltration [7–9]. Although chemical processing has some drawbacks, such as high sludge production, the relatively high investment capital [10] does not make this processing difficult to implement.

https://doi.org/10.35762/AER.2023020

Processing using biofiltration is indeed more preferred than other biological treatments that have been introduced, this is of course because the potential for reducing pollutants produced is quite high compared to the others, however, processing using biofiltration is still used as a third or tertiary treatment which is capable of significantly reducing pollutants in wastewater [11]. Processing with biofiltration involves the utilization of bacteria as a breakdown of pollutant elements that enter the liquid waste; later, these bacteria will be mobilized into the biofilm that has been formed, and the presence of biofilm and bacteria in the media will attract pollutants, which are in charge of breaking down pollutant elements into elements that are safer to release into the environment [12]. Several studies have shown that biofiltration can also be used to reduce pollutants in industrial gas waste and eliminate odor disturbances that may arise from gases containing harmful pollutants [13–17]. This is because biofiltration is known can remove volatile organic compounds [18].

In several municipal WWTP, biofilters were applied to remove nitrogenous pollutants and organic matter that are harmful to the environment. This is because the findings show that biofilters can be used to treat various types of pollutant problems in conventional drinking water treatment [19], gas and oil [20], raw waste [20–21], domestic wastewater [22–23], and groundwater [24]. Several studies have also developed biofilter operating conditions, including differential dissolved oxygen concentration, temperature, and filter media, which in general can affect the ability of biofilters to reduce pollutants in wastewater [25–27]. The layer of the biofilter media is very important for understanding the number of microbial structures that appear during the operation of the biofilter. Fungi, microbial activity, and bacterial viability greatly determine the effectiveness of a biofiltration reactor for reducing existing pollutants [28]. To maximize the formation of biofilms on the media, it is important to pay attention to the type of media used in the biofiltration reactor because it greatly affects the formation of aerobic and anaerobic zones, which can affect the distribution of dissolved oxygen in wastewater. [13]. However, many bio-filtration designers currently focus only on the absorption properties of biofilters rather than the formation of bacterial colonies, which will later break down pollutant elements into elements that are harmless to the environment [29–32]. The lack of information about the performance of biofilter reactors on technical and semi-technical scales is an obstacle in the development of this science because most of the previous research was carried out at the laboratory scale [15, 17, 28, 30, 33].

Energy saving is one of the reasons why many biological treatment processes are carried out compared to others, and flexibility, environmental friendliness, and lower costs also encourage other researchers to be more active in researching biological waste treatment. [10, 34–43]. Several studies related to biofilters are also interested in developing alternative media to further improve the performance efficiency of biofilms and bacteria, including wood, straw, and other fibers [44–46]. This was done to replace media that are often used, such as sand and gravel. Many pollutants in wastewater are known to occur in the scrubber system, which are then broken down by bacteria into compounds that are safer to be discharged into the environment [14, 47–48]. In the nitrification process, the microbial population in the biofilm is considered a nitrifier community whose function is to convert nitrite compounds into gases that are safely disposed of in the environment [49]. In this process, the nitrification process involves autotrophic bacteria, which convert ammonium to nitrite, and bacteria convert nitrile to nitrate [50].

Although research [51–55] has discussed several information of biofilter information have been discussed, a review of the role of microorganisms and factors that influence the effectiveness of biofiltration has not been found. The main objective was to answer the following questions:1. Which bacteria appear during biofiltration?, 2. What factors affect microorganism-assisted biofiltration?, and 3. How does the abundance of bacteria occur in a medium biofilter? This article specifically examines the above and explains it in detail by presenting data and tables from previous studies. The novelty of this research is that there has never been a study that thoroughly discusses the types of bacteria, factors that influence bacteria to appear in biofilms, and how the abundance of bacteria can occur in biofilters. In this review, article data were developed from reputable sources from SCOPUS, EBSCO, and Proquest. The data obtained were then poured into tables and analyzed in depth to find links to the research questions.

Material and method

Supporting data for this review were obtained from articles that had been published by previous studies of reputable categories, such as Scopus, EBSCO, and Proquest. These data were then synthesized based on research needs by dividing them into several parameters that will be discussed, namely, the types of microorganisms that assist in the biofiltration process and the pollutants removed, and how the temperature factor, organic loading rate, dissolved oxygen, and retention time affect the biofiltration process in reducing pollutants in liquid waste. Data that have been separated based on parameters are then entered into tables and analyzed, and then poured into the results and discussion in this study, supported by related theories.

Results and discussion

1) Types of bacteria that play important role in the biofilter

Several type of bacteria are found in the biofilter reactor and most of them are known for their benefits and existence, for more details can be seen in Table 1.

The pollutants that appear in the table above are very harmful to the environment, and their pollution occurs in wastewater samples, biotrickling filters, and biofilms, which has encouraged the development of processing methods to remove both organic matter and heavy metals. Biofiltration is an alternative method for removing organic matter and heavy metals [76]. This is because in the biofiltration reactor there is a medium where bacteria can grow and assist in the process of reducing existing pollutants [77]. In summary, pollutants present in liquid waste pass through the media [78] and are degraded by existing microorganisms [79, 80]. Microorganisms that grow on media degrade and develop biofilms. Good media have good surface area [81–82], water retention for biofilms to live on [83], and pollutant homogeneity [84]. These conditions provide space for microorganisms to reduce pollutants in liquid waste [47].

Table 1 Types of bacteria and their role in the biofilter reactor

No.	Bacterial type	Pollutans removal	Existence	References
1	*Comamonadacea*	Volatile fatty acids and aromatic compounds	Wastewater sample from biotrickling filter	[56]
2	*Proteobacteria, Bacteroidetes,* and *Actinobacteria*	Ammonium	More in biotrickling filter water samples than in biofilms	[57–58]
3	*Burkholderiales*	Ferric ions and hydrogen	-	[59]
4	*Comamonas testosteroni*	Nitrate	Biofilm	[58, 60]
5	*Comamonas nitrativorans*	Nitrate, nitrite and nitrous oxide	Wastewater sample from biotrickling filter	[61]
6	*Flavobacteriaceae, Alcaligenaceae, Cytophagaceae, Cryomorphaceae, Piscirickettsiaceae and Trueperaceae*	-	Wastewater sample from biotrickling filter	[62]
7	*Proteobacteria, Bacteroidetes dan Actinobacteria*	-	More in biotrickling filter water samples than in biofilms	[63–64]
8	*Pseudomonas taiwanensis, Acinetobacter guillouiae, Klebsiella pneumoniae*	Chromium, copper and zinc	Wastewater sample	[65]
9	*Azolla*	Strontium	Wastewater sample	[66]
10	*Rhodospirillum s* sp.	Cadmium, mercury, lead and nickel	Wastewater sample	[67]
11	*Eichhornia crassipes*	Lead, chromium, xinc, manganese and copper	Wastewater sample	[68]
12	*Gallionella ferruginea, Leptothrix* sp.	Arsenic and manganese	Wastewater sample	[69]
13	*Gracilaria* sp.	Aluminum, chromium and zinc	Wastewater sample	[70]
14	*Desulfovibrio* sp.	Zinc, copper, iron, arsenic and nickel	Wastewater sample	[71]
15	*Thiomonas* sp.	Arsenic and iron	Wastewater sample	[72]
16	*Thauera selenatis*	Zinc, copper, cadmium, nickel, mercury, lead, cobalt and chromium	Wastewater sample	[73]
17	*Sargassum filipendula*	Nickel and Copper	Wastewater sample	[74]
18	*Thiobacillus thiooxidans*	Zinc and copper	Wastewater sample	[75]

1.1) Organic pollutants removal

Comamonadacea can remove volatile fatty acid pollutants and aromatic compounds in a biotrickling filter [56] under both aerobic and anaerobic conditions. *Proteobacteria*, *Bacteroidetes*, and *Actinobacteria* are known to be able to remove ammonium, and their presence is higher in water samples than in biofilms [56–58]. In other studies, *Burkholderiales* were shown to be able to remove ferric ions, and it is also known that *Burkholderiales* have aerobic and anaerobic genera, and these bacteria are also able to oxidize hydrogen. Interestingly, these bacteria are also known as fermentative bacteria in the solution fermentation process [59]. In subsequent studies, it was found that the *Comamonas testosterone* bacterium is present in biofilms and is known to be able to reduce nitrate; in general, these bacteria are abundant in biofilms, so the presence of these bacteria will accelerate nitrate reduction in wastewater [60]. In addition, it is also known that *Comamonas testosterone* in bulk in an aerobic environment appears in both aerobic and anaerobic condition in biofilms [58].

Furthermore, *Comamonas nitrativorans* bacteria found in biotrickling filter water samples are known to reduce nitrite, nitrate and nitrous oxide [61]. Several bacteria, such as *Alcaligenaceae*, *Cryomorphaceae*, *Cytophagaceae*, *Piscirickettsiaceae*, *Flavobacteriaceae* and *Trueperaceae*, were identified to be present in the filter wastewater. Several bacteria exist in two places, namely biotrickling filters and biofilms, but the number is greater in biotrickling filters, including Bacteroidetes, Proteobacteria, and Actinobacteria [63–64]. *Alcaligenaceae*, *Cryomorphaceae*, *Cytophagaceae*, *Piscirickettsiaceae*, *Flavobacteriaceae*, and *Trueperaceae* bacteria in natural conditions have also been found in leachate waste in landfills [85–86].

1.2) Heavy metal pollutans removal

All heavy metals that enter the biofilter reactor are removed by biodegradation by bacteria previously attached to the biofilm [65, 87]. Several media have been found to reduce heavy metals because ion exchange occurs during biofiltration [88–89]. All heavy metals enter the biofilter reactor and are degraded by bacteria that grow on the biofilm to produce compounds that are insoluble and less toxic to the environment. This process is called adsorption, precipitation, bio-remediation, or absorption [90–92]. Heavy metals that pass through a biofilter reactor are converted into water and biomass, which can be safely discharged. Heavy metal methylation is another alternative that occurs in biofilter reactors, which are supported by bacteria present in biofilms [93–94].

Bacteria that can biodegrade heavy metals using biofiltration have been identified to be numerous, including Pseudomonas taiwanensis, Acinetobacter guillouiae, Klebsiella pneumoniae which are capable of reducing heavy metals of chromium, copper, and zinc types [65], Azolla which reduces strontium [66].

It is known also that *Rhodospirillum* sp. reduces mercury, cadmium, lead and nickel [67], *Thauera selenatis* reduces zinc, copper, cadmium, nickel, mercury, lead, cobalt and chromium [73], *Eichhornia crassipes* reduces chromium, manganese, lead, zinc and cadmium [68], *Leptothrix* sp. and *Gallionella ferruginea* reduce manganese and arsenic [69], *Sargassum filipendula* reduces copper and nickel [74], *Gracilaria* sp. reduces aluminum, zinc and chromium [70], *Thiobacillus thiooxidans* reduces zinc and copper [75], *Desulfovibrio* sp. reduces zinc, copper, iron, nickel and arsenic [71], *Thiomonas* sp. reduces arsenic and iron [72].

2) Several Factors affecting biofiltration effectiveness and efficiency

In a biofilter reactor, a complex procedure called biological filtration uses bacteria to break down the contaminants. Environmental factors affect biological aspects of wastewater remediation [95–97]. Temperature, dissolved oxygen, pH, and hydraulic retention time (HRT) have been measured in particular [98–101], nutrient supply, and biological organisms [102–103].

2.1) Temperature

By changing the temperature in the biofilter reactor, which impacts how well microorganisms develop on the formed biofilm, the performance of the biofilter can be controlled. Low temperatures are not ideal for the development of microorganisms, because some bacteria cannot endure them. Therefore, when low temperatures are present, bacteria that have already attached to the biofilm or are currently doing so will die [104–105]. Low temperatures are also known to contribute to long acclimatization [106] and low nitrification rates [107] Additionally, it has been stated that 18°C is the ideal temperature for producing effective biofilter performance [107].

According to Brown et al. [108] temperature stimulation of biofilms has a significant effect on the metabolism and growth of bacteria. Thus, relatively warm temperatures may cause bacteria in the biomass and biofilms to multiply. Some studies have suggested that increasing temps may encourage the development of bacteria in biofilms [109–111]. Every living entity in the reactor experiences an increase in metabolism as the temperature increases. The composition of the bacteria residing in the reactor is known to vary with temperature [112–

113]. Ciliates are microorganisms that can thrive in reactors [114–115]. Instead of causing an increase in the quantity of microbial populations or the rate of photosynthesis, an increase in temperature may also result in a change in taxonomy [116–117]. Despite the notion that temperature is beneficial for the activity of photosynthetic enzymes [118–119], low nutrient amounts can prevent bacterial growth [120– 121].

In the three-dimensional biofilm framework, the microbial communities were closely packed. The reaction of the biofilm to heat microbes adhering to the biofilm is modulated by the interactions between microbial groups [122–123]. Increasing temperatures can result in community changes when microbial species interact, which cannot be anticipated from the reactions of a single species [124]. Bacteria in biofilms fight one another for nutrients [125] while also taking advantage of one another [126].

2.2) Hydraulic retention time

The retention time must be considered if biofilter units are to be used over an extended period where retention duration has an impact on cost effectiveness as a direct result of how much substrate is handled [127–129]. Faster heterotrophic growth results from a prolonged retention time [130]. However, because it maintains a long retention time, extended retention also has some drawbacks such as cost consumption. [131].

According to [132–133], nitrite and nitrate effluents increase with a shorter hydraulic retention period. Based on the research conducted by [134], increased organic loading rate, hydraulic loading, and fluid shift as a result of hydraulic retention time aided bacterial development and biofilm formation. The bacterial community can degrade organic materials, and organic matter removal is more effective when the hydraulic retention time increases [135]. Thus, the reduction in organic matter during the pollutant degradation process can be influenced by the proper hydraulic retention time. A longer contact time between the wastewater and sedimentation rate of the treatment reactor can improve pollutant removal capacity [136–137].

2.3) Organic loading rate

Owing to the capacity of bacteria to disseminate organic processes beneath the flow of organic matter for the formation and refinement of biofilms that have been and will be created, the organic loading rate factor may have an effect on the rate at which biofilms grow [138]. The accumulation of biomass, biofilm development, and denitrification processes are all affected by the organic loading rate [139]. Excessive wastewater foam, which prevents the development of biofilms, is a drawback of increasing the organic loading rate [138, 140–141] and decreasing the number of potential adsorption sites [142]. The gas formation rate remained constant as the organic loading rate increased, but the percentage of the effluent increased [143].

2.4) Dissolved oxygen

Dissolved oxygen is essential for cellular activity and pollutant biodegradation. The growth of the microbial community depended on the quantity of dissolved oxygen in the wastewater. This is due to the fact that many aerobic microorganisms rely on dissolved oxygen for life and growth [144]. Additionally, adequate air can promote biofilm development [145]. Low dissolved levels result in ineffective contaminant abatement [146].

As dissolved oxygen is used to oxidize ammonium, iron, and manganese, it has a major impact on the treatment of biological systems. Additionally, energy is typically required when oxygen is dissolved in water; as a result, the higher the dissolved oxygen in the water, the higher the energy intake that takes place. The increased energy of the biofilter reactor enables greater pollutant reduction [147].

2.5) Biological organisms

Biological organisms that serve as catalysts for biofiltration are the primary ingredients. Biofilms are frequently created by microorganisms, such as bacteria, protozoa, invertebrates, and fungi. Bacteria and fungi are thought to be beneficial for the growth of microbial populations in media. To complete the process of pollutant breakdown, heterotrophic microbes were immobilized. The cells initially adhered to the biofilter material on the reactor surface. Subsequently, microbial cells colonize the surface to create an active layer that can absorb pollutants [12]. Another method is to affix synthetic microorganisms to biofilter materials. Microencapsulation, membranes, cross-linking, carrier bonding, and trapping have been used to immobilize cells artificially [12]. These microorganisms grow on bioreactor substrates and are responsible for odor control and pollutant degradation [148–149].

2.6) Supply nutrient

Nutrition is crucial for assessing the effectiveness of biofiltration. Pollutants provide energy to microbes by serving as carbon sources. The primary macronutrients are potassium, sulfur, nitrogen, and phosphorus, while metals and vitamins constitute the majority of the micronutrients [102]. These minerals were added to the medium in either the liquid or solid form. In aqueous solutions, most mineral compounds are dissolved and used as nutrient solutions in the biofilters. $FeSO_4$, $CaCl_2$, KNO_3, $(NH_4)2SO_4$, KH_2PO_4, $MnSO_4$, $MgSO_4$, NH_4HCO_3, and NH_4Cl are frequently used mineral ions [150–151]. Numerous studies have shown that nutrient availability promotes microbial development [102, 152].

Conclusion

Thus, bacteria play an important role in biofiltration. Several types of bacteria were identified in the biofilter reactor in both biofilm and wastewater samples. In this process, bacteria are mobilized into the media and attached to the media so that the pollutants that pass through the media are broken down and degraded by microorganisms. These microorganisms behave like biocatalysts and also directly develop biofilms where they attach so that the biofilm will be wider, and the more area these microorganisms can occupy for growth. Some factors that affect the growth of biofilms also have a direct effect on the attached bacteria, such as the symbiosis of mutualism, where one organism and the other will need each other. Factors that support the symbiosis of mutualism between biofilms and bacteria include the type of media (area, size, and surface roughness), pollutant homogeneity, and water retention, which help biofilms to remain alive. In addition to helping in the process of organic pollutant degradation, these bacteria are known to help degrade heavy metals. The following types of bacteria can help biodegrade organic and heavy metal pollutants such as *Comamonadacea*, which can biodegrade volatile fatty acids and aromatic compounds. Proteobacteria, Bacteroidetes, and Actinobacteria can biodegrade ammonium. *Burkholderiales* can biodegrade ferric ions and hydrogen. *Comamonas testosteroni* is able to biodegrade nitrates. *Pseudomonas taiwanensis*, *Acinetobacter guillouiae*, and *Klebsiella pneumoniae* can reduce copper, chromium and zinc levels. *Azolla* biomass reduces strontium. *Rhodospirillum* sp. can biodegrade cadmium, mercury, lead, and nickel. *Gallionella ferruginea* and *Leptothrix* sp. can biodegrade arsenic and manganese. *Gracilaria* sp. can biodegrade aluminum, chromium, and zinc. *Desulfovibrio* sp. can biodegrade copper, zinc, nickel, iron, and arsenic. *Thiomonas* sp. can biodegrade arsenic and iron. *Thauera selenatis* can biodegrade copper, zinc, cadmium, nickel, lead, cobalt, chromium, and mercury. *Thiobacillus thiooxidans* can degrade both zinc and copper. *Sargassum filipendula* biodegrades copper and nickel.

Meanwhile, in the findings of the factors that affected biofiltration, it was identified that there were four that played an important role such as temperature, dissolved oxygen, hydraulic retention time and organic loading rate, biological organisms, and supply nutrients. Temperature functions to control the performance of biofilms and bacteria in biofilms, where low temperatures will be very dangerous for the survival of bacteria that function to break down pollutants because it will reduce nutrient intake from wastewater for bacteria, so that they cannot develop and fall to the bottom of the bioreactor and are not replaced by other bacteria. Many bacteria that play an important role in biofilter reactors cannot survive at low temperatures. Retention time is also a key factor in biofilter performance because a longer contact time between bacteria and wastewater will further increase the number of bacteria that can adhere to the media, considering the roughness and breadth of the media. The rate of entry of the pollutant load is a key factor in biofilters because the rate of organic loading enhances the growth of existing bacterial biofilms. To summarize the conclusions, refer to the following Figure 1.

https://doi.org/10.35762/AER.2023020

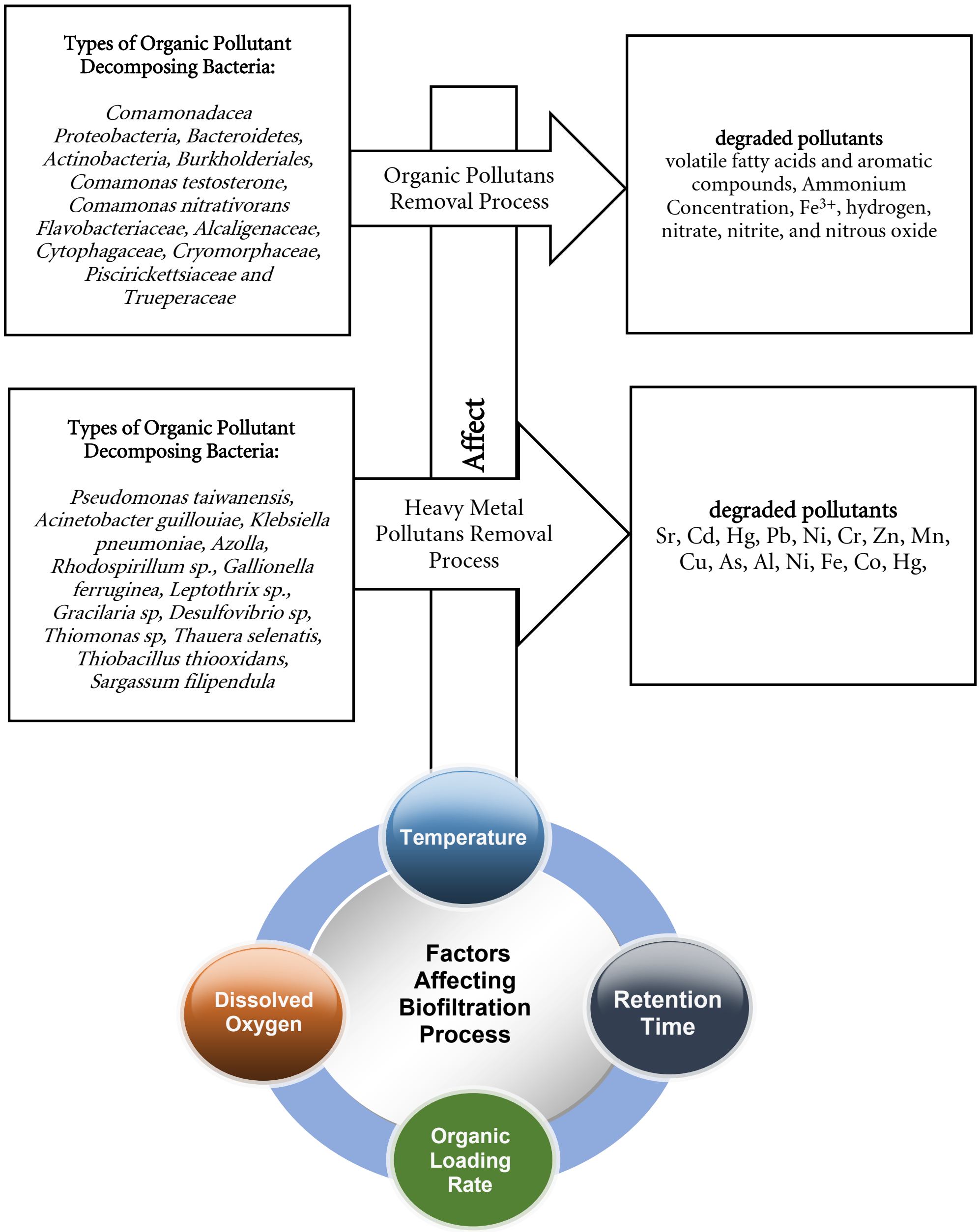

Figure 1 Summary conclusion.

References

[1] Bahrodin, M.B., Zaidi, N.S, Kadier, A., Hussein, N., Syafiuddin, A., Boopathy, R. A novel natural active coagulant agent extracted from the sugarcane bagasse for wastewater treatment. Applied Sciences, 2022, 12(16), 7972.

[2] Lani, N.H.M., Yusop, Z., Syafiuddin, A. A review of rainwater harvesting in Malaysia: Prospects and challenges. Water (Switzerland), 2018, 10, 1–21.

[3] Yao, S., Ni, J., Chen, Q., Borthwick, A.G.L. Enrichment and characterization of a bacteria consortium capable of heterotrophic nitrification and aerobic denitrification at low temperature. Bioresource Technology, 2013, 127, 151–157.

[4] Malila, R., Lehtoranta, S., Viskari, E.L. The role of source separation in nutrient recovery – Comparison of alternative wastewater treatment systems. Journal of Cleaner Production, 2019, 219, 350–358.

[5] Cecconet, D., Callegari, A., Hlavнnek, P., Capodaglio, A.G. Membrane bioreactors for sustainable, fit-for-purpose greywater treatment: A critical review. Clean Technologies and Environmental Policy, 2019, 21, 745–762.

[6] Capodaglio, A.G. Integrated, decentralized wastewater management for resource recovery in rural and peri-urban areas. Resources, 2017, 6(2), 22.

[7] Zaidi, N.S., Sohaili, J., Muda, K., Saidi, M.S. Optimisation of static magnetic field (SMF) on physical properties of biomass using central composite design experiment. Journal of Physics: Conference Series, 2020, 1529, 042094.

[8] Nur Syamimi, Z., Muda, K., Sohaili, J., Sillanpaa, M. Optimization of activated sludge physical properties by magnetic field via response surface modeling. Applied Mechanics and Materials, 2014, 567, 98–103.

[9] Syafiuddin, A., Salmiati, S., Hadibarata, T., Kueh, A.B.H., Salim, M.R., Zaini, M.A.A. Silver nanoparticles in the water environment in Malaysia: Inspection, characterization, removal, modeling, and future perspective. Scientific Reports, 2018, 8, 1–15.

[10] Gupta, V.K., Ali, I. Wastewater treatment by biological methods. Environmental Water, 2013, 179–204.

[11] Garcia-Sanchez, L., Gutierrez-Macias, T., Estrada-Arriaga, E.B. Assessment of a Ficus benjamina wood chip-based aerated biofilter used for the removal of metformin and ciprofloxacin during domestic wastewater treatment. Journal of Chemical Technology & Biotechnology, 2019, 94, 1870–1879.

[12] Cohen, Y. Biofiltration - The treatment of fluids by microorganisms immobilized into the filter bedding material: A review. Bioresource Technology, 2001, 77, 257–274.

[13] Maia, G.D.N., Sales, G.T., Day, G.B.V., Gates, R.S., Taraba, J.L. Characterizing physical properties of gas-phase biofilter media. Trans ASABE, 2012, 55, 1939–1950.

[14] Wery, N. Bioaerosols from composting facilities-A review. Frontiers in Cellular and Infection Microbiology, 2014, 4, 1–9.

[15] Ralebitso-Senior, T.K., Senior, E., Di Felice, R., Jarvis, K. Waste gas biofiltration: Advances and limitations of current approaches in microbiology. Environmental Science and Technology, 2012, 46, 8542–8573.

[16] Fletcher, L.A., Jones, N., Warren, L., Stentiford, E.I. Understanding biofilter performance and determining emission concentrations under operational conditions, 2014.

[17] Tang, H.M., Hwang, S.J., Hwang, S.C. Waste Gas Treatment in Biofilters. Journal of the Air & Waste Management Association, 1996, 46, 349–354.

[18] Omri, I., Aouidi, F., Bouallagui, H., Godon, J.J., Hamdi, M. Performance study of biofilter developed to treat H_2S from wastewater odour. Saudi Journal of Biological Sciences, 2013, 20, 169–176.

[19] McKie, M.J., Andrews, S.A., Andrews, R.C. Conventional drinking water treatment and direct biofiltration for the removal of pharmaceuticals and artificial sweeteners: A pilot-scale approach. Science of the Total Environment, 2016, 544, 10–17.

[20] Riley, S.M., Ahoor, D.C., Cath, T.Y. Enhanced biofiltration of O&G produced water comparing granular activated carbon and nutrients. Science of the Total Environment, 2018, 640–641, 419–428.

[21] Gilbert, S., Gasperi, J., Rocher, V., Lorgeoux, C., Chebbo, G. Removal of alkylphenols and polybromodiphenylethers by a biofiltration treatment plant during dry and wet-weather periods. Water Science and Technology, 2012, 65, 1591–1598.

[22] Cui, B., Yang, Q., Zhang, Y., Liu, X., Wu, W., Li, J. Improving nitrogen removal in biological aeration filter for domestic sewage treatment via adjusting microbial community structure. Bioresource Technology, 2019, 293, 122006.

[23] Tao, C., Peng, T., Feng, C., Chen, N., Hu, Q., Hao, C. The feasibility of an up-flow partially aerated biological filter (U-PABF) for nitrogen and COD removal from domestic wastewater. Bioresource Technology, 2016, 218, 307–317.

[24] Zeng, H., Yin, C., Zhang, J., Li, D. Start-up of a biofilter in a full-scale groundwater treatment plant for iron and manganese removal. International Journal of Environmental Research and Public Health, 2019, 16(5), 698.

[25] Lekang, O.I., Kleppe, H. Efficiency of nitrification in trickling filters using different filter media. Aquacultural Engineering, 2000, 21, 181–199.

[26] Kim, T.G., Yun, J., Hong, S.H., Cho, K.S. Effects of water temperature and backwashing on bacterial population and community in a biological activated carbon process at a water treatment plant. Applied Microbiology and Biotechnology, 2014, 98, 1417–1427.

[27] Cheng, Q., Nengzi, L., Bao, L., Wang, Y., Yang, J., Zhang, J. Interactions between ammonia, iron and manganese removal using pilot-scale biofilters. Journal of Water Supply: Research and Technology - AQUA, 2017, 66, 157–165.

[28] Le Borgne, S., Baquerizo, G. Microbial ecology of biofiltration units used for the desulfurization of biogas. ChemEngineering, 2019, 3, 1–26.

[29] Runye, Z., Kennes, C., Zhuowei, C., Lichao, L., Jianming, Y., Jianmeng, C. Styrene removal in a biotrickling filter and a combined UV-biotrickling filter: Steady- and transient-state performance and microbial analysis. Chemical Engineering Journal, 2015, 275, 168–178.

[30] Pandey, R.A., Padoley, K.V., Mukherji, S.S., Mudliar, S.N., Vaidya, A.N., Rajvaidya, A.S., Subbarao, T.V. Biotreatment of waste gas containing

pyridine in a biofilter. Bioresource Technology, 2007, 98, 2258–2267.

[31] Ghasemi, R., Golbabaei, F., Rezaei, S., Pourmand, M.R., Nabizadeh, R., Jafari, M.J., Masoorian, E. A comparison of biofiltration performance based on bacteria and fungi for treating toluene vapors from airflow. AMB Express, 2020, 10, 8.

[32] Li, L., Lian, J., Han, Y., Liu, J. A biofilter integrated with gas membrane separation unit for the treatment of fluctuating styrene loads. Bioresource Technology, 2012, 111, 76–83.

[33] Rene, E.R., Kar, S., Krishnan, J., Pakshirajan, K., Lypez, M.E., Murthy, D.V.S., Swaminathan, T. Start-up, performance and optimization of a compost biofilter treating gas-phase mixture of benzene and toluene. Bioresource Technology, 2015, 190, 529–535.

[34] Mouchet, P. From conventional to biological removal of iron and manganese in France. Journal AWWA, 1992, 84, 158–167.

[35] Syafiuddin, A., Boopathy, R., Mehmood, M.A. Recent advances on bacterial quorum quenching as an effective strategy to control biofouling in membrane bioreactors. Bioresource Technology Reports, 2021, 15, 100745.

[36] Ratnasari, A., Zaidi, N.S., Syafiuddin, A., Boopathy, R., Kueh, A.B.H., Amalia, R., Prasetyo, D.D. Prospective biodegradation of organic and nitrogenous pollutants from palm oil mill effluent by acidophilic bacteria and archaea. Bioresource Technology Reports, 2021, 15, 100809.

[37] Hadibarata, T., Syafiuddin, A., Al-Dhabaan, F.A., Elshikh, M.S., Rubiyatno, Biodegradation of Mordant orange-1 using newly isolated strain Trichoderma harzianum RY44 and its metabolite appraisal. Bioprocess and Biosystems Engineering, 2018, 41, 621–632.

[38] Al Farraj, D.A., Elshikh, M.S, Al Khulaifi, M.M., Hadibarata, T., Yuniarto, A., Syafiuddin, A biotransformation and detoxification of Antraquione Dye Green 3 using halophilic Hortaea sp. International Biodeterioration and Biodegradation, 2019, 140, 72–77.

[39] Al Farraj, D.A., Hadibarata, T., Yuniarto, A., Syafiuddin, A., Surtikanti, H.K., Elshikh, M.S., Al Khulaifi, M.M., Al-Kufaidy, R. Characterization of pyrene and chrysene degradation by halophilic Hortaea sp. B15. Bioprocess and Biosystems Engineering, 2019, 42, 963–969.

[40] Mostafa, A.A.F., Elshikh, M.S., Al-Askar, A.A., Hadibarata, T., Yuniarto, A., Syafiuddin, A. Decolorization and biotransformation pathway of textile dye by Cylindrocephalum aurelium. Bioprocess and Biosystems Engineering, 2019, 42, 1483–1494.

[41] Al Farraj, D.A., Hadibarata, T., Yuniarto, A., Alkufeidy, R.M., Alshammari, M.K., Syafiuddin, A. Exploring the potential of halotolerant bacteria for biodegradation of polycyclic aromatic hydrocarbon. Bioprocess and Biosystems Engineering, 2020, 43, 2305–2314.

[42] Syafiuddin, A., Boopathy, R., Hadibarata, T. Challenges and solutions for sustainable groundwater usage: Pollution control and integrated management. Current Pollution Reports, 2020, 6, 310–327.

[43] Syafiuddin, A., Fulazzaky, M.A. Decolorization kinetics and mass transfer mechanisms of Remazol Brilliant Blue R dye mediated by different fungi. Biotechnology Reports, 2021, 29, e00573.

[44] Sosa-Hernandez, D.B, Vigueras-Cortes, J.M., Garzon-Zuniga, M.A. Mesquite wood chips (Prosopis) as filter media in a biofilter system for municipal wastewater treatment. Water Science and Technology, 2016, 73, 1454–1462.

[45] Saliling, W.J.B., Westerman, P.W., Losordo, T.M. Wood chips and wheat straw as alternative biofilter media for denitrification reactors treating aquaculture and other wastewaters with high nitrate concentrations. Aquacultural Engineering, 2007, 37, 222–233.

[46] Vigueras-Cortes, J.M., Villanueva-Fierro, I., Garzon-Zuniga, M.A., De Jesъs Navar-Chaidez, J., Chaires-Hernandez, I., Hernandez-Rodriguez, C. Performance of a biofilter system with agave fiber filter media for municipal wastewater treatment. Water Science and Technology, 2013, 68, 599–607.

[47] Ibanga, I.E., Fletcher, L.A., Noakes, C.J., King, M.F., Steinberg, D. Pilot-scale biofiltration at a materials recovery facility: The impact on bioaerosol control. Waste management, 2018, 80, 154–167.

[48] Hu, X.R., Han, M.F., Wang, C., Yang, N.Y., Wang, Y.C., Duan, E.H., His, H.C., Deng, J.G. A short review of bioaerosol emissions from gas bioreactors: Health threats, influencing factors and control technologies. Chemosphere, 2020, 253, 126737.

[49] Juhler, S., Revsbech, N.P., Schramm, A., Herrmann, M., Ottosen, L.D.M., Nielsen, L.P. Distribution and rate of microbial processes in an ammonia-loaded air filter biofilm. Applied and Environmental Microbiology, 2009, 75, 3705–3713.

[50] Ge, S., Wang, S., Yang, X., Qiu, S., Li, B., Peng, Y. Detection of nitrifiers and evaluation of partial nitrification for wastewater treatment: A review. Chemosphere, 2015, 140, 85–98.

[51] Tekerlekopoulou, A.G., Pavlou, S., Vayenas, D. V. Removal of ammonium, iron and manganese from potable water in biofiltration units: A review. Journal of Chemical Technology and& Biotechnology, 2013, 88, 751–773.

[52] Basu, O.D., Dhawan, S., Black, K. Applications of biofiltration in drinking water treatment - A review. Journal of Chemical Technology and Biotechnology, 2016, 91, 585–595.

[53] Marsidi, N., Abu Hasan, H., Sheikh Abdullah, S.R. A review of biological aerated filters for iron and manganese ions removal in water treatment. Journal of Water Process Engineering, 2018, 23, 1–12.

[54] Terry, L.G., Summers, R.S. Biodegradable organic matter and rapid-rate biofilter performance: A review. Water Research, 2018, 128, 234–245.

[55] Wang, Y., Fu, Y., Wang, C., Wen, N. Dissimilar emission characteristics between bioaerosol and suspended particles from gaseous biofilters and bioaerosol health risk evaluation. Aerosol and Air Quality Research, 2018, 18, 1874–1885.

[56] Kristiansen, A., Pedersen, K.H., Nielsen, P.H., Nielsen, L.P., Nielsen, J.L., Schramm, A. Bacterial community structure of a full-scale biofilter treating pig house exhaust air. Systematic and Applied Microbiology, 2011, 34, 344–352.

[57] Kristiansen, A., Lindholst, S., Feilberg, A., Nielsen, P.H., Neufeld, J.D., Nielsen, J.L. Butyric acid- and dimethyl disulfide-assimilating microorganisms in a biofilter treating air emissions from a livestock facility. Applied and Environmental Microbiology, 2011, 77, 8595–8604.

[58] Bl6zquez, E., Bezerra, T., Lafuente, J., Gabriel, D. Performance, limitations and microbial diversity of a biotrickling filter for the treatment of high loads of ammonia. Chemical Engineering Journal, 2017, 311, 91–99.

[59] Willems, A. The Family Rhodocyclaceae BT - The Prokaryotes: Alphaproteobacteria and Betaproteobacteria, Fourth. Springer-Verlag, Berlin Heidelberg, 2014.

[60] Wu, Y., Shukal, S., Mukherjee, M., Cao, B. Involvement in Denitrification is Beneficial to the Biofilm Lifestyle of Comamonas testosteroni: A mechanistic study and its environmental implications. Environmental Science and Technology, 2015, 49, 11551–11559.

[61] Etchebehere, C., Errazquin, M.I., Dabert, P., Moletta, R., Muxн, L. Comamonas nitrativorans sp. nov., A novel denitrifier isolated from a denitrifying reactor treating landfill leachate. International Journal of Systematic and Evolutionary Microbiology, 2001, 51, 977–983.

[62] Griffiths, E., Gupta, R.S. Identification of signature proteins that are distinctive of the Deinococcus-Thermus phylum. International Microbiology, 2007, 10, 201–208.

[63] Dworkin, M., Falkow, S., Rosenberg, E. The Prokaryotes: An evolving electronic resource for the microbial community, 3rd ed., Springer, New York, 2006.

[64] Pal, L., Kraigher, B., Brajer-Humar, B., Levstek, M., Mandic-Mulec, I. Total bacterial and ammonia-oxidizer community structure in moving bed biofilm reactors treating municipal wastewater and inorganic synthetic wastewater. Bioresource Technology, 2012, 110, 135–143.

[65] Majumder, S. Studies on removal of heavy metals from wastewater using biofiltration. Birla Institute of Technology and Science, 2015.

[66] Cohen-Shoel, N., Barkay, Z., Ilzycer, D., Gilath, I., Tel-Or, E. Biofiltration of toxic elementary by Azolla biomass. Water, Air, & Soil Pollution, 2002, 135, 93–104.

[67] Chatterji, A.K. Introduction to Environmental Biotechnology, 3rd ed., Asoke K. Ghosh, PHI Learning Private Limited, New Delhi India, 2011.

[68] Tiwari, S., Dixit, S., Verma, N. An effective means of biofiltration of heavy metal contaminated water bodies using aquatic weed Eichhornia crassipes. Environmental Monitoring and Assessment, 2007, 129, 253–256.

[69] Katsoyiannis, I.A., Zouboulis, A.I. Application of biological processes for the removal of arsenic from groundwaters. Water Research, 2004, 38, 17–26.

[70] Kang, K.H., Sui, Z. Removal of eutrophication factors and heavy metal from a closed cultivation system using the macroalgae, Gracilaria sp. (Rhodophyta). Journal of Oceanology and Limnology, 2010, 28, 1127–1130.

[71] Jong, T., Parry, D.L. Removal of sulfate and heavy metals by sulfate reducing bacteria in short-term bench scale upflow anaerobic packed bed reactor runs. Water Research, 2003, 37, 3379 –3389

[72] Casiot, C., Morin, G., Juillot, F., Bruneel, O., Personne, J.C., Leblanc, M., …, Elbaz-Poulichet, F. Bacterial immobilization and oxidation of

arsenic in acid mine drainage (Carnoules creek, France). Water Research, 2003, 37, 2929–2936.
[73] Mergeay, M., Monchy, S., Vallaeys, T., Auquier, V., Benotmane, A., Bertin, P., Taghavi, S., Dunn, J., Van Der Lelie, D., Wattiez, R. Ralstonia metallidurans, a bacterium specifically adapted to toxic metals: Towards a catalogue of metal-responsive genes. FEMS Microbiology Reviews, 2003, 27, 385–410.
[74] Rinku, N.H., Patel, V., Jasrai, R.T., College R.P.T.P.S. Removal of cadmium, chromium and lead from filamentous alga of Pithophora sp. of industrial wastewater. International Journal of Environmental Science, 2012, 3, 2010–2013.
[75] Nagashetti, V., Javed, A., Trivedi, D., Prasad Bhusal, K. Biosorption of Heavy Metals from Soil by Pseudomonas Aeruginosa. International Journal of Innovative Technology and Exploring Engineering, 2013, 2:2278–3075
[76] Vikrant, K., Kailasa, S.K., Tsang, D.C.W., Lee, S.S., Kumar, P., Giri, B.S., Singh, R.S., Kim, K.H. Biofiltration of hydrogen sulfide: Trends and challenges. Journal of Cleaner Production, 2018, 187, 131–147.
[77] Berenjian, A., Chan, N., Malmiri, H.J. Volatile organic compounds removal methods: A review. American Journal of Biochemistry and Biotechnology, 2012, 8, 220–229.
[78] Gymez-Borraz, T.L., Gonzalez-Sanchez, A., Bonilla-Blancas, W., Revah, S., Noyola, A Characterization of the biofiltration of methane emissions from municipal anaerobic effluents. Process Biochemistry, 2017, 63, 204–213.
[79] Carpenter, C.M.G., Helbling, D.E. Removal of micropollutants in biofilters: Hydrodynamic effects on biofilm assembly and functioning. Water Research, 2017, 120, 211–221.
[80] Jeong, S., Cho, K., Jeong, D., Lee, S., Leiknes, T.O., Vigneswaran, S., Bae, H. Effect of engineered environment on microbial community structure in biofilter and biofilm on reverse osmosis membrane. Water Research, 2017, 124, 227–237.
[81] Srivastva, N., Singh, R.S., Dubey, S.K. Efficacy of wood charcoal and its modified form as packing media for biofiltration of isoprene. Journal of Environmental Management, 2017, 196, 252–260.
[82] Rene, E.R., Sergienko, N., Goswami, T., Lypez, M.E., Kumar, G., Saratale, G.D., Venkatachalam, P., Pakshirajan, K., Swaminathan, T. Effects of concentration and gas flow rate on the removal of gas-phase toluene and xylene mixture in a compost biofilter. Bioresource Technology, 2018, 248, 28–35.
[83] Macaitis, K., Misevicius, A., Paskevicius, A., Raudoniene, V., Repeckiene, J. Effectiveness research on a wavy lamellar plate-type biofilter with a capillary system for the humidification of the packing material applying introinduced microorganisms. Journal of Environmental Engineering and Landscape Management, 2014, 22, 254–263.
[84] Cassini, F., Scheutz, C., Skov, B.H., Mou, Z., Kjeldsen, P. Mitigation of methane emissions in a pilot-scale biocover system at the AV Miljш Landfill, Denmark: 1. System design and gas distribution. Waste Management, 2017, 63, 213–225.
[85] Miao, L., Wang, S., Li, B., Cao, T., Zhang, F., Wang, Z., Peng, Y. Effect of carbon source type on intracellular stored polymers during endogenous denitritation (ED) treating landfill leachate. Water Research, 2016, 100, 405–412.
[86] Tan, N.C.G., Kampschreur, M.J., Wanders, W., van der Pol, W.L.J., van de Vossenberg, J., Kleerebezem, R., van Loosdrecht, M.C.M., Jetten, M.S.M. Physiological and phylogenetic study of an ammonium-oxidizing culture at high nitrite concentrations. Systematic and Applied Microbiology, 2008, 31, 114–125.
[87] Gallardo-Rodrнguez, J.J., Rios-Rivera, A.C., Von Bennevitz, M.R. Living biomass supported on a natural-fiber biofilter for lead removal. Journal of Environmental Management, 2019, 231, 825–832.
[88] de Paris Junior, O., Scapini, T., Camargo, A.F., Venturin, B., Dalastra, C., Kubeneck, S., …, Treichel, H. Removal of chromium from wastewater by swine hair residues applied as a putative biofilter. Environmental Science and Pollution Research, 2019, 26, 33014–33022.
[89] Lim, H.S., Lim, W., Hu, J.Y., Ziegler A, Ong SL Comparison of filter media materials for heavy metal removal from urban stormwater runoff using biofiltration systems. Journal of Environmental Management, 2015, 147, 24–33.
[90] Li, H., Huang, S., Zhou, S., Chen, P., Zhang, Y. Study of extracellular polymeric substances in the biofilms of a suspended biofilter for nitric oxide removal. Applied Microbiology and Biotechnology, 2016, 100, 9733–9743.
[91] Valls, M., De Lorenzo, V. Exploiting the genetic and biochemical capacities of bacteria for the remediation of heavy metal pollution. FEMS Microbiology Reviews, 2002, 26, 327–338.

[92] Kumari, M., Tripathi, B.D. Effect of Phragmites australis and Typha latifolia on biofiltration of heavy metals from secondary treated effluent. International Journal of Environmental Science and Technology, 2015, 12, 1029–1038.

[93] Srivastava, N.K., Majumder, C.B. Novel biofilmtration methods for the treatment of heavy metals from industrial wastewater. Journal of Hazardous Materials, 2008, 151, 1–8.

[94] White, C., Sayer, J., Gadd, G. Microbial solubalization and immobilization of toxic metals. FEMS Microbiology Reviews, 1997, 20:503–516

[95] Luo, G., Xu, G., Gao, J., Tan, H. Effect of dissolved oxygen on nitrate removal using polycaprolactone as an organic carbon source and biofilm carrier in fixed-film denitrifying reactors. Journal of Environmental Sciences (China), 2016, 43, 147–152.

[96] Ding, A., Zhao, D., Ding, F., Du, S., Lu, H., Zhang, M., Zheng, P. Effect of inocula on performance of bio-cathode denitrification and its microbial mechanism. Chemical Engineering Journal, 2018 343, 399–407.

[97] Xu, Z., Dai, X., Chai, X. Effect of influent pH on biological denitrification using biodegradable PHBV/PLA blends as electron donor. Biochemical Engineering Journal, 2018, 131, 24–30.

[98] Liu, Y., Gan, L., Chen, Z., Megharaj, M., Naidu, R. Removal of nitrate using Paracoccus sp. YF1 immobilized on bamboo carbon. Journal of Hazardous Materials, 2012, 229–230, 419–425.

[99] Lu, H., Wang, X., Zang, M., Zhou, J., Wang, J., Guo, W. Degradation pathways and kinetics of anthraquinone compounds along with nitrate removal by a newly isolated Rhodococcus pyridinivorans GF3 under aerobic conditions. Bioresource Technology, 2019, 285, 121336.

[100] Su, J.F., Shi, J., Xin, M.F. Aerobic denitrification and biomineralization by a novel heterotrophic bacterium, Acinetobacter sp. H36. Marine Pollution Bulletin, 2017, 116, 209–215.

[101] Hu, B., Wang, T., Ye, J., Zhao, J., Yang, L., Wu, P., Duan, J., Ye, G. Effects of carbon sources and operation modes on the performances of aerobic denitrification process and its microbial community shifts. Journal of Environmental Management, 2019, 239, 299–305.

[102] Weckhuysen, B., Vriens, L., Verachtert, H. The effect of nutrient supplementation on the biofiltration removal of butanal in contaminated air. Applied Microbiology and Biotechnology, 1993, 39, 395–399.

[103] Morales, M., Hernбndez, S., Cornabй, T., Revah, S., Auria, R. Effect of drying on biofilter performance: Modeling and experimental approach. Environmental Science & Technology, 2003, 37, 985–992.

[104] Shah, S.B., Bhumbla, D.K., Basden, T.J., Lawrence, L.D. Cool temperature performance of a wheat straw biofilter for treating dairy wastewater. Journal of Environmental Science and Health, Part B, Pesticides, Food Contaminants, and Agricultural Wastes, 2002, 37, 493–505.

[105] Zhang, D.Y., Li, W.G., Zhang, S.M., Liu, M., Zhao, X.Y., Zhang, X.C. Bacterial community and function of biological activated carbon filter in drinking water treatment. Biomedical and Environmental Sciences, 2011, 24, 122–131.

[106] Halle, C., Huck, P.M., Peldszus, S. Emerging contaminant removal by biofiltration: Temperature, concentration, and EBCT impacts. American Water Works Association, 2015, 107, E364–E379.

[107] Zhang, Q., Chen, X., Luo, W., Wu, H., Liu, X., Chen, W., Tang, J., Zhang, L. Effects of temperature on the characteristics of nitrogen removal and microbial community in post solid-phase denitrification biofilter process. International Journal of Environmental Research and Public Health, 2019, 16(22), 4466.

[108] Brown, J.H., Gillooly, J.F., Allen, A.P., Savage, V.M., West, G.B. toward a metabolic theory of ecology. Ecology, 2004, 85, 1771–1789.

[109] Ratkowsky, D.A., Olley, J., McMeekin, T.A., Ball, A. Relationship between temperature and growth rate of bacteria cultures. Journal of Bacteriology, 1982, 149, 1–5.

[110] Sander, B.C., Kalff, J. Factors controlling bacterial production in marine and freshwater sediments. Microbial Ecology, 1993, 26, 79–99.

[111] Sand-Jensen, K., Pedersen, N.L., Sшndergaard, M. Bacterial metabolism in small temperate streams under contemporary and future climates. Freshwater Biology, 2007, 52, 2340–2353.

[112] Lindstrцm, E.S., Kamst-Van Agterveld, M.P., Zwart, G. Distribution of typical freshwater bacterial groups is associated with pH, temperature, and lake water retention time. Applied and Environmental Microbiology, 2005, 71, 8201–8206.

[113] Lear, G., Anderson, M.J., Smith, J.P., Boxen, K., Lewis, G.D. Spatial and temporal heterogeneity of the bacterial communities in stream epilithic biofilms. FEMS Microbiology Ecology, 2008, 65, 463–473

[114] Weisse, T., Stadler, P., Lindstrom, E.S., Kimmance, S.A., Montagnes, D.J.S. Interactive effect of temperature and food concentration on growth

rate: A test case using the small freshwater ciliate Urotricha farcta. Limnology and Oceanography, 2002, 47, 1447–1455.
[115] Norf, H., Arndt, H., Weitere, M. Impact of local temperature increase on the early development of biofilm-associated ciliate communities. Oecologia, 2007, 151, 341–350.
[116] Baulch, H.M., Schindler, D.W., Turner, M.A., Findlay, D.L., Paterson, M.J., Vinebrooke, R.D. Effects of warming on benthic communities in a boreal lake: Implications of climate change. Limnology and Oceanography, 2005, 50, 1377–1392.
[117] Ventura, M., Liboriussen, L., Lauridsen, T., Sшndergaard, M., Sшndergaard, M., Jeppesen, E. Effects of increased temperature and nutrient enrichment on the stoichiometry of primary producers and consumers in temperate shallow lakes. Freshwater Biology, 2008, 53, 1434–1452.
[118] Davison, I.R. Environmental effects on algal photosynthesis. Journal of Phycology, 1991, 27, 2–8.
[119] Necchi, O. Photosynthetic responses to temperature in tropical lotic macroalgae. Phycological Research, 2004, 52, 140–148
[120] Christoffersen, K., Andersen, N., Sшndergaard, M., Liboriussen, L., Jeppesen, E. Implications of climate-enforced temperature increases on freshwater pico- and nanoplankton populations studied in artificial ponds during 16 months. Hydrobiologia, 2006, 560, 259–266.
[121] Staehr, P.A., Sand-Jensen, K.A.J. Seasonal changes in temperature and nutrient control of photosynthesis, respiration and growth of natural phytoplankton communities. Freshwater Biology, 2006, 51, 249–262.
[122] Vasseur, D.A., McCann, K.S. A mechanistic approach for modeling temperature-dependent consumer-resource dynamics. American Naturalist, 2005, 166, 184–198.
[123] Hansen, S.K., Rainey, P.B., Haagensen, J.A.J., Molin, S. Evolution of species interactions in a biofilm community. Nature, 2007, 445, 533–536.
[124] Jiang, L., Morin, P.J. Temperature-dependent interactions explain unexpected responses to environmental warming in communities of competitors. Journal of Animal Ecology, 2004, 73, 569–576.
[125] Rier, S.T., Stevenson, R.J. Effects of light, dissolved organic carbon, and inorganic nutrients on the relationship between algae and heterotrophic bacteria in stream periphyton. Hydrobiologia, 2002, 489, 179–184.
[126] Romanн, A.M., Sabater, S. Effect of primary producers on the heterotrophic metabolism of a stream biofilm. Freshwater Biology, 1999, 41, 729–736.
[127] Kadlec, R., Knight, R., Vymazal, J., Brix, H., Cooper, P., Hoberl, R. Constructed Wetlands for Pollution Control, 1st Edition. IWA Publishing, 2000.
[128] Kim, M.S., Cha, J., Kim, D.H. Fermentative biohydrogen production from solid wastes, 1st ed. Biohydrogen, 2013, 259–283.
[129] Velvizhi, G. Overview of bioelectrochemical treatment systems for wastewater remediation. Microbial Electrochemical Technology, 2019, 587–612.
[130] Nogueira, R., Melo, L.F., Purkhold, U., Wuertz, S., Wagner, M. Nitrifying and heterotrophic population dynamics in biofilm reactors: Effects of hydraulic retention time and the presence of organic carbon. Water Research, 2002, 36, 469–481.
[131] Hasan, H.A., Abdullah, S.R.S., Kamarudin, S.K., Kofli, N.T. HRT effect on simultaneous cod, ammonia and manganese removal from drinking water treatment system using a biological aerated filter (BAF). Environmental Engineering and Management Journal, 2018, 17, 199–207.
[132] Ovez, B., Ozgen, S., Yuksel, M. Biological denitrification in drinking water using Glycyrrhiza glabra and Arunda donax as the carbon source. Process Biochemistry, 2006, 41, 1539–1544.
[133] Wang, X.M., Wang, J.L. Nitrate removal from groundwater using solid-phase denitrification process without inoculating with external microorganisms. International Journal of Environmental Science and Technology, 2013, 10, 955–960.
[134] Song, X., Yang, X., Hallerman, E., Jiang, Y., Huang, Z. Effects of hydraulic retention time and influent nitrate-n concentration on nitrogen removal and the microbial community of an aerobic denitrification reactor treating recirculating marine aquaculture system effluent. Water (Switzerland), 2020, 12, 1–19.
[135] Li, P., Zuo, J., Wang, Y., Zhao, J., Tang, L., Li, Z. Tertiary nitrogen removal for municipal wastewater using a solid-phase denitrifying biofilter with polycaprolactone as the carbon source and filtration medium. Water Research, 2016, 93, 74–83
[136] Reddy, K.R., Busk, T.A.D. Utilization of aquatic plants in water pollution control. Water Science and Technology, 1987, 19, 61–79.

[137] Kadlec, R.H., Wallace, S. Treatment Wetlands, 2nd Edition. Treatment Wetlands, 2008.

[138] Dalahmeh, S.S., Pell, M., Hylander, L.D., Lalander, C., Vinneres, B., Jцnsson, H Effects of changing hydraulic and organic loading rates on pollutant reduction in bark, charcoal and sand filters treating greywater. Journal of Environmental Management, 2014, 132, 338–345.

[139] Lee, H.S., Park, S.J., Yoon, T.I. Wastewater treatment in a hybrid biological reactor using powdered minerals: Effects of organic loading rates on COD removal and nitrification. Process Biochemistry, 2002, 38, 81–88.

[140] Bhattacharya, J., Dev, S., Das, B. Design of Wastewater Bioremediation Plant and Systems. Low Cost Wastewater Bioremediation Technology, 2018, 265–313.

[141] Lefebvre, O., Shi, X., Wu, C.H., Ng, H.Y. Biological treatment of pharmaceutical wastewater from the antibiotics industry. Water Science and Technology, 2014, 69, 855–861.

[142] Lalander, C., Dalahmeh, S., Jцnsson, H., Vinneres, B. Hygienic quality of artificial greywater subjected to aerobic treatment: A comparison of three filter media at increasing organic loading rates. Environmental Technology (United Kingdom), 2013, 34, 2657–2662.

[143] Ganesan, K., Saravanan, V., Rajamohan, S, Saravanan, P., Rajasimman, M. Performance studies on biofilter for VOC removal under various organic loading rates and gas empty bed residence times. American International Journal of Research in Science, Technology, Engineering and Mathematics, 2019, 25, 55–62.

[144] Abu Hasan, H., Muhammad, M.H., Ismail, N.I. A review of biological drinking water treatment technologies for contaminants removal from polluted water resources. Journal of Water Process Engineering, 2020, 33, 101035.

[145] Hasan, H., Abdullah, S., Kamarudin, S., Kofli, N. A review on the design criteria of biological aerated filter for COD, ammonia and manganese removal in drinking water treatment. Journal – The Institution of Engineers, Malaysia. 2009, 70 (4), 25–33.

[146] Kalkan, C., Yapsakli, K., Mertoglu, B., Tufan, D., Saatci, A. Evaluation of biological activated carbon (BAC) process in wastewater treatment secondary effluent for reclamation purposes. Desalination, 2011, 265, 266–273.

[147] Cheng, Q. Competitive mechanism of ammonia, iron and manganese for dissolved oxygen using pilot-scale biofilter at different dissolved oxygen concentrations. Water Science and Technology: Water Supply, 2016, 16, 766–774.

[148] Maestre, J.P., Gamisans, X., Gabriel, D., Lafuente, J. Fungal biofilters for toluene biofiltration: Evaluation of the performance with four packing materials under different operating conditions. Chemosphere, 2007, 67, 684–692.

[149] Zamir, S.M., Halladj, R., Nasernejad, B. Removal of toluene vapors using a fungal biofilter under intermittent loading. Process Safety and Environmental Protection, 2011, 89, 8–14.

[150] Kumar, T.P., Rahul, AnilKumar, M., Chandrajit, B. Biofiltration of volatile organic compounds (VOCs) – An overview. Research Journal of Chemical Sciences, 2011, 1(8), 83–92.

[151] Delhomenie, M.C., Heitz, M. Biofiltration of air: A review. Critical Reviews in Biotechnology, 2005, 25, 53–72.

[152] Agu, I., Ibiene, A., Okpokwasili, G. Effect of micronutrients and macronutrients on the biodegradation of phenol in biological treatment of refinery effluent. Microbiology Research Journal International, 2017, 18, 1–12.