Chimica Techno Acta
published by Ural Federal University
eISSN 2411-1414; chimicatechnoacta.ru

REVIEW
2022, vol. 9(2), No. 202292S3
DOI: 10.15826/chimtech.2022.9.2.S3

Modern biotechnological methods in wastewater treatment: a review

C.L. Beya [ab]*, O.N. Kanwugu [a], M.N. Ivantsova [a]

a: Institute of Chemical Engineering, Ural Federal University, Ekaterinburg 620002, Russia
b: Polytechnic Faculty, Department of Industrial Chemistry, University of Lubumbashi, Lubumbashi 7110501, DR Congo
* Corresponding author: borhomelwamba@gmail.com

This paper belongs to the MOSM2021 Special Issue.

Abstract

Given that water is the main solvent in living organisms as well as in domestic and industrial activities, it must be treated as carefully as possible after multiple uses to get a harmless water quality. To remove the undesirable materials (e.g. organic matters, surfactants, petroleum products, unwanted metals, dyes, et.), the physicochemical water treatment process is used as the common method. This method of wastewater treatment uses flocculation – coagulation technique, which consists of mixing coagulant matters with water to collect, in solid clusters, the materials in suspension by gravity. Recently, environmental scientists have suggested biotechnology methods as the main alternatives in the treatment of wastewater, as they offer more benefits to the water quality and human health than chemical methods. This paper describes and assesses some modern biotechnology methods used in wastewater treatment.

Keywords

wastewater and biological treatment
bioadsorption
membrane biofilm reactor
BES

Received: 02.11.21
Revised: 08.04.22
Accepted: 09.04.22
Available online: 16.04.22

1. Introduction

Water is source of all life and a vital resource for all mankind in the sense that each human consists averagely of 65–70% water. For the environment water remains the object par excellence, without which no life is possible [1]. After being used water is said to be waste due to the presence of some pollutants, which affect its quality. These pollutants include heat, sediments, inorganic chemicals, organic compounds, radioactive substances, and dead organic matter; it should be noted that most of the pollution from our wastewater is organic [2]. Rivers can absorb and degrade these organic pollutants to a certain extent by the self-purification process. Even though nature is capable of self-cleansing, the amount of organic matter we produce far exceeds the self-purification capacity of the watercourse [3]. According to WHO, approximately 30% of all diseases and 40% of deaths throughout the world are due to polluted water [4]. It is, thus, essential to develop technologies capable of treating wastewater to allow its reuse without damaging the ecosystem.

Biotechnology finds a wide range of applications in many fields, such as the environmental decontamination, the food industry, and the mining sector [5]. As a modern technology and in comparison to the conventional physicochemical method, which uses mainly chemicals to treat wastewater, biotechnology methods consist of using microorganisms such as algae, fungi, bacteria or their parts, which interact with and remove unwanted matters within wastewater [6–7]. A successful use of biotechnology in the wastewater treatment, however, needs to properly integrate microorganisms with the modern bioreactors. This is because microbial communities require certain conditions to live (under aerobic or anaerobic conditions) and then to oxidize or incorporate organic matters in wastewater into cells that can be eliminated by a removal process or sedimentation [8].

The bioadsorption, the membrane biofilm reactor, microbial fuel cells and the biofilters are modern technologies allowing treating the wastewater using biotechnology methods. Indeed, biotechnological treatment is extensively used for the removal as well as stabilization of biodegradable matters in wastewater [6–7]. Scientists and environment engineers have realized that major issues for reclaiming water quality are concerned either with oxidized contaminants, or with those that do not share electrons, but receive them [6]. Biotechnological processes for wastewater treatment are more suitable to achieve this goal than electrochemical treatment. In general, the wastewater treatment process relies on the combination of separate treatment processes, which allow the generation of an effluent of specified characteristics from a wastewater of a known rate and composition [9].

This paper is intended to give a brief description of modern wastewater treatment technologies using biotechnological processes and some of their applications.

2. Types of biological wastewater treatment systems

According to some researches, biological wastewater treatment processes can be summarized in three main systems which include: Bioremediation, Phytoremediation and Mycoremediation [10]. Mycoremediation, thought to be an effective method of combating the ever-growing problem of water pollution, uses fungi's digestive enzymes or their derivatives to break down contaminants like heavy metals, pesticides, and hydrocarbons and remove pollutants from water [11]. Phytoremediation, on the other hand, uses plants and some rhizosphere microorganisms to aid in the recovery of polluted water [12]. The former (microbial bioremediation) relies on aerobic and anaerobic microbial treatments such as oxidation ponds, aeration and anaerobic lagoons, aerobic and anaerobic bioreactors, activated sludge, percolating or trickling filters, rotating biological contactors, etc. [10]. Besides these, biostimulation, which employs a combination of indigenous microorganisms and environmental modifications (e.g. additional mineral nutrients for the enhancement of pollutants' metabolism by microbes) and bioaugmentation, where extra cultures of microbes with particular contaminant reducing abilities are added to a polluted area, have enjoyed wide utilization [13]. In addition, bioelectrochemical systems (BES) and bioadsorption can also be classified as modern biotechnological processes of wastewater treatment. In fact, bioelectrochemistry is a mix of biotechnology and electrochemistry incorporating electrodes within bioreactors where biological and electrochemical processes take place [14], while bioadsorption, which occurs along with biodegradation, is a special adsorption process using organic or biological matters as adsorbents in bioreactors [15].

3. Bioadsorption

Bioadsorption is an adsorption process that uses a biological material called bioadsorbent, which typically includes microorganisms and their components, seaweed, vegetables, industrial waste, agricultural waste, and natural waste as adsorptive medium [16–17]. This process aims to remove or recover organic and inorganic substances in aqueous solutions. The bioadsorption process occurs by interactions between contaminants such as metal oxides or metal hydroxides and specific active sites (carboxyl, amino, sulfate groups, among others), present in the coatings of the biomaterial [16].

In general, the chemical and physical structures of an adsorbent determine its adsorption and desorption performance [18–19]. For instance, the type of adsorption forces and the desorption capability of an adsorbent are influenced by chemical structures such as functional groups. On the other hand, physical structures, i.e. specific surface area and pore size, dictate the accessibility of an adsorbent to dyes [18]. Bioadsorption processes for decontamination of wastewaters can be carried out either continuously, in fixed-bed reactors/columns, or discontinuously, in batch reactors. This method is mostly used in marine oily and dye wastewater treatment. Bioadsorption is mainly applied in dye wastewater treatment due to its technical feasibility, flexibility and operation simplicity (Figure 1) [18–21].

4. Mechanism of adsorption in dye wastewater treatment

The interaction between a cell surface and positive ions of dye is the underlying principle of bioadsorption in living biomass. Polysaccharides, proteins, and lipids, which are parts of the cell surface of living biomass, have negative charges, that accumulate sufficient amount of positive ion of dyes present in wastewater [21–22]. The presence of hydroxyl, nitro, azo groups increase adsorption of dye, while sulfonic acid groups decrease adsorption. Thus, ion-exchange mechanisms account for the efficiency and selectivity of adsorption by microbial biomass [21].

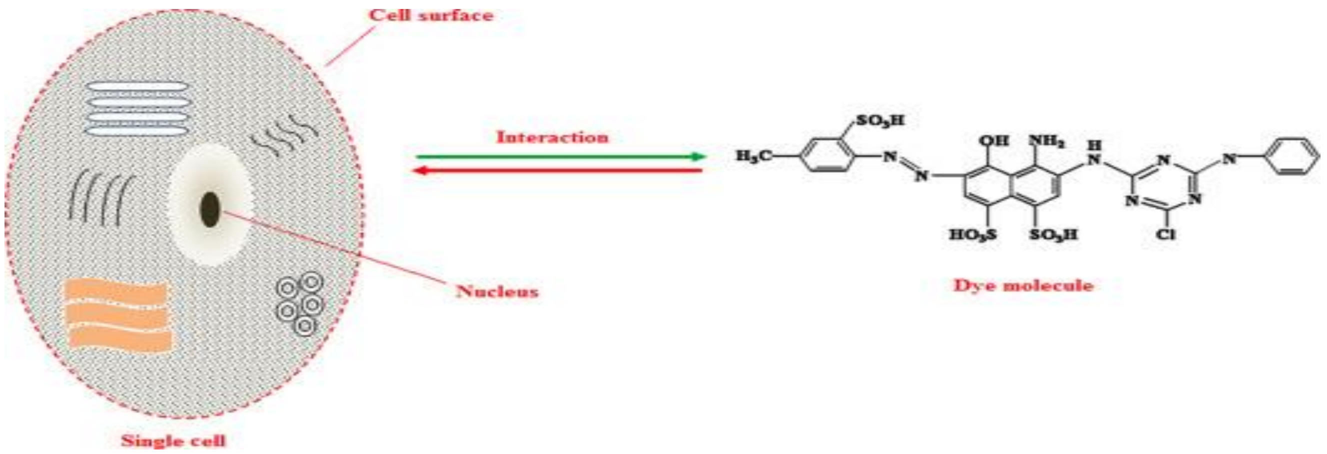

Figure 1 Interaction between microbial biomass and dye. Reproduced with permission [21]; 2019, Elsevier.

Major factors affecting industrial-scale treatment of dye wastewater through bioadsorption technology include adsorption and desorption capability as well as reusability of the bioadsorbent, all of which are based on its chemical and physical structures (Figure 2). However, industrial-scale treatment of dye wastewater via bioadsorption technologies remains stagnant, mainly due to its high costs [18].

5. The membrane biofilm reactors

Treatment of wastewater with biofilm technology was inspired by the industrial operation of trickling filters in the early 1880 [23]. The biofilm method is a type of biological sewage treatment technology similar tothe activated sludge method in the sense that the treatment processes of activated sludge and aerobic biofilm reactors are less dependent on temperature, although temperature plays a decisive role in most wastewater treatment processes [24]. In fact, biofilm is formed by growing and breeding microorganisms on filter material or carrier. Recently, new membrane reactors, including the micro porous membrane bioreactor (MBR), moving bed biofilm reactor (MBBR), sequential batch biofilm reactor (SBBR), and the up flow anaerobic sludge bed-anaerobic biological filter (UASB-BF) have been made [23–25]. Biofilm processes in relation to wastewater treatment are divided into two groups: the moving-medium and the mixed-medium systems. In the former, the biofilm media are static in the reactors and the biological reactions take place in the biofilm developed on the static media (trickling filters and biological aerated filters), while the biofilm media are kept constantly in motion in the moving-medium systems. Hydraulic, mechanical, or air forces (moving-bed biofilm reactors, vertically moving biofilm reactors, fluidized bed biofilm reactor, and rotating biological contactors) are employed to move the biofilm media in the moving-medium systems [23]. The use of biofilm systems in wastewater treatment is rapidly increasing because of its alluring approach of pollutant removal from wastewater, which is both cost-effective and environmentally sound [26]. The biofilm structures can be smooth or rough, fluffy or dense, as well as flat or filamentous; the structure is influenced by both the chemical composition of the surrounding medium and the hydrodynamics of the system [27].

6. Biofilm formation and mechanism

Usually, 3 steps are involved in the biofilm formation, namely, the biofilm attachment, growth, and detachment. Surface, nutrients, and water are the minimum requirements for its formation (Figure 4) [26].

Once the sewage gets in contacts with the biofilm, organic pollutants in the wastewater are taken in as nutrients by the microorganisms on the biofilm, resulting in the purification of the sewage wastewater [29].

Biofilms are hugely complex; they have a difficult structure for quantification and are heterogeneous consortia of cells which are significantly influenced by the environmental and mechanical conditions to which they are subjected. During the quantification, different parameters must be taken into account, including specific surface area, porosity, thickness, surface area coverage, thickness variability, fractal dimension, density, and pore radius [27].

Table 1 presents the advantages and disadvantages of some of the membrane biofilm reactors used in wastewater treatment.

7. Bioelectrochemical systems

The bioelectrochemical systems (BES), as noted earlier, combine two sciences in industrial wastewater treatment. This technology uses the integration of electrodes within the biological reactors to regain resources present in the wastewater and takes advantage of a solid electron acceptor or donor interactivity with microorganisms to achieve bioenergy recovery from organic substances [14, 31].

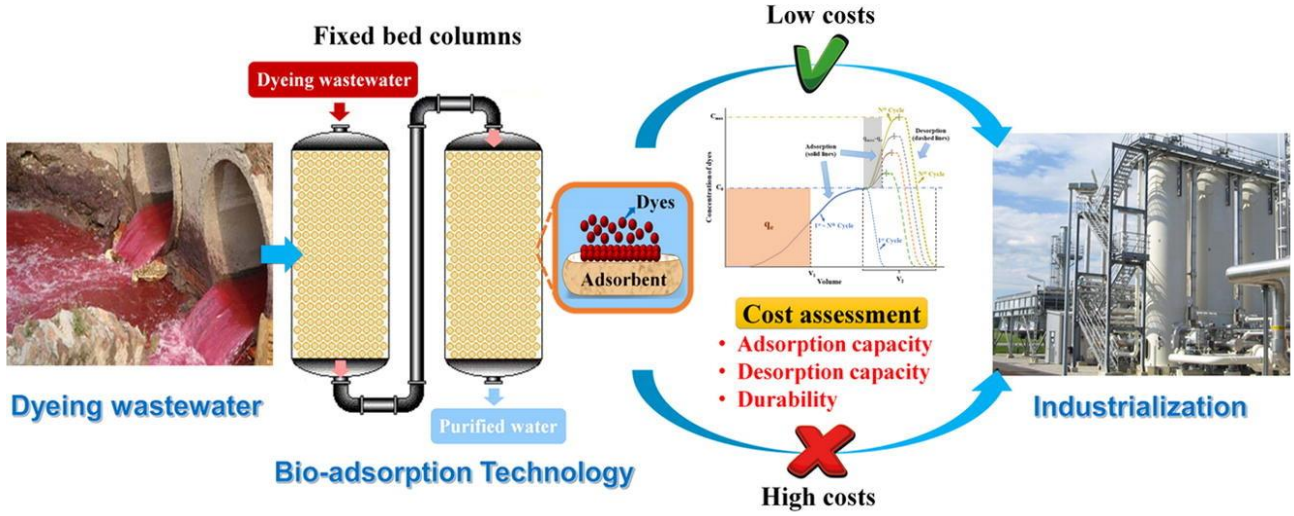

Figure 2 Dye wastewater treatment. Reproduced with permission [18]; 2019, Elsevier.

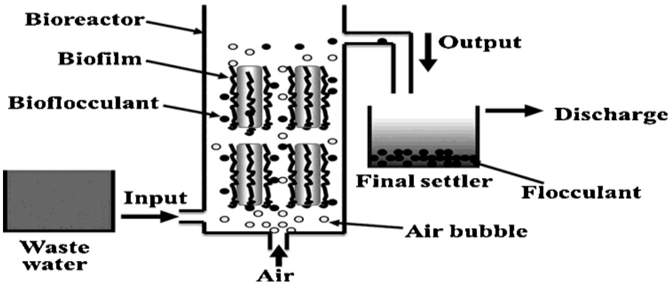

Figure 3 A biofilm reactor model used in wastewater treatment. Reproduced with permission [28]; 2015, Elsevier.

8. Processes within the bioelectrochemical reactors

The BES catalyze distinct oxidation and reduction reactions by using microorganisms attached to electrodes (anode and cathode) with the aim of recovering resources contained in the wastewater. Bacteria in wastewater degrade organic matter and release electrons and protons, which are collected at the anode and cathode, respectively, while CO_2 is released [32]. The anode (negative or reducing electrode) transfers electrons to the external circuit but oxidizes during the electrochemical reaction, whereas the cathode (positive or oxidizing electrode) gains electrons from the external circuit but is reduced during the electrochemical reaction, necessitating additional contaminant treatment [33].

Thus, electrons that result from oxidation are transmitted to the anode and are important to electrical energy generation [14]. Three features are mainly focal while using BES technology in the wastewater treatment: trapping electrical power from organic pollutants in microbial fuel cells, collecting additional products like CH_2, H_2 and high standard water in microbial electrosynthesis cells, and eliminating contaminants such as perchlorate, heavy metal etc. [31].

9. Assessment of BES in wastewater treatment

The bioelectrochemical systems allow the improvement of the current processes performance and are the potential alternative energy storage systems.

These systems are particularly able to carry out the electromethanogenesis process, which consists in the conversion of CO_2 (carbon dioxide) to methane (Figure 5). In addition, the BES present advantage in terms of:

- stabilizing the biological process, increasing both quality and quantity of biogas produced;
- reducing the high costs of wastewater treatment resulting from conventional water purification technologies;
- reusing the products obtained during the process, as other sorts of sources of energy.

Table 1 Comparison among Bioreactors: merits and limitations. Adapted from [30].

Bioreactor	Merits	Limitations
Moving bed biofilm reactor (slurry reactor)	Heterogeneous version of stirred tank. High cell concentration in biofilm promotes rate of bioconversion.	Capacity wise inferior to column reactors. Biofilm could get disturbed due to high rate of agitation.
Fluidized bed biofilm reactor	Operates at high capacities, provides high degree of bioconversion. Once fully fluidized, pressured drop across the bed remains constant and does not increase with increase in feed flow rate. Degree of bioconversion increases with increase in feed flow rate due to bed expansion.	Entrainment loss of particle-biofilm aggregates possible. Operating cost higher than trickle bed (packed bed).
Semifluidized bed biofilm reactor	Higher degree of bioconversion (than fluidized beds) at higher capacities and low reactor volume requirement. Degree of bioconversion increases with increase in feed flow rate, even if reactor volume is kept constant.	Higher operating cost than fluidized beds. Continuous, circulating mode of operation not possible.
Inverse fluidized biofilm reactor	Low operating cost due to down flow mode of operation. Larger size particles could be used. Reasonably large degree of bioconversion.	Lower capacity than fluidized /semi-fluidized bed. Larger reactor volume requirement.

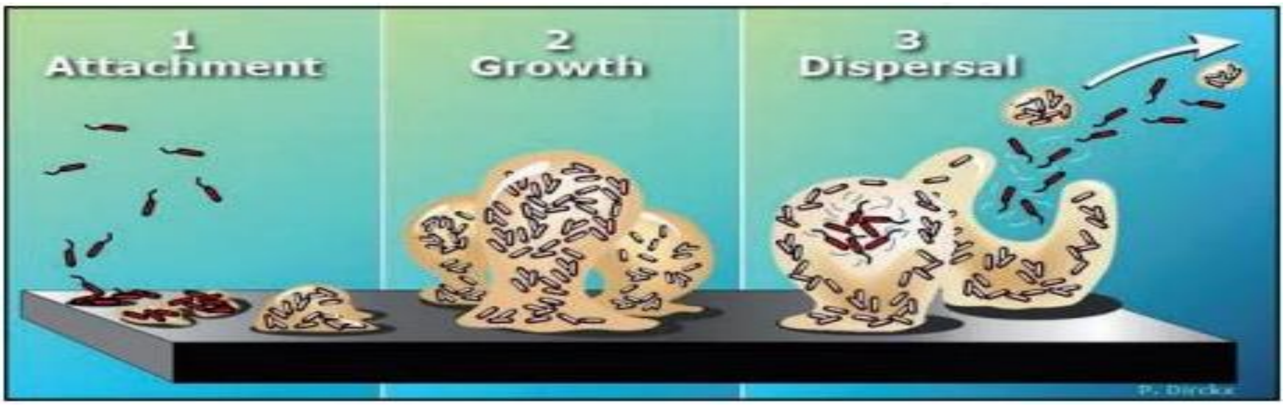

Figure 4 Biofilm life cycle. Reproduced from [26]; 2019, Intechopen.

It should be noted that actually the BES technology is still experimental and has not yet been proven in terms of its technical and economic viability on industrial scale [31].

10. Conclusions and recommendations

The big problem in the wastewater treatment is to oxidize all soluble and insoluble organic compounds present.
The use of microorganisms in sewage treatment through modern biological methods has shown to be more efficient at achieving this goal. Compared to chemicals, microorganisms offer several benefits such as being environmentally friendly, cost-effective, and abundant in nature. Although their use in bioreactors seems perfect, choosing the right microorganism remains difficult and tricky since it depends on areas of its use. In the papermaking and dying industry wastewater, which are the examples of alkaline wastewater, a detachment of a biofilm may happen, which could lead to a collapse of biological wastewater treatment systems. It would, thus, be much better and useful to make bioflocculant-producing strains that can form biofilm in alkaline conditions. Nevertheless, it is still difficult to define a universal method that could be used for the elimination of all contaminants from wastewater. One of the major reasons is because, practically, only few industries have been successful in removing the production of all wastewater requiring disposal unit after treatment even if the theory of zero discharge is still popularly adopted. Therefore, water treatment with both biotechnological and traditional methods must be monitored continuously to ensure that the desired water quality is always achieved.

Supplementary materials

No supplementary materials are available.

Funding

This research had no external funding.

Acknowledgments

None.

Author contributions

Conceptualization: C.L.B., O.N.K., M.N.I.
Data curation: M.N.I.
Formal Analysis: C.L.B., O.N.K., M.N.I.
Funding acquisition: C.L.B., O.N.K., M.N.I.
Investigation: C.L.B.
Methodology: C.L.B., O.N.K., M.N.I.
Project administration: O.N.K., M.N.I.
Resources: C.L.B., O.N.K., M.N.I.
Software: C.L.B., O.N.K., M.N.I.
Supervision: M.N.I.
Validation: C.L.B., O.N.K., M.N.I.
Visualization: C.L.B.
Writing – original draft: C.L.B.
Writing – review & editing: O.N.K., M.N.I.

Conflict of interest

The authors declare no conflict of interest.

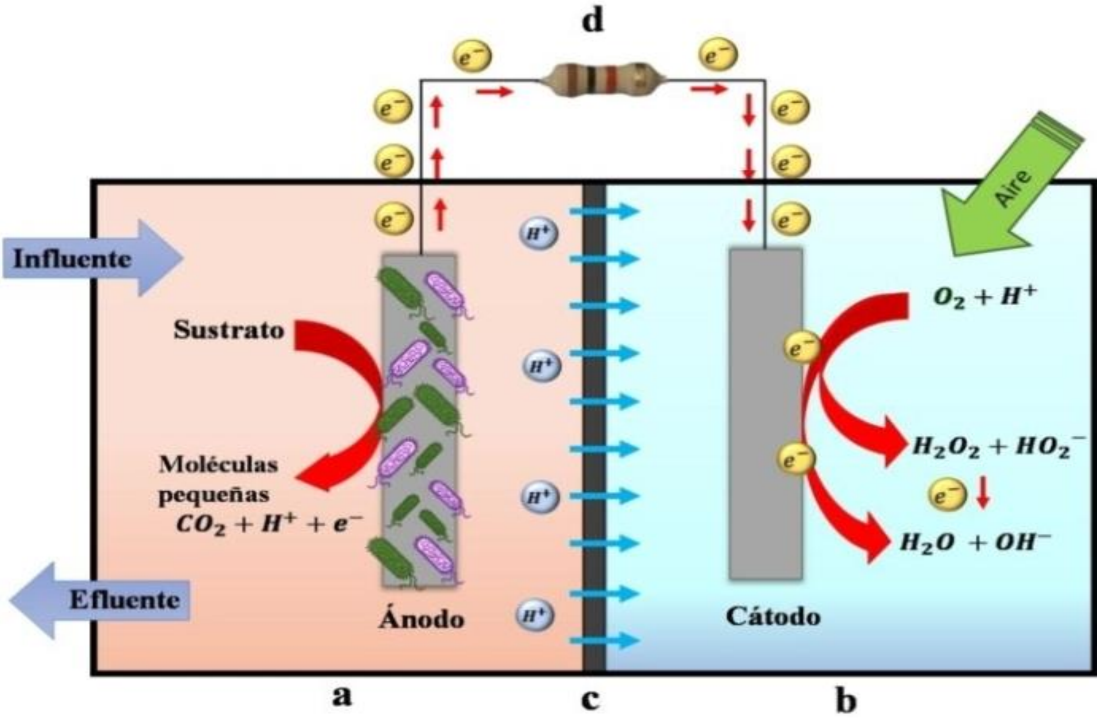

Figure 5 BES scheme. Reproduced from [34]; 2019, infoANALÍTICA.

Additional information

Authors' IDs:

Beya, Charles L.: R^G ;
Kanwugu, Osman N., Scopus ID 57195573903;
Ivantsova, Maria N., Scopus ID 6507519617.

Websites of

Ural Federal University: https://urfu.ru/en;
University of Lubumbashi: https://www.unilu.ac.cd.

References

1. Rockstrom J. Balancing water for humans and nature. The New Approach in Ecohydrology. Routledge; 2004. 272 p. doi:10.4324/9781849770521
2. Englande AJ, Krenkel P, Shamas J. Wastewater treatment &water reclamation. Earth Syst Environm Sci. 2015;1–32. doi:10.1016%2FB978-0-12-409548-9.09508-7
3. Alsace-Moselle. Pourquoi traiter les eaux usées? 2017. French. Available from: https://www.sdea.fr/index.php/fr/l-eau/les-eaux-usees/pourquoi-traiter-les-eaux-usees
4. Sehar S, Naz I. Role of the biofilms in wastewater treatment. In book: Microbial Biofilms - Importance and Applications. IntechOpen: London; 2016. P. 121–144. doi:10.5772/63499
5. Biotechnology and its applications. Available from: https://ncert.nic.in/textbook/pdf/lebo112.pdf
6. Rittmann BE. Environmental biotechnology in water and wastewater treatment. J Environ Eng. 2010;136(4). doi:10.1061/(ASCE)EE.1943-7870.0000140
7. Buyukgungor H, Gurel L. The role of biotechnology on the treatment of wastes. African J Biotechnol. 2009;8(25):7253–7262. doi:10.4314/ajb.v8i25
8. Seib MD, Berg KJ, Zitomer DH. Influent wastewater microbiota and temperature influence anaerobic membrane bioreactor microbial community. Bioresour Technol. 2016;216:446–452. doi:10.1016/j.biortech.2016.05.098
9. Crini G, Lichtfouse E. Advantages and disadvantages of techniques used for wastewater. Environ Chem Lett. 2019;17:145–155. doi:10.1007/s10311-018-0785-9
10. Samer M. Biological and chemical wastewater treatment processes. In book: Wastewater Treatment Engineering. InTech Europe; 2015;150:1–50. doi:10.5772/61250
11. Mrozik A. Microbial action in wastewater and sludge. Water. 2021;13(6):846. doi:10.3390/w13060846
12. Mora-Ravelo SG, Alarcon A, Rocandio-Rodriguez M., Vanoye-Eligio V. Bioremediation of wastewater for reutilization in agriculture systems : a review. Appl Ecol Environ Res. 2017;15(1):33–50. doi:10.15666/aeer/1501_033050
13. Kumar R. Application environment biotechnology in waste-water monitoring and treatment. Incorporating health criteria into waste disposal & reuse standards. Delhi. 2006. Available from: http://www.rainwaterharvesting.org/cse/programme/health/pdf/conf2006/water2_kumar_rita.pdf
14. Amapex. Wastewater treatment. Innovation in wastewater treatment: biotechnology and electrochemistry. 2020. Available from: http://www.amapex.net/wastewater-treatment-biotechnology/?lang=en
15. Crini G, Lichtfouse E, Wison L, Morin-Crini N. Conventional and non-conventional adsorbents for wastewater treatment. Environ Chem Lett. 2019;17(1):195–213. doi:10.1007/s10311-018-0786-8
16. Costa TB, Silva MGC, Vieira MGA. Recovery of rare-earth metals from aqueous solutions by bio/adsorption using nonventional materials: a review with recent studies and promising approaches in column applications. J Rare Earths. 2020;38(4):339–355. doi:10.1016/j.jre.2019.06.001
17. González AG, Pokrovsky OS, Santana-Casiano JM, Gonzalez-Davila M. Bioadsorption of heavy metals. In book: Prospects and Challenges in Algal Biotechnology. Singapore: Springer Nature; 2017; 233–255. doi:10.1007/978-981-10-1950-0_8
18. Li W, Mu B, Yang Y. Feasibility of industrial-scale treatment of dye wastewater via bioadsorption technology. Bioresour Technol. 2019;277:157–170. doi:10.1016/j.biortech.2019.01.002
19. Derco J, Vrana B. Biosorption of Heavy Metals. IntechOpen. (Chapter 2). 2018. doi:10.5772/intechopen.72099
20. Fernandez-Gonzalez R, Martin-Lara MA, Blazquez G, Perez A, Calero M. Recovering Metals from aqueous solutions by biosorption onto hydrolyzed olive cake. Water. 2019;11(12):2519. doi:10.3390/w11122519
21. Sahu O, Singh N. Significance of bioadsorption process on textile industry wastewater. In book: The Impact and Prospects of Green Chemistry for Textile Technology. 2019. 367–416. doi:10.1016/B978-0-08-102491-1.00013-7
22. Aragaw TA, Bogale FM. Biomass-based adsorbents for removal of dyes from wastewater: a review. Front Environ Sci. 2021;9:1–24. doi:10.3389/fenvs.2021.764958
23. Qureshi N, Annous BA, Ezeji TC, Kacher P, Maddox IS. Biofilm reactors for industrial bioconversion processes: employing. Microb Cell Fact. 2005;4(24):1–21. doi:10.1186/1475-2859-4-24
24. Lazarova V, Manem J. Biofilm characterization and activity analysis in water and wastewater treatment. Water. 1995;29(10):2245–2245. doi:10.1016/0043-1354(95)00054-0
25. Melo FL. Biofilm formation and its role in fixed film processes. In book: Water Wastewater Microbiology. 2003; 337–349. doi:10.1016/b978-012470100-7/50021-2
26. Wang S, Parajuli S, Sivalingam V, Bakke R. Biofilm in moving bed biofilm process for wastewater treatment. In book: Bacterial Biofilms. IntechOpen: London. 2019. doi:10.5772/intechopen.88520
27. Butler CS, Boltz J. Biofilm processes and control in water and wastewater treatment. In book: Comprehensive Water Quality and Purification. 2014;90–107. doi:10.1016/B978-0-12-382182-9.00083-9
28. Liu C, Wang K, Jiang J-H, Liu W-J, Wang J-Y. A novel bioflocculant produced by a salt-tolerant, alkaliphilic and biofilm-forming strain Bacillus agaradhaerens C9 and its application in harvesting Chlorella minutissima UTEX2341. Biochem Eng J. 2015;93:166–172. doi:10.1016/j.bej.2014.10.006
29. Han H, Zhang J, Chu W, Chen J, Zhou G. Research progress and prospects of marine oily wastewater treatment: a review. Water. 2019;11(12):2517. doi:10.3390/w11122517
30. Narayanan CM, Narayan V. Biological wastewater treatment and bioreactor design: a review. Sustain Environ Res. 2019;29(33):1–17. doi:10.1186/s42834-019-0036-1
31. Lu Y, Qin M, Yuan H, Abu-Reesh IM, He Z. When bioelectrochemical systems meet forward osmosis: accomplishing wastewater treatment and reuse through synergy. Water. 2015;7(1):38–58. doi:10.3390/w7010038
32. Future brief: Bioelectrochemical systems Wastewater treatment, bioenergy and valuable chemicals delivered by bacteria. bristol: Science Communication Unit, University of the West of England (UWE), Bristol. 2013;5. Available from: https://ec.europa.eu/environment/integration/research/newsalert/pdf/FB5_en.pdf
33. Jain A, He Z. Cathode-enhanced wastewater treatment in bioelectrochemical systems. Clean Water. 2018;1(1):23. doi:10.1038/s41545-018-0022-x
34. Rosero, K.M., et al.. Constructed wetlands and microbial fuel cells as individual and combined systems for wastewater treatment: a review. infoANALÍTICA, 2019. **7**(2):15-37. doi:10.26807/ia.v7i2.100