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Communication

Reviviscence of Biological Wastewater Treatment – A Review

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Abstract: Biological treatment remains one of the most eco-friendly and cost-effective techniques to eliminate pollutants from wastewater in spite of the development of other technologies such as chemical treatment methods and advanced oxidation processes. This paper discusses briefly the main features and recent advances of wastewater treatment (WT). Some future trends are also viewed. Membrane Bioreactor (MBR), Moving Bed Bioreactor (MBBR), and Fixed Bed Bioreactors (FBBR) are largely employed techniques in WT particularly for industrial uses with an elevated biochemical oxygen demand charge like food and beverages, dairy, chemical, leachate and others. Integrations of minutely anaerobic and aerobic methods importantly improved the elimination of specific and non-specific in vitro toxicities. Therefore, optimizing biological WT may conduct to a considerably ameliorated detoxification. Surplus sludge treatment and disposal are regarded as an increasing defy for wastewater treatment plants (WTTPs) because of economic, environmental and regulatory elements. There is thus a fundamental need in expanding procedures for decreasing sludge generation in biological WT processes. Great attention for minimizing sludge formation occurs following procedures founded on mechanisms of lysis-cryptic growth, uncoupling metabolism, maintenance metabolism, and bacterivorous predation. On the other hand, heavy metals presence in wastewater still constitute a handicap for large acceptance of this technology based on cultivating bacteria for organic matter removal.

Keywords: Wastewater Treatment (WT), Biological Process, Biofilm Bacteria, Microorganisms, Wastewater Treatment Plants (WTTPs)

1. Introduction

Biological treatment method in wastewater treatment plants (WWTPs) is mainly comprised of two lines, namely the wastewater treatment (WT) line for the removal of organic carbon and nutrients from wastewater, and the sludge treatment line for the disposal of waste activated sludge [1, 2]. Compared to chemical treatment methods, biological treatment has lower chemical and energy requirements while achieving satisfactory removal efficiency, making it the most economical and environmentally friendly method for municipal WT [3-7].

Membrane Bioreactor (MBR), Moving Bed Bioreactor (MBBR), and Fixed Bed Bioreactors (FBBR) are largely employed techniques in WT particularly for industrial uses with an elevated biochemical oxygen demand (BOD) charge like food and beverages, dairy, chemical, leachate and others [8, 9].

Since industrial uses frequently possess volatile water inflows, equalization tanks are employed for water storage and probably pH neutralization as well as flocculation [10-18]. Afterwards screens and in some cases clarifiers are employed to eliminate an appreciable part of solid matter [9, 19].

MBR is an integration of a membrane process such as ultrafiltration (UF) and the activated sludge process (Figure 1) [20, 21]. The UF membrane is frequently submerged in the activated sludge basin or in a separate tank [22, 23]. Microorganisms assimilate the organic matter (OM) in sewage while consuming oxygen [24]. Since the membrane holds the microorganisms and OM in the basin, elevated Mixed Liquor Suspended Solids (MLSS) amounts are reached [9, 25, 26].

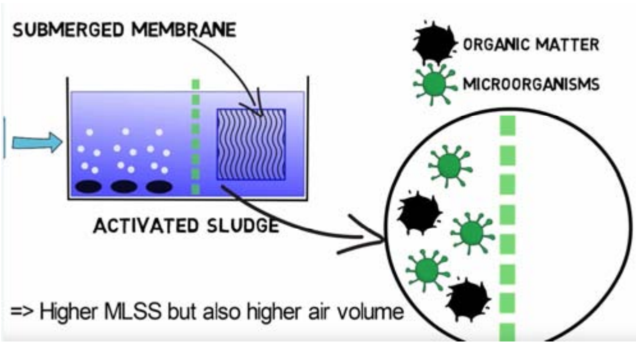

Figure 1. *MBR principle [9].*

The elevated microorganism amount needs an important air volume, not only for oxygen supply but also to form sufficient mixing, scouring of the membranes, and to reduce fouling [9, 24].

MBBR employs free-floating plastic fill media for attached biofilm development. To maintain the plastic fill media in suspense their density is near to the density of water. Continuous aeration or mixing ensures a useful contact between OM and fixed biofilm for performant BOD removal [9, 24].

FBBR functions identically as MBBR with the distinction that the biofilm is fixed to attached fill media blocks. The fill media blocks are frequently ordered as submerged, retrievable cages inside the basin. Diffused aeration underneath the cage units provides the biofilm with the needed oxygen and controls scouring of the fill media blocks [9, 24].

Both MBBRs and FBBRs necessitate sludge settling after the biological treatment. For this objective, lamella clarifiers are placed. In comparison, MBRs do not need lamella clarifiers since sludge is retained back by the membranes. Nevertheless, a significant fraction of sludge must be continuously pumped back to the main basin to restrict MLSS concentration increase, and to remove waste sludge [9, 27-30].

This paper discusses briefly the main features and recent advances of WT. Some future trends are also viewed.

2. Comparing MBR, MBBR, and FBBR

Table 1 presents a comparison of MBR, MBBR and FBBR illustrating various benefits and disadvantages for industrial wastewater applications [31].

	MBR	MBBR	FBBR
Effluent water quality	Excellent	Good	Good
Resistance	Poor	Good	Excellent
Difficulty of Operation	High	Easier	Easiest
Required space	Lowest	Low	Low
Energy consumption	High	Moderate	Low

Figure 2. *Scale of comparison of MBR, MBBR, and FBBR [31].*

Table 1. *Comparison of the three systems focusing on diverse advantages and disadvantages [31].*

Criterion	Description
Effluent water quality	MBRs present frequently a moderately better BOD elimination than MBBRs or FBBRs. Very fine membranes can even hold back germs so that the water effluent quality is usually better.
Resistance to influent peaks and grease leaks	MBRs are extremely sensible to varying influent values. Grease leaks will form clogging of the fine membranes so that they must be cleaned or changed. MBBRs are less sensible as MBRs even if the hazard of fill media clogging is elevated in case of interrupted mixing and grease leaks. Instead, FBRs are very robust and present an extremely appreciable handling of either varying influent values, grease leaks or interrupted oxygen supply.
Difficulty level of operation	MBRs need controlling of the activated sludge process as well as backwashing of the membranes in defined periods [32]. Consequently, their function may be difficult and higher qualifications are needed. MBBRs and FBRs are more forgiving and particularly FBRs are easy to work.
Required space	The higher MLSS degree of MBRs authorize more BOD elimination per water volume. As a result, their necessitated space is lower compared to MBBRs and FBBRs.
Energy consumption	Because of higher MLSS, permanent backwashing of the membrane and fouling prevention, MBRs require an increased air volume thus have a high-energy demand and cost. FBRs need less energy as MBBRs since the air supply of the biofilm is placed directly underneath the fill media that conducts to a better oxygen absorption.
Overall cost	The installation costs for all three systems are approximately identical. Nevertheless, over time MBRs are more expensive than MBBRs and FBBRs due to more elevated operational and maintenance costs.

MBRs are convenient for applications that need high-quality water effluent. On the other hand, MBBRs and particularly FBBRs are appropriate for pretreatment of elevated BOD degrees (Figure 2). Their resistant and forgiving design make them satisfactory for different industrial wastewater applications. Moreover, the simple operation and maintenance ensure a long-lifetime product solution for low cost in the long term [31].

3. BOD or the Treated Wastewater Quality Indicator

BOD is the most significant employed evaluation to define water quality [33]. It is a measurement unit and stands for the required quantity of oxygen by aerobic biological organisms to decompose OM [34]. Comparatively, chemical oxygen demand (COD) stands only for everything that may be chemically oxidized and is consequently less specific [35].

The biochemical process of BOD elimination may be defined with Eq. (1) [33, 36]:

$$\text{Organic matter (OM)} + O_2 \rightarrow CO_2 + H_2O \quad (1)$$

As more elevated the level of water pollution, as more OM is present and as more oxygen is required for the oxidization, therefore, as more increased is the BOD degree [37]. The most frequently laboratory test method employed is named the BOD_5 test. For this testing technique, one liter of wastewater is filled into a testing bottle and the consumed oxygen during 5 days of incubation is measured (Figure 3). The test method uses 5 days of incubation time; as after 5 days, most OM has already been decomposed [33]. The test sample is continuously agitated under the absence of light and a sensor measures the decline of pressure produced by oxygen use.

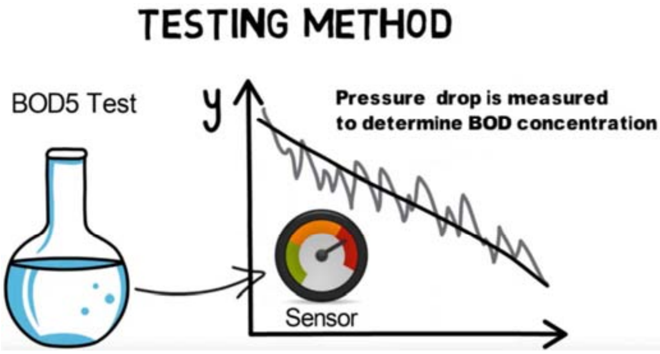

Figure 3. *BOD_5 test principle [33].*

Usual values for BOD concentrations are 2 to 8 mg/L in slightly polluted rivers. Comparatively, untreated sewage in the US has a BOD level of about 300 mg/L whereas European sewage averages around 600 mg/L. The lower BOD levels in the US are formed by a greater water use per capita [33].

WWTPs employ several techniques to augment BOD elimination importantly [38, 39]. One usual process is to augment the quantity of biological organisms through giving more surface area for fixed growth [40]. Fill media plastic blocks are composed of corrugated sheets, and ensure a good water and air mixing to supply the biological organisms with nutrients and oxygen. Each fill media block can provide up to 250 m^2 surface area for attached growth [33].

4. Useful Biofilm Bacteria in Wastewater Treatment

Biofilm bacteria are usually viewed as unpleasant and dangerous. This is comprehensible since we usually encounter biofilm bacteria fixed to shower heads, pipes, kitchen sinks or chillers at home or public places. In such situations, biofilm bacteria may generate corrosion, fouling or even conduct to Legionella development. During the last decade, public media discovered an elevated public interest for the risks of biofilm bacteria as the headlines illustrated in Figure 4 display [41].

Figure 4. *Biofilm bacteria as viewed by public media [41].*

However, for the treatment of wastewater, biofilm bacteria are extremely useful and fundamental. Water holds free-floating bacteria. When the bacteria are fixed to a surface, the biofilm development is launched. Van der Waals forces and hydrophobic features of the microorganisms or the media surface may enhance the fixing operation [42]. Once microbial growth has commenced, the biofilm bacteria develop via cell division and additional free-floating microbes that attach to the near bacteria colonists [41, 43, 44].

WWTPs employ biofilm bacteria to eliminate BOD and nitrogen [45]. As mentioned above, BOD defines the total quantity of dissolved oxygen required to transform OM [46]. Bacteria will decay the OM to solids that may be settled down as sludge [47]. While bacteria for BOD elimination are simple to develop, bacteria for nitrogen elimination are harder and necessitate precise situations [48]. Situations for nitrifying biofilm bacteria are for instance elevated quantities of dissolved oxygen and nitrogen, a pH degree among 7 and 8, also a water temperature among 5 and 40 degree Celsius [49, 50]. Nitrifying bacteria possess a long lifetime and double only every 20 hours under favorable situations (as a comparison, most bacteria double every 30 minutes) [51]. As a result, it takes around 4 weeks until a stable nitrifying biofilm is generated and fixed to a surface. As more surface for fixed biofilm development is accessible as more BOD and nitrogen in wastewater may be removed [52]. With a view to greatly augment surface area, various types of plastic fill media either attached or free floating are employed in WWTPs [41]. Relying on the implementation, plastic fill media may assure 200 m^2 surface area per one m^3 of tank volume.

Organic nitrogen converts into gaseous ammonia (NH_3) in wastewater [53]. At a pH degree among 7 and 8 (as frequent for urban wastewater), almost all gaseous ammonia will be detected in the ionic form ammonium (NH_4^+) [54]. In the nitrification phenomenon, nitrifying bacteria make easier the oxidation of ammonium (NH_4^+) initially to nitrite (NO_2^-) followed by the oxidation of nitrite to nitrate (NO_3^-) [2, 41, 55]:

First step:

$$NH_4^+ + O_2 \rightarrow H^+ + H_2O + NO_2^- + ATP^* \quad (2)$$

Second step:

$$NO_2^- + O_2 \rightarrow NO_2^- + ATP \quad (3)$$

*ATP: Adenosine triphosphate.

Nitrate remains hazardous and present in the wastewater. Consequently, one more stage must be followed to transform ammonium into a nonpoisonous matter. Heterotrophic microorganisms will denitrify nitrate (NO_3^-) into nitrogen gas (N_2) [41, 56, 57].

5. Focusing on the Sorption and Biotransformation of Organic Micropollutants

New techniques for WT have been improved during the last decades following the integration of bioreactors working under various redox conditions [58-60]. Their performance in the removal of organic micropollutants (OMPs) has not been visibly evaluated at present. Alvarino et al. [61] paid particular attention to comprehending the sorption and bioconversion of a chosen set of 17 OMPs, comprising pharmaceuticals [62, 63], hormones, and personal care products, through biological WT operations. Away from taking into account the action of "conventional" functioning variables, recent parameters like biomass conformation and particle size, upward velocity exercised or the introduction of adsorbents have been examined. It has been observed that the OMP elimination throughout sorption not only is a function of their physicochemical features and additional factors, like the biomass conformation and particle size, or some working situations also important. MBRs have manifested to improve the sorption and biotransformation of several OMPs. The same is applicable to techniques founded on the direct introduction of activated carbon in bioreactors. The OMP bioconversion level and mechanism are mostly determined via the redox potential and the primary substrate activity. The integration of various redox potentials in hybrid reactor devices may importantly improve the total OMP elimination performance. Sorption and bioconversion may be synergistically advanced in bioreactors via the injection of activated carbon. A more profound comprehension of the principal factors affecting OMP decrease will permit enhancing the biological methods in the future.

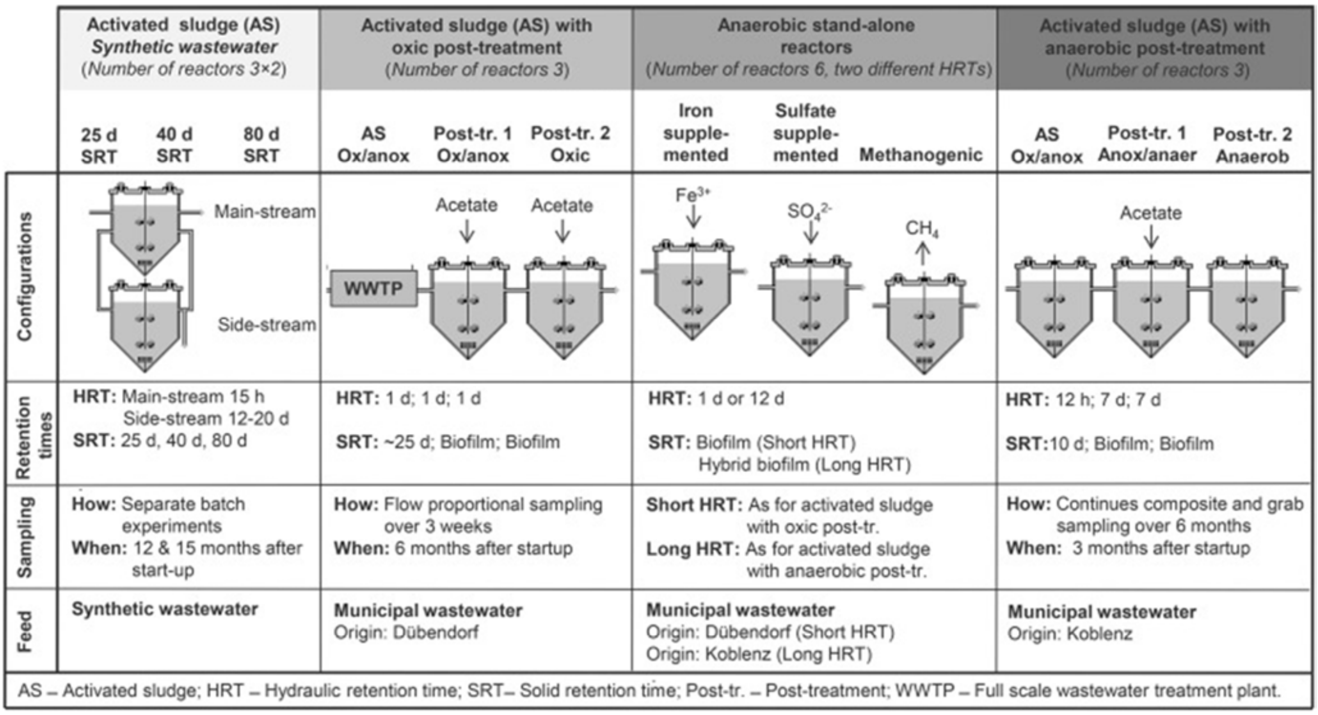

Figure 5. *Reactor devices and sampling techniques [64].*

Falås et al. [64] studied the elimination of organic microcontaminants in 15 various bioreactors during short and long-term tests. Short-term batch tests were realized with activated sludge from three parallel sequencing batch reactors (25, 40, and 80 d solid retention time, SRT) fed with synthetic wastewater without microcontaminants during 12 months (Figure 5). Regardless of the minimal micropollutant exposure, the synthetic wastewater sludges were able to decompose diverse microcontaminants existing in municipal wastewater. The decomposition happened instantly following spiking (1-5 mg/L), manifested no strong or systematic linkage to the sludge age, and proceeded at rates similar to those of municipal wastewater sludges. Therefore, the findings from the batch tests show that decomposition of organic microcontaminants in biological WT is completely insensitive to SRT augmentations from 25 to 80 days, and not necessarily formed through exposure to microcontaminants. Long-term tests with urban wastewater were realized to evaluate the capacity for extended biological microcontaminant elimination under changing redox conditions and substrate levels (carbon and nitrogen). Thirty-one organic microcontaminants were observed through an influent-effluent sampling of twelve municipal wastewater reactors. In conformity with the findings from the sludges grown on synthetic wastewater, different compounds like bezafibrate, atenolol, and acyclovir were importantly eliminated in the activated sludge processes fed with urban wastewater. Finished elimination of two compounds, diuron, and diclofenac was attained in anoxic biofilm treatment. A few aerobically enduring microcontaminants like venlafaxine, diatrizoate, and tramadol were eliminated under anaerobic conditions; however, a considerable number of microcontaminants remained in all biological treatments. Conjointly, these findings denote that some enhancements in biological microcontaminant elimination may be obtained via joining various aerobic and anaerobic treatments; however, such ameliorations remain limited to a restricted number of compounds.

Völker et al. [65] and Bouju et al. [66] reached the same conclusions than those of Falås et al. [64].

The fast-growing employment of engineered nanoparticles (NPs) in consumer products necessarily conducts to their larger existence in WWTPs. Puay et al. [67] focused on the impacts of zinc oxide nanoparticles (ZnO-NPs) on process efficiency and bacterial community behaviors of biological WT in a lab-scale sequencing batch reactor, along with their fate within the process. They noted that ZnO-NPs generated inferior settleability of the activated sludge and a considerable diminution in eliminating nitrogen and phosphorus during the procedure. Denaturing gradient gel electrophoresis analysis established that the bacterial community in the activated sludge begun to be less various following subjection to ZnO-NPs. Moreover, the formation of extracellular polymeric substances (EPS) augmented, with the EPS generating a tight matrix to keep the cells from the NPs [68]. The NPs were eliminated completely from wastewater, at most through sorption to the sludge.

In both chemical and biochemical engineering, fluidization has been proved to augment the performance of different techniques; however, it has not been largely employed in large-scale wastewater treatment. Nelson et al. [69] realized the circulating fluidized-bed bioreactor (CFBBR) for treating wastewater. In such a method, carrier particles grow a biofilm constituted of bacteria and additional microorganisms. The outstanding mixing and mass transfer feature, which are intrinsic to fluidization, render this technique extremely effective at treating both municipal and industrial wastewater. Investigations of lab- and pilot-scale systems established that the CFBBR is able to eliminate more than 90% of the influent OM and 80% of the nitrogen, and forms less than one-third as much biological sludge as the activated sludge method. Thanks to its elevated performance, the CFBBR may also be implemented to treat wastewaters with high organic solid concentrations, which are harder to treat using classical technologies since they necessitate more important contact periods; the CFBBR may also be employed to decrease the system size and footprint. Moreover, it is much better at handling and recovering from dynamic loadings (i.e., varying influent volume and concentrations) than current systems [70]. In a general way, the CFBBR has been proved to be an extremely performant method of treating wastewater and to be apt of dealing with bigger bulks of wastewater employing a smaller reactor volume and a more reduced contact period. Finally, its compact design possesses the capacity for more geographically localized and isolated WT devices.

An investigation was realized in a different configuration of fluidization; indeed, Sokoła et al. [71] realized similar version to CFBBR presented above. The biological WT was tested in the inverse fluidized bed reactor (IFBR) in which polypropylene particles of density 910 kg/m^3 were fluidized by an upward flow of gas. Evaluations of COD versus contact period t were realized for different ratios of settled bed volume to reactor volume (V_b/V_R) and air velocities u_g. The greatest COD elimination was reached while the reactor was set at the ratio $(V_b/V_R)_m$ = 0.55 and an air velocity u_{gm} = 0.024 m/s. Upon these parameters, the amount of COD was really at steady-state for periods longer than 30 h. Therefore, these levels of $(V_b/V_R)_m$, u_{gm} and t may be viewed as the optimal working conditions for a reactor employed in treatment of industrial wastewaters. A diminution in COD from 36,650 to 1950 mg/L (95% COD reduction), was attained if the reactor was optimally maintained at $(V_b/V_R)_m$ = 0.55, u_{gm} = 0.024 m/s and t = 30 h. The pH was followed in the interval 6.5-7.0 and the temperature was fixed at 28-30°C. The biomass charge was efficiently monitored in an IFBR with support particles whose matrix particle density was smaller than that of liquid. The steady-state biomass charge was function of the ratio (V_b/V_R) and an air velocity u_g. In the culture performed following the switching from the batch to the continuous procedure, the steady-state biomass charge was reached after around 2-week operation. In the cultures realized following modification in (V_b/V_R) at a fixed u_g, the steady-state mass of cells developed on the particles was obtained after around 6-day operation. For a fixed ratio (V_b/V_R), the biomass charge was function of u_g. With modification in u_g at a fixed (V_b/V_R), the new steady-state biomass charge happened after the culturing for around 2 days.

6. Energy Recovery Inside Innovative Biological Wastewater Treatment (WT) Process

Piergrossi et al. [72] performed in excellent research in which they showed a full-scale energy recovery system able to extract, using a water source heat pump, the leftover thermal bioenergy available in a Sequencing Batch Biofilter Granular Reactor (SBBGR) inside the WT process (Figure 6). Heat pump compressor engine was powered by a 5.1 kW Photovoltaic plant, the thermal energy being recovered is accumulated by two phase change materials tanks (PCM) for heat and cold latent energy storage whose capacity is 0.3 and 0.5 m^3, respectively; thermal energy excess was dissipated through evaporator and condenser devices. Thermal energy extracted from SBBGR ranged from 0 to 14.5 kWh as a function of environmental temperature and temperature set point of SBBGR. It was predominately influenced by environmental temperature through radiation and no decay of SBBGR efficiencies was noted throughout energy extraction even at the lowest temperature set point (i.e. 15°C). Findings obtained established that SBBGR technique, due to its special process scheme, lets wastewater heat extraction inside the treatment process working, rendering it truly the only WT device capable to exchange energy at low temperature (15°C) without damage to treatment efficiencies and, at the same time, to function a thermal regulation of the treatment reactors, merging the optimization of thermo-dependent biological processes with energy recovery systems.

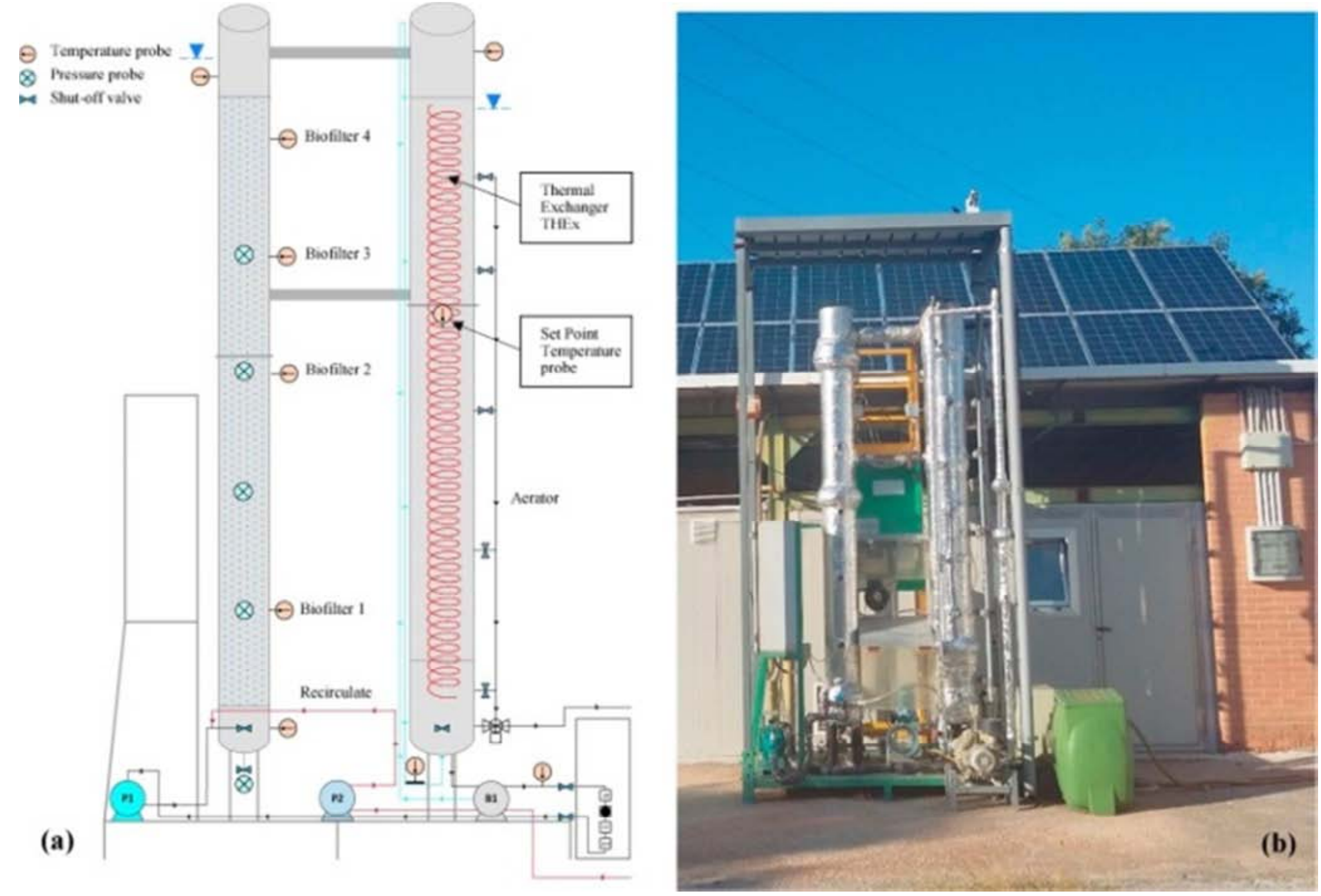

Figure 6. *SBBGR pilot plant. (a) SBBGR pilot plant scheme (b) SBBGR picture 2017 [72].*

Life cycle assessment (LCA) has been established to work as an advantageous instrument to assess the environmental effects of WWTPs. Nevertheless, using LCA procedure in the field of WT remains in development. Zang et al. [73] reviewed the LCA investigations concerning biological (activated sludge) WWTPs, with the objective to give a qualitative explanation of the linked environmental effect categories: eutrophication potential, global warming potential, toxicity-related impacts, energy balance, water use, land use and other effect categories. They summarized probable sources for each impact category of WWTPs to give data concerning the crucial features in WWTP devices that might affect LCA findings. Furthermore, Zang et al. [73] assessed fresh expansion and the usage status of characterization models for each effect category. Their survey showed that it is fundamental to realize site-specific LCA investigations on WWTPs. The particularity is most typical for the eutrophication capacity and toxicity-related impact categories, which require the implementation of spatial differentiated characterization methods, taking into account the emission location, spatial dimensions (transfer between environmental compartments) and even properties of pollutants. Even if substantial signs of progress have been reached, their usages in the field of WT remain restricted. For the global warming potential impact category, it is most important to evaluate exactly the greenhouse gas (GHG) emissions, since nitrous oxide (N_2O) and methane (CH_4), as well as fossil origin carbon dioxide (CO_2) in wastewater, possess the capacity to make considerable contributions.

7. Variability of Microbial Community Composition

The biological capacity of classical WTTPs to eliminate microcontaminants mostly is a function of process parameters and the prevalent microbial community. With a view to investigate this relationship and to correlate the presence of genera with working parameters, Wolff et al. [74] integrated five pilot-scale reactors with various process indicators into two reactor cascades and fed with the effluent of the primary clarifier of an urban WWTP. All reactors and the WWTP were monitored for the elimination of 33 microcontaminants using LC-MS/MS and the existence of the microbial community employing 16S rRNA gene sequencing. The global elimination of the microcontaminants was somewhat enhanced (ca. 20%) using the reactor cascades comparatively with the WWTP while some chemicals like diatrizoate, venlafaxine or diclofenac displayed an elevated decrease (ca. 70% in one or both cascades). To examine the various bacteria in more information, the global community was divided into a core and a specialized community. Despite their profoundly diverse working indicators (particularly redox parameters), the changing treatments present a core community composed of 143 genera (9% of the overall community). Moreover, the alpha- and beta-biodiversity, as well as the presence of many genera belonging to the specialized microbial community, may be related to the predominant operation parameters of the individual treatments [75]. Members of the specialized community as well as are linked to the elimination of some groups of microcontaminants. As a consequence, the comparison of the specialized community with microcontaminant decrease and working parameters through correlation analysis is a considerable tool for advanced evaluation of the predominant process indicators. Following a developed data collection, this manner may as well be employed to define organisms as parameters for working situations which are useful for an enhanced decrease of particular microcontaminants.

8. Reducing Excess Sludge Formation

Excess sludge treatment and disposal actually constitute an emerging defy for WWTPs because of economic, environmental and regulatory considerations. Thus, there is a crucial motive force to investigate and promote designs and techniques for minimizing the excess sludge formation in biological WT methods. Wei et al. [76] assessed the existing plannings for decreasing sludge generation following the next mechanisms: lysis-cryptic growth, uncoupling metabolism, maintenance metabolism, and predation on bacteria. The plannings for sludge decrease have to be assessed and selected for a feasible usage employing costs analysis and assessment of environmental impact [77]. Elevated costs still restrict techniques of sludge ozonation-cryptic growth and MBR from spreading usage in full-scale WWTPs. Bioacclimation and harmful to the environment are the main impasses for chemical uncoupler in feasible implementation. Sludge decrease formed by oligochaetes can display a cost-effective method for WWTPs if unstable worm growth is solved. Using any planning for decreasing sludge formation may possess an effect on the microbial community in biological WT processes. This effect may affect the sludge features and the quality of effluent [78].

9. Conclusions

The main points drawn from this short communication may be given as:

1. During the last three decades, rapid urbanization and economic growth have generated many environmental problems like river pollution and water blooms in lakes, particularly in developing countries. Considering the stringent discharge guidelines and standards for classical WWTPs, WWTPs still encounter difficulties in eliminating excess nutrients efficiently from wastewater.
2. The OMP bioconversion level and mechanism are mostly determined via the redox potential and the primary substrate activity. The integration of various redox potentials in hybrid reactor devices may importantly improve the total OMP elimination performance. Sorption and bioconversion may be synergistically advanced in bioreactors via the injection of activated carbon. A more profound comprehension of the principal factors affecting OMP decrease will permit enhancing the biological methods in the future.
3. Integrations of minutely anaerobic and aerobic methods importantly improved the elimination of specific and non-specific in vitro toxicities. Therefore, optimizing biological WT may conduct to a considerably ameliorated detoxification.
4. Surplus sludge treatment and disposal are regarded as an increasing defy for WTTPs because of economic, environmental and regulatory elements. There is thus a fundamental need in expanding procedures for decreasing sludge generation in biological WT processes. Great attention for minimizing sludge formation occurs following procedures founded on mechanisms of lysis-cryptic growth, uncoupling metabolism, maintenance metabolism, and bacterivorous predation.

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