Innovations for the Treatment of Effluents in the Food Industry

Luiza Helena da Silva Martins, Andrea Komesu, Sabrina Baleixo da Silva, Ali Hassan Khalid, Johnatt Allan Rocha de Oliveira, Eduardo Dellosso Penteado, Camilo Barroso Teixeira

L. H. S. Martins, Federal Rural University of Amazonia (UFRA), Belém PA, 66.077-830 BRAZIL (e-mail: luiza.martins@ufra.edu.br). A. Komesu, Federal University of São Paulo (UNIFESP), Santos SP, 11070-100 BRAZIL (e-mail: andrea.komesu@unifesp.br). S.B. Silva, Federal University of Para (UFPA), Belém PA, 66.075-900 BRAZIL (e-mail: sabrinabaleixo@gmail.com). A. H. Khalid, National University of Sciences & Technology (NUST), Pakistan (e-mail: chaudary.ali1448@yahoo.com). J. A. R. Oliveira, Federal University of Para (UFPA), Belém PA, 66.075-900 BRAZIL (e-mail: johnattrocha@yahoo.com.br). E. D. Penteado, Federal University of São Paulo (UNIFESP), Santos SP, 11070-100 BRAZIL (e-mail: eduardo.penteado@unifesp.br). C. B. Teixeira, Federal University of Para (UFPA), Belém PA, 66.075-900 BRAZIL (e-mail: camilobt@ufpa.br).

DOI: https://doi.org/10.34024/jsse.2023.v1.15461

***Abstract*— During the processing phases of the food business, a large amount of water is used, resulting in a large volume of effluents. Raw materials, sanitary water for food processing, transportation, cooking, dissolving, auxiliary water, cooling, cleaning, and so on are all utilized extensively in the business. Traditional anaerobic or aerobic biological wastewater treatment processes can be employed to handle organic compounds found in food sector effluent. However, some hazardous chemicals to a microbial population may be present in the effluent due to varied consumption. The effluent may contain significant levels of suspended particles, nitrogen in various chemical forms, lipids, oils, phosphorus, chlorides, and high organic content. There are traditional and well-established methods for treating effluents in the food industry, such as the coagulation-flocculation process, electrochemical processes, and biological processes, which have proven to be quite effective when used as treatment methods in a variety of industries; however, such methods have limitations. Innovative techniques, such as microbial fuel cells (MFCs), microalgae, water ultrafiltration, nanofiltration, and membrane technologies, can replace or complement traditional methods in the future. The treatment method chosen will be determined by the industry's and its wastewater's characteristics.**

***Keywords*— water waste treatment, food industry, methods, new technologies.**

I. INTRODUCTION

Due to the diversified consumption and multitude of functional food products that exist internationally, the food business is one of the most resource-demanding divisions of the industry, which creates a severe problem with the compositions of food industry wastewater. Water is used extensively in the industry for various purposes, including raw materials, sanitary water for food processing, transportation, cooking, dissolving, auxiliary water, cooling, cleaning, and so on [1].

According to Dave and Das [1], organic compounds effluent in the food sector are generally biodegradable and can be treated using classic anaerobic or aerobic biological processes. On the other hand, some harmful chemicals to a microbial community may be present in the effluent because of diversified consumption. Significant levels of suspended particles, nitrogen in various chemical forms, fats, oils, phosphorus, chlorides, and high organic content may be present in the effluent.

Wastewater has become a significant inconvenience for industrial processes, which have searched for approaches to reduce environmental damage and recovery of this waste increasingly studied. This process is usually expensive and energy-intensive due to the large amounts of pollutants and volumes of water that are treated and traditionally generated by industries and human activities [2].

There are conventional and already consolidated methods for the treatment of effluents in the food industry, including the following: coagulation-flocculation process, electrochemical processes, and biological processes, which proved to be quite efficient when used as treatment methods in many industries; however, such methods end up having their limitations [3]–[5]. However, over the years, innovative techniques can replace or act in conjunction with conventional methods, which can be seen below.

Microbial fuel cells (MFCs) present advantages because direct generation and energy are possible; they are processes without aeration requirements and have low or zero toxicity in forming by-products [6]. In addition, they generate little sludge with possible regeneration of microorganisms and water recovery, product recovery, tiny carbon footprint, and lower operating costs. According to [7], these systems have applications in effluent treatment and bioelectricity generation and in producing biohydrogen, biosensors, and recovery.

There is an excellent potential for microalgae to replace the use of fossil fuels, allowing at the same time to reduce the

This paragraph of the first footnote will contain the date on which you submitted your paper for review. It will also contain support information, including sponsor and financial support acknowledgment. For example, "This work was supported in part by the São Paulo Research Foundation (FAPESP), under Grant 2021-XYZ."

greenhouse effect through the reduction of carbon dioxide present in the air through photosynthesis. As a result, microalgae cultivation has drawn attention due to its high efficiency and ability to remove nutrients and produce biomass for the generation of third-generation biofuels, also recognized for their ecological appeal [8].

Several advantages are attributed to algae; in addition to not competing with other crops for productive land and water, their use favors the reduction of greenhouse gas emissions as they fix carbon dioxide, which contributes to air quality. They can also be used as protein sources, usable as animal feed and fertilizers [9], [10].

Usually, the reuse of effluents presents the need for treatments that precede the reuse to reduce the concentration of a particular pollutant and thus guarantee subsequent use. The choice of the type of treatment used will vary according to the characteristics of the industry and its wastewater. Water ultrafiltration installations are considered reliable and sustainable for obtaining safe drinking water from small communities in developing countries. Although they present themselves as a technology still inaccessible to developing countries, it should be strongly considered for water treatment due to its modularity and adaptability to contaminants [11].

The use of membrane technologies such as Nanofiltration (NF) and reverse osmosis (RO) have been increasingly applied as a separation technique in desalination, selective separation, and other chemical and environmental engineering areas [12].

Although the nanofiltration process demonstrates a propensity to foul the membrane, it efficiently removes a wide variety of contaminants. However, other drawbacks in this process are related to the formation of brines with high concentrations of magnesium, calcium, and chloride, in addition to other ions, which have a direct impact on their disposal, which limits the application of this technology [13].

This paper discusses the conventional and non-conventional processes used in the food industry, focusing on the most innovative techniques and their importance for the industrial food sector.

II. Conventional methods of effluents

A. *Coagulation-flocculation process*

Coagulation-flocculation is the most economical and straightforward method among the various physicochemical methods. It is commonly applied to reduce color, suspended particles, and colloids in effluents as the first step in solid-liquid separation [14]. This method can remove almost 60% of the organic matter in food processing wastewater. Still, the performance process depends on many other operating factors and system characteristics (properties of coagulants or flocculants, temperature, concentration and pH value, type and characteristics of wastewater) [3].

Amin et al. [3] studied wastewater treatment from meat processing units using the coagulation-flocculation process. The coagulants used were "ferric chloride, ferrous sulfate, and aluminum sulfate, and the removal efficiency of chemical oxygen demand (COD) were 73%, 79%, and 79%, respectively, and for total suspended solids (TSS) were 93%, 93%, and 92%, respectively". Therefore, "ferrous sulfate and aluminum sulfate are the most efficient coagulants." In another study, Panhwar et al. [15] used the same coagulants (alum, ferric chloride, and ferrous sulfate) followed by activated charcoal in the treatment of sugar industry wastewater. The comparison between the coagulants showed that the alum has greater removal efficiency than the rest of the coagulants used. The total dissolved solids were decreased to 87%, and total suspended solids were up to 98%.

Meraz et al. [16] used "chitosan (high and low molecular weight) to improve the coagulation-flocculation efficiencies in nejayote (wastewater from the tortilla industry). The authors obtained efficiencies of 80% of turbidity removal at pH = 5.5 with both chitosans". Recent critical reviews of coagulation-flocculation have addressed the application of this process in treating various industrial wastewaters. Zhao et al. [17] reviewed the use of this process in the treatment of oily wastewater. They showed that "coagulation/flocculation is a promising and indispensable technology."

On the other hand, they concluded: that "the development of efficient green natural coagulants/flocculants, determination of components of different oily wastewater and study of dissolved oil treatment are expected to improve the treatment efficiency" [17]. Teh et al. [18] reviewed the recent applications of coagulation-flocculation in various industrial wastewaters, such as dye/textile wastewater, agricultural wastewater, food processing industry wastewater, pulp, paper wastewater, and tannery wastewater, and others. They also discussed the "challenges and drawbacks of this treatment process together with possible improvements" [18].

Although the coagulation-flocculation process is inexpensive and straightforward, it has some disadvantages. According to Crini and Lichtfouse [19]: "it requires adjunction of non-reusable chemicals (coagulants, flocculants, aid chemicals), requires physicochemical monitoring of the effluent (pH), and increased sludge volume generation (management, treatment, cost)" [19]. In addition, "it is ineffectiveness in removing heavy metals and emerging contaminants and has a complexity of scaling up procedure" [18].

B. *Electrochemical processes*

Electrochemical processes, such as "electrochemical oxidation, electrocoagulation, and electro-Fenton, have been widely applied as suitable methods for treating various types of wastewaters" [14]. Recently, Sandoval and Salazar [20] reviewed "the application of electrochemical treatments to the treatment of meat and dairy processing industries effluents, which contain high organic matter concentration." In addition, "an overview of added-value products and energy recovery from these industrial wastewaters is also presented with future perspectives" [20].

The electrode type, electrode distance, electrode arrangement, pH, temperature, reaction duration, and current density are all parameters that influence electrochemical treatment efficiency. For the electrochemical treatment process, a large range of electrode materials can be utilized, each with its own cost, availability, and treatment performance characteristics [21].

Rech and Paulino [22] evaluated the "scale-up of a laboratory reactor to full-scale plant for the electro flocculation of dairy food industry wastewater." According to Rech and Paulino [22], "In comparison to typical wastewater treatment systems, the scale-up of the laboratory reactor to a full-scale facility was architecturally, operationally, and economically feasible" [22]. Varank et al. [23] compared the electrocoagulation (EL) and electro-Fenton (EF) for food industry wastewater treatment. They obtained the following results: "optimum conditions for the chemical oxygen demand (COD) removal of 21.36 min, pH 10 and 86 mA/cm^2 in EC, whereas 27.11 min, pH 2.38, 86 mA/cm^2 and H_2O_2/COD:2 in EF process. COD removal efficiencies were 29.4% for EC, and 59.1% for EF processes, and higher than 99% total suspended solids removal efficiencies were achieved" [23].

Turan [21] studied "the application of hybrid electrocoagulation–electrooxidation system for the treatment of dairy wastewater using different electrode connections, such as the monopolar and bipolar connections using iron, aluminum, and oxidized titanium" [21]. The results obtained showed "better COD removal efficiency for the bipolar connection mode. However, low metal dissolution levels were registered for the monopolar connection mode. Besides, the bipolar connection mode was found to cost higher than the monopolar one" [21]. Chakchouk et al. [24] also studied the "combined electrocoagulation–electrooxidation system" for the treatment of dairy industry effluent. The coupled process "eliminates 60% of COD in 21 min, removes the colloidal and suspended particles and eliminates color, turbidity, phosphorus, K+ and NTK" [24].

Sharma and Simsek [25] studied the "treatment of canola-oil refinery effluent using the combined electrocoagulation and electrooxidation and electrochemical peroxidation methods." Considering the treatment efficiency, "both techniques could be suggested as effective alternative treatment techniques for canola-oil wastewaters." However, "a stepwise regression modeling results suggested that combined electrocoagulation and electrooxidation process was superior to electrochemical peroxidation methods" [25].

Very recently, Asfaha et al. [4] reviewed "the potential of a hybrid of the electrocoagulation–electrooxidation processes for treating wastewater generated from various sources." In this review, it was assessed that "a hybrid process has the potential of removing various pollutants (COD, TOC, NH4+-N, nitrates, phenol, virus mitigation/inactivation)" [4]. Moreover, in most studies on hybrid processes, "it has been proven that electrocoagulation as a pretreatment of electrooxidation is more effective in removing colloidal particles and persistent organic compounds than a separate operation. In general, it has been shown by various researchers that the electrochemical method is an efficient technology for removing numerous pollutants" [4].

C. Biological processes

The biological methods have been widely used to treat the food industry wastewater due to the high organic content (COD over 500 mg L^{-1}) and biodegradability of organic matter (the relation BOD/COD is also over 0.5). This stream is also characterized by "high nutrients such as nitrogen (N, including ammonia) and phosphorous (P)," which can be used by microorganisms. In this sense, contaminates from food industry wastewater can be removed by aerobic, anaerobic, and facultative microorganisms in suspended or fixed biofilm processes [14].

In the aerobic process, the microorganism transforms the organic matter into inorganic molecules (carbon dioxide and water - CO_2 and H_2O) and biomass using oxygen (O_2) as the final electron acceptor [26]. The most common aerobic reactors are the suspend such as "aerated lagoons, sequencing batch reactors (SBR), activated sludge processes; aerobic jet loop reactors and the attached growth process" [14]. In these processes, aeration devices help to supply oxygen in tanks.

In the literature, "the efficiency of wastewater treatment (COD removal) depends significantly on the kind of food industry and the operating conditions such as dissolved-oxygen concentration, hydraulic retention time (HRT), recycling ratio of sludge, mixed liquor-suspended solid (MLSS), temperature, pH" [14]. Abdulgader et al. [27] observed that "aerated lagoons sequencing batch reactor and the activated sludge process achieved high COD removal efficiency at an organic loading rate (OLR) up to 3 kg COD m^{-3}d^{-1}, while for higher OLR the COD removal efficiency decreased". Because of this, until the 1990s, these reactors design was "the mostly used in food industry wastewater treatment plant worldwide, because of their simplicity and low-cost treatment techniques" [4], [14]. However, these configurations generate sludge at high rates leading to settling problems which decrease the process's efficiency [14]. Moreover, the environmental requirements for the discharge of these wastewaters were more restrictive.

In this sense," aerobic attached biofilm reactors have attracted increasing attention in recent years because of their ability to remove large amounts of biodegradable organic load even at very high concentrations" [28]. Support material with high specific surface area and roughness is employed to develop the attached biofilm [29]. "Trickling filters, packed bed reactors, and rotating biological contactors" are the most common reactors designed used to treat the food industry wastewater [14]. In the trickling filter, wastewater flows downward and forms a thin layer around the media and biofilm which also transfers the oxygen from the atmosphere [29].

"Over time, the thickness of slim layer increase resulting in an insufficient oxygen transfer, and thus sloughing of biomass can be observed" [4]. Different types of material can be used as support material in trickling filters and packed bed reactors, such as coke, gravel, polyurethane foam, ceramic, or plastic media. Tatoulis et al. [28] observed that "attached aerobic systems had higher COD removal efficiency than the suspended ones." In these systems, "the organic matter removal efficiencies varied from 60–85% when operated at OLRs of 1.2–8.1 kg BOD m^{-3} d^{-1}" [28].

Another kind of biological treatment for high-strength wastewater is the anaerobic process, which converts the organic matter into reduced organics compounds (alcohol, acids), carbon dioxide, and methane [29]. Despite the aerobic system consuming energy from the aeration system, the anaerobic process can recover energy in biogas form, "13.5 MJ of energy from methane per kg of COD removed, resulting in 1.5 kWh electrical energy production" (assuming an electric conversion efficiency of 40%) [30]. Even though the anaerobic process had good organic matter removal efficiency (over 60% of COD and 90% of BOD) [31], in some cases, high levels of energy are needed to maintain the optimal temperature for the food industry wastewater treatment [29]. Furthermore, the anaerobic system had lower sludge production because the anaerobic cell yields are almost 10% of that observed in the aerobic system. In anaerobic systems, "the cell yield is estimated between 0.4 to 0.8 g VSS g^{-1} COD removed while anaerobic system varying between 0.035 to 0.13 g VSS g^{-1} COD removed" [32]. Another advantage of anaerobic high-rate reactors to treat food industry wastewater is reducing area requirements compared to conventional activated sludge systems [30].

However, the bottlenecks to applying the anaerobic process in food industry wastewater treatment are the intolerance of shock loadings, the need for skilled personnel, and possible pretreatment and post-treatment [33]. The pretreatment can reduce the concentration of solids and floatable fat, oils, and grease content present in food processing wastewater. It can improve pollutant removal in the anaerobic process [31]. The produced effluent in an anaerobic system is not suitable for final disposal according to the environmental requirements for discharge, especially for nitrogen compounds [14]. Because of these, anaerobic systems need post-treatment processes [34].

Different configurations of anaerobic reactors, such as "anaerobic lagoons, anaerobic filters (AF), anaerobic fluidized-bed reactors, up-flow anaerobic sludge blankets (UASBs), expanded granular sludge beds (EGSB), and anaerobic SBRs," can be used for food industry wastewater [14].

In covered anaerobic lagoons (anaerobic ponds), the wastewater enters at one side, and the effluent is removed from the other, with a maximum depth of 5 meters [31]. Because of this, hydraulic retention time (HRT) is one of the foremost parameters to project this system, being typically used between 40-60 days [4]. Thus, the availability of land is one of the main factors that allow the usage of anaerobic ponds for food processing wastewater treatment. Temperature is another factor that influences this system's performance once the seasonal variation in temperature affects the reaction rate of anaerobic microorganisms present in the ponds [31]. In the literature, the removal of organic matter efficiency obtained using anaerobic is over 80 %, and the methane yield is around 0.5 m^3 CH_4 kg^{-1}-COD removed [4].

Anaerobic filters are tanks that have support material inside to retain bacteria. Several packing types can be used for biomass immobilization, such as activated carbon, plastic particles, rock particles, or ceramic rings [4]. Some highlights of anaerobic filters are the "good stability at higher loading rates and the capacity to support large toxic and organic shock." However, "the bottleneck of this reactor is the media clogs due to increasing biofilm thickness, and high suspend solids concentrations" [4]. The COD removal efficiency varies between 55 – and 95%, and methane yield is around 0.42 m^3 CH_4 kg^{-1}-COD removed when an anaerobic filter reactor treats food industry wastewater [4].

Upflow anaerobic sludge blanket (UASB) reactors have been shown to be effective in treating food processing wastewater, removing more than 70% of organic matter (COD) and creating 0.2-0.4 m^3 CH_4 kg^{-1}-COD removed methane [4]. In UASB technology, the wastewater flows from bottom to top, traveling in a blanket of sludge, where there are microorganisms in flocculent/granular particles [31]. The flow velocity and biogas homogenize the sludge blanket, ensuring an even distribution of the wastewater; the liquid flow velocity is one of the most significant parameters in this kind of reactor [4].

Besides the sludge blanket, another essential compartment in the UASB reactor is the three-phase separator, where treated effluent and biogas can be acquired, and solids are retained and returned to the bottom [4]. The success of the UASB reactor depends on the "concentration of the influent organic matter, and the bottleneck of this process to treat food processing wastewater is the inability to operate at higher loading rates due to the suspended and colloidal particles (cellulose, protein, and fats) presented in this kind of wastewater, being necessary a pretreatment" [4].

One advance in UASB reactor development is the expanded granular sludge bed (EGSB) reactor which has a higher superficial liquid velocity applied than that used in UASB reactor (5-10 m h^{-1} in EGSB reactor compared to up three mh^{-1} in UASB reactor) [31]. The higher up-flow velocity expanded or fluidized the granular sludge bed, avoiding the short circuit and death zone in the reactors and improving the removal of the organic matter.

Although in the literature, there are many reports of full-scale applications of aerobic and anaerobic processes in food processing wastewater treatment, there is more need to study the parameters that affect the biological process (temperature, nutrients, clogging, support material, energy requirement, biomass washout) to improve the operations at lower hydraulic retention time and higher organic loads [4]. Moreover, recently, many researchers have been using the concept of circular economy and biorefinery to obtain compounds from wastewater treatment, and more information is necessary to apply it in a full-scale system.

III. NON-CONVENTIONAL AND INNOVATIVE METHODS OF TREATMENT OF EFFLUENTS

A. *Microbial Fuel Cell (MFC)*

Wastewater and solid bio-waste can be used as potential renewable raw materials to obtain value-added products and bioenergy. Bioelectrochemical systems (BES) are promising alternative technologies such as microbial fuel cells (MFCs) and microbial electrolysis cells (MECs), which are used for treating wastewater and for waste conversion to bioenergy. Some products such as biochar, biofuel, and other valuable products can be obtained by thermo- and biochemical technologies using feedstock, and biowastes from various sectors, including an organic fraction of municipal solid waste and agricultural residues, animal manure, food wastes, and sewage sludge [35].

MFC represents an eco-friendly approach that can generate electricity and simultaneously purify wastewater, accomplish up to 50% chemical oxygen demand (COD) removal, and obtain power densities in the range of 420–460 mW.m^{-2}. The metabolism power of bacteria or yeast cells is used for electricity generation [36].

Electroactive bacterial species (EABs) use the same substrates as in anaerobic biodegradation to transfer electrons and directly produce current from the chemical energy contained in an organic biodegradable substrate [37], [38].

The most used microorganisms in the MFCs belong to the *Shewanella*, *Proteobactor*, and *Pseudomonas* families. In wastewater-based MFCs, mixed cultures are primarily used [39]. However, based on the type of substrates, the microbial community present in the system has different profiles. For example, the dominant phylotypes involving carbon uptake with acetate include *Geobacter* and *Rhodocyclaceae*. With glucose, both *Enterobacteriaceae* and *Geobacter* are prevalent [40].

The MFC device structure comprises an anode compartment with cells, with or without a mediator, and an electrode separated from a cathode compartment. In the case of an anaerobic anode chamber, it may be required to use membranes while the cathode uses oxygen. In the cathode compartment, there are an electrode and an electron acceptor. A circuit couples both anode and cathode and electrons flow from the biological cells to the cathode electron acceptor due to the redox potentials of the active components, which are arranged in ascending order [39].

MFC application is limited at the laboratory scale for wastewater treatment and energy recovery in the current scenario. The large-scale application of MFC technology is not possible yet due to high cost, system development, and energy recovery is minimal. To determine whether the technology's envisioned benefits can be realized in the end, it is necessary to reconsider the technology's difficulties and viability.

Some studies revealed that the main issues as proper selection of microbes, operation mode, suitable material, and improved MFC types are critical to achieving higher power density and coulombic efficiency. Though the electricity generated is still at the demonstration stage, there is no industrial application yet [41].

MFC scaling-up is limited to microbes-electrode interactions, design aspects, electrochemical limitations, and a multidisciplinary approach to environmental electrochemistry and biotechnology [36]. For the transformation of benchtop MFC models towards the field applications, Jadhav et al. [42] suggest that enlarging the size of electrodes and stacking modular units is a possible solution for MFC scaling-up. Recent scientific and technical studies of industrial dairy wastewater evolve different approaches considering the main issues as process intensification and reactor design; evaluation of several microbial strains from different phylum as microalgae, and actual DW evaluation performance to improve the MFC operation [43].

Parihar et al. [44] used an *Enterococcus faecalis* electrochemically active isolated from the biofilm of a dual-chamber MFC fed with DW. The strain was selected by dye-reduction based electron-transfer activity (DREAM) assay for electrochemical activity (0.43) evaluation and cyclic voltammetry (CV) for characterization. CV studies revealed that the redox compounds present in the DW were exploited by the strain for extracellular electron transfer towards the anode. The performance presented a COD removal efficiency of 53.5% with a maximum current density of 258 mA.m^{-2}, the power density of 144 mW.m-2, and a coulombic efficiency of 10.89%.

Faria et al. [45] used a dual-chamber MFC connecting two compartments of transparent polymethylmethacrylate. The two compartments were physically separated by a proton exchange membrane. The electrodes were made by carbon sheets with a biofilm formation on an anode surface using pre-screened municipal wastewater. They evaluated the performance of a continuous MFC applied in synthetic effluent prepared with low fat pasteurized milk without nutrient supplementation and obtained a maximum voltage of 576 mV during continuous operation, corresponding to a power density of 1.9 W m^{-3} with the maximum COD removal (63 ± 5%) achieved after 20 days of continuous operation. In addition, the coulombic efficiency average was around 10.5 ± 10%, with a maximum of 24.2 ± 1.5%. Although good performance, it is essential to observe synthetic effluent preparation, which does not correspond to daily wastewater COD values in the dairy industry, which presents significant variations due to process operations and discontinuity in the production cycles of different products.

Farizoglu and Uzuner [46] changing the current studies of synthetic and isolated substrates for actual different types of industrial wastewater with a higher level of organic matter positively impacts a crucial role in harvesting MFCs "green electricity."

Faria et al. [45] studied brewery residue sludge isolates in anodic chamber and observed a fine whitish biofilm formation on the anode, this observation showed that there is a positive correlation between the time 'of the formation of *Geobacter* biofilm at the anodic terminal'.

The process intensification approach has been evaluated considering the integration of MFC with other treatment technologies. Although MCF (Microbial fuel cell) is a technology under development, it is described as promising and capable of making sustainable energy production possible through the degradation of organic matter existing in wastewater, making it possible to produce direct current and carry out the wastewater treatment simultaneously. This system works like batteries, in which anodes and cathodes are connected through an electrical wire. However, in this process, microbes generate electrons in the anode chamber and proceed to the cathode chamber, reducing O_2 [47].

Like batteries, the substrates located on the anode side are the fuel required for biochemical conversion [48]; MFC systems allow biochemical reduction to carry out electron transport. Such systems can simply oxidize carbonates to carbon dioxide (CO_2). So usually, an MFC contains two electrodes (anode and cathode). The bacteria in the anode carry out the decomposition of the organic matter of the wastewater, which produces electrons, and these flow to the cathode through an external circuit, producing electricity. In the end, protons diffuse from the anode to the cathode [49].

IV. Microalgae

The food industry produces large amounts of polluted water, and, in many cases, wastewater treatment is expensive and harmful to the environment. Using more economically viable means of treating wastewater has been one of the most significant technological pursuits. Bioremediation of sewage and contaminated water is an alternative approach to restoring the environment by manipulating organisms, including microalgae, as essential mediators in the transformation of pollutants, for example, through so-called biofiltration algal mats (TAP), which have shown promising results.

According to Ruan et al. [50] is a viable alternative for tertiary water treatment, its cultivation in effluents can promote the assimilation of nutrients and other contaminating compounds such as heavy metals and drugs. In addition to demonstrating favorable economic and environmental costs, as it is natural and low-cost [50]. Microalgae can assimilate through photosynthesis the compounds they need and that are present in wastewater, which favors their growth [51].

Factors such as growth rate, salinity tolerance, sedimentation capacity, good shear and resistance properties, as well as characteristics such as a high concentration of oils and saturated fatty acids, favor the successful cultivation of microalgae on a large scale and to treat sanitary effluents and biofuel production [52].

Microalgae can sequester nutrients (nitrogen and phosphorus) and heavy metals and reduce wastewater COD and BOD. Microalgae metabolize these compounds resulting in the biosynthesis of useful macronutrients such as lipids and proteins. Wastewater treatment using microalgae represents an effective, efficient, economic, and eco-friendly sustainable remediation technology [53].

Gani et al. [54] evaluated the feasibility of organic compounds and nutrient removal from food processing wastewater (FPW) using Botryococcus s in an enclosed photobioreactor. The maximum growth rate of Botryococcus s cultivated in FPW was 1.83 mg day^{-1} with the highest reductions of COD (96.1%), total organic carbon removal (TOC) 87.2%, and total phosphorus (TP) 35.4% after 12 days of phytoremediation.

Sirohi et al. [55] discuss the application of a novel microalgal-bacterial consortium as a solution for the resource recovery and treatment of dairy, starch, and aquaculture wastewater. The authors considered the use of biofilm reactors containing anaerobic and aerobic sludge, which has shown COD removal of 80–90% for dairy and 90% for starch processing wastewater. Considering this bacterial-microalgal synergism, Yadav et al. [56] utilize microalgal biomass for electricity generation in the MFCs.

Chlorella s was used as substrate in the anode and as a live culture to constitute a bio-cathode. The results demonstrated the novelty and efficacy of bacterial-algal synergistic metabolism in producing bioelectricity using inorganic and organic wastes. Sustainable applications of the microalgae-based MFC are reliable for wastewater treatment and bio-electricity generation and versatile for bio-hydrogen energy production, desalination, and carbon sequestration [57].

Recent studies also evaluated the process integration of microalgae technologies with other green technologies. Ferreira et al. [58] reported the use of Tetradesmus obliquus biomass resulting from brewery wastewater treatment with (To-CO_2) and without CO_2 supplementation (To) couple with subcritical water extraction (SWE) for extracting purified compounds from wastewater-grown microalga biomass aiming at obtaining microbiologically safe products for zero waste sustainable biorefinery process. The results indicated that T. obliquus extracts and residues are valuable sources of aliphatic saturated, unsaturated, and alkylated (mostly methylated) hydrocarbons, phenols, esters, and ketones. The polyphenols content doubled when T. obliquus was supplemented with CO_2 for all the tested temperatures. The microbiological analysis showed liquid extracts and residues innocuity, representing safe sources of bioactive components.

Hamidian & Zamani [59] evaluated wastewater treatment (DWW) and bioactive-rich biomass production by Chlorella sorokiniana EAKI grown in undiluted and diluted DWW and concluded that DW cultivation of C. sorokiniana can be an effective approach. to reduce the cost of producing microalgae biomass rich in bioactive compounds such as antioxidant compounds for animal feed or aquaculture applications.

Scenedesmus sp has pharmacological properties addressing the health benefits as a cosmetic remedy or food ingredient. Interestingly, Scenedesmus s cultured in ultra-filtrated olive mill wastewater (UFOMW) may provide a valuable source of safe antioxidants with an enhanced biological potential that can be commercially exploited in the food and/or pharmaceutical industries [60].

Maalej et al. [60] recently reported the use of olive mill wastewater treatment by microalgae as a safe method to reduce pollutants. Scenedesmus s was cultivated in BG11 medium enriched with 20% of UFOMW, and polyphenols were then extracted, identified, and quantified by HPLC–DAD analysis. The addition of UFOMW increased the production of some phenolic compounds with low cytotoxicity on average versus cancer cells. UFOMW improved the antioxidant capacity and promoted melanogenesis, enzyme, and lysozyme inhibition.

V. Ultrafiltration and Nanofiltration combined with reverse osmosis

The ultrafiltration (UF) membrane method has been widely used in the food processing sector for the past 20 years because of its benefits over traditional processes, such as high selectivity and lower power consumption. UF membranes have become an essential part of food technology as a tool for separation and concentration [61].

The increasing energy costs and demand for food products with higher nutritional value and green processing methods have favored the membrane technology implementation. The good utilization of membrane filtration in the food industry is related to juice concentration, beverage industry, dairy industry, whey processing, sugar industry, and wastewater treatment [62].

Membrane technology is efficient, energy-saving, and environmentally friendly; widely used in food processing, desalination, wastewater treatment, and the medical industry. The use of microfiltration, ultrafiltration, Nanofiltration, reverse osmosis, and membrane distillation has been showing be promising [63].

Morelos-Gomez et al. [64] investigated graphene oxide (GO) membranes using molecular dynamics models and experimental observations, finding that Coulomb interactions dominated protein adsorption while lactose interactions with GO layers were modest. In contrast to standard nanofiltration and ultrafiltration membranes, which have dense, low fouling layers, the fouling layers in the GO membranes were porous from the milk filtration test, allowing for enhanced permeation flow and water flow recovery. recovery of water flow

Whey protein concentrates (a by-product of the dairy industry obtained during the making of cheese and casein) are a viable feedstock for the food sector due to protein functional and nutritional qualities [65]. The same authors reported whey protein concentration and purification utilizing ultrafiltration and diafiltration and a mathematical model to maximize process profit. The results obtained showed a protein content, according to the data from the simulation, would reach 98.6 wt.%, representing a final profit of US$ 81.00 per kilogram of the product while generating 67 L of effluent. Experimentally, to produce a 70.0 wt.% (42 $kg \cdot m^{-3}$) protein content product, up to 40 L of effluent can be created. According to the model, even though the effluent increase in generation, the UF-DF coupled process significantly increases process profitability relative to increased effluent treatment cost.

Díaz-Montes & Castro-Nuñoz [66] investigated the fractionation of Nejayote (a by-product of the nixtamalization of maize kernels) from various maize varieties using three different membranes, one microfiltration and two ultrafiltration (with different molecular weight cut-offs of 100kDa and 1kDa) that were strategically applied to extract phenolic acids while retaining other molecules.

Retention in the membrane system was observed during the first stage of carbohydrates. In contrast, in the second stage, a recovery of phenolics at 768-800 mg GAE/L was achieved. In the third step, there was the presence of 14 phenolic acids, including ferulic and p-coumaric acids, derived from caffeic and ferulic acids, along with other molecules of sugars according with Díaz-Montes & Castro-Nuñoz [66].

Garnier et al. [67] evaluated the application viability of Reverse Osmosis (RO) or tight Nanofiltration (NF) for the treatment of cauliflower blanching wastewater, aiming at the production unit recycling. UF (100 000 $g.mol^{-1}$ molecular weight cut-off) was required before NF or RO was necessary to decrease turbidity below 1 NTU. Three NF and one RO membranes were tested at bench-scale in a crossflow filtration mode. The results showed that only RO was allowed to reach the desired quality for a reuse purpose, with an acceptable residual COD content of 225 $mgO_2.L^{-1}$.

Kyllönen et al. [68] developed a membrane-based reuse water concept for candy industry wastewater, emphasizing the pretreatment stage to reduce fouling. Candy gelation wastewater containing suspended solids and sugar compounds tended to foul membranes, making pretreatment essential. The results showed that cross-rotational ultrafiltration, which prevents fouling on membranes, functioned well in removing the substance. On the other hand, conventional filtration technologies presented a low flux, even when the viscosity of the wastewater was reduced using surfactants. Due to high pressure, the wastewater had a high COD, meaning a solid fouling potential for reverse osmosis membranes.

VI. DISSOLVED AIR FLOTATION

Dissolved air flotation is described as one of the most economical and effective methods of recovering and removing solids, ions, and microorganisms, reducing COD and BOD and increasing sludge thickness in domestic effluents and urban effluent treatment plants [69].

During the flotation process, bubbles are generated by saturating part of the effluent with air in tanks at pressures above atmospheric pressure. A sudden decompression occurs in a needle valve or flow constriction device, generating tiny bubbles from 30 to 100 µm [70].

This technology has excellent applicability due to its high yield and efficiency related to existing equipment. Other advantages are described as the selective recovery of valuable ions such as gold, palladium, silver, and pollutants. The exchange of experiences and technology between mineral flotation and water and effluent treatment can bring new and optimized industrial treatment procedures [69]. The dissolved air flotation method is one of the most effective for removing solids and oils and enabling the reduction of BOD, being the type of flotation most used for water and wastewater treatment [71].

VII. CONCLUSIONS

Many techniques still need to be explored and improved to provide a more concrete solution to effluent problems. We must consider that the food industry is a heterogeneous industry, which will generate effluents with different physical-chemical compositions. As a result, the ideal is to keep our needs in mind when faced with challenges, with innovative techniques coming as an aid to achieving greater sustainability.

REFERENCES

[1] S. Dave and J. Das, “Technological model on advanced stages of oxidation of wastewater effluent from food industry,” in *Advanced Oxidation Processes for Effluent Treatment Plants*, Elsevier, 2021, pp. 33–49. doi: 10.1016/B978-0-12-821011-6.00002-5.

[2] C. Munoz-Cupa, Y. Hu, C. Xu, and A. Bassi, “An overview of microbial fuel cell usage in wastewater treatment, resource recovery and energy production,” *Science of The Total Environment*, vol. 754, p. 142429, Feb. 2021, doi: 10.1016/j.scitotenv.2020.142429.

[3] A. Amin, Gh. Al Bazedi, and M. A. Abdel-Fatah, “Experimental study and mathematical model of coagulation/sedimentation units for treatment of food processing wastewater,” *Ain Shams Engineering*

Journal, vol. 12, no. 1, pp. 195–203, Mar. 2021, doi: 10.1016/j.asej.2020.08.001.

[4] Y. G. Asfaha, A. K. Tekile, and F. Zewge, "Hybrid process of electrocoagulation and electrooxidation system for wastewater treatment: A review," *Clean Eng Technol*, vol. 4, p. 100261, Oct. 2021, doi: 10.1016/j.clet.2021.100261.

[5] A. Aziz, F. Basheer, A. Sengar, Irfanullah, S. U. Khan, and I. H. Farooqi, "Biological wastewater treatment (anaerobic-aerobic) technologies for safe discharge of treated slaughterhouse and meat processing wastewater," *Science of The Total Environment*, vol. 686, pp. 681–708, Oct. 2019, doi: 10.1016/j.scitotenv.2019.05.295.

[6] S. Jayashree, S. T. Ramesh, A. Lavanya, R. Gandhimathi, and P. V. Nidheesh, "Wastewater treatment by microbial fuel cell coupled with peroxicoagulation process," *Clean Technol Environ Policy*, vol. 21, no. 10, pp. 2033–2045, Dec. 2019, doi: 10.1007/s10098-019-01759-0.

[7] H. J. Mansoorian, A. H. Mahvi, A. J. Jafari, and N. Khanjani, "Evaluation of dairy industry wastewater treatment and simultaneous bioelectricity generation in a catalyst-less and mediator-less membrane microbial fuel cell," *Journal of Saudi Chemical Society*, vol. 20, no. 1, pp. 88–100, Jan. 2016, doi: 10.1016/j.jscs.2014.08.002.

[8] S. S. Low *et al.*, "Microalgae Cultivation in Palm Oil Mill Effluent (POME) Treatment and Biofuel Production," *Sustainability*, vol. 13, no. 6, p. 3247, Mar. 2021, doi: 10.3390/su13063247.

[9] A. Ruiz-Marin, L. G. Mendoza-Espinosa, and T. Stephenson, "Growth and nutrient removal in free and immobilized green algae in batch and semi-continuous cultures treating real wastewater," *Bioresour Technol*, vol. 101, no. 1, pp. 58–64, Jan. 2010, doi: 10.1016/j.biortech.2009.02.076.

[10] S. Das and N. Mangwani, "Recent developments in microbial fuel cells: a review," 2010.

[11] J. M. Arnal, B. Garcia-Fayos, G. Verdu, and J. Lora, "Ultrafiltration as an alternative membrane technology to obtain safe drinking water from surface water: 10 years of experience on the scope of the AQUAPOT project," *Desalination*, vol. 248, no. 1–3, pp. 34–41, Nov. 2009, doi: 10.1016/j.desal.2008.05.035.

[12] C. Korzenowski, M. Minhalma, A. M. Bernardes, J. Z. Ferreira, and M. N. de Pinho, "Nanofiltration for the treatment of coke plant ammoniacal wastewaters," *Sep Purif Technol*, vol. 76, no. 3, pp. 303–307, Jan. 2011, doi: 10.1016/j.seppur.2010.10.020.

[13] F. Elazhar *et al.*, "Nanofiltration-reverse osmosis hybrid process for hardness removal in brackish water with higher recovery rate and minimization of brine discharges," *Process Safety and Environmental Protection*, vol. 153, pp. 376–383, Sep. 2021, doi: 10.1016/j.psep.2021.06.025.

[14] A. G. Tekerlekopoulou, Ch. N. Economou, T. I. Tatoulis, C. S. Akratos, and D. V. Vayenas, "Wastewater treatment and water reuse in the food industry," in *The Interaction of Food Industry and Environment*, Elsevier, 2020, pp. 245–280. doi: 10.1016/B978-0-12-816449-5.00008-4.

[15] A. Panhwar *et al.*, "TREATMENT OF FOOD-AGRO INDUSTRY EFFLUENT BY PHYSICO-CHEMICAL METHODS," 2020.

[16] K. A. S. Meraz, S. M. P. Vargas, J. T. L. Maldonado, J. M. C. Bravo, M. T. O. Guzman, and E. A. L. Maldonado, "Eco-friendly innovation for nejayote coagulation–flocculation process using chitosan: Evaluation through zeta potential measurements," *Chemical Engineering Journal*, vol. 284, pp. 536–542, Jan. 2016, doi: 10.1016/j.cej.2015.09.026.

[17] C. Zhao *et al.*, "Application of coagulation/flocculation in oily wastewater treatment: A review," *Science of The Total Environment*, vol. 765, p. 142795, Apr. 2021, doi: 10.1016/j.scitotenv.2020.142795.

[18] C. Y. Teh, P. M. Budiman, K. P. Y. Shak, and T. Y. Wu, "Recent Advancement of Coagulation–Flocculation and Its Application in Wastewater Treatment," *Ind Eng Chem Res*, vol. 55, no. 16, pp. 4363–4389, Apr. 2016, doi: 10.1021/acs.iecr.5b04703.

[19] G. Crini and E. Lichtfouse, "Advantages and disadvantages of techniques used for wastewater treatment," *Environ Chem Lett*, vol. 17, no. 1, pp. 145–155, Mar. 2019, doi: 10.1007/s10311-018-0785-9.

[20] M. A. Sandoval and R. Salazar, "Electrochemical treatment of slaughterhouse and dairy wastewater: Toward making a sustainable process," *Curr Opin Electrochem*, vol. 26, p. 100662, Apr. 2021, doi: 10.1016/j.coelec.2020.100662.

[21] N. B. Turan, "The application of hybrid electrocoagulation–electrooxidation system for the treatment of dairy wastewater using different electrode connections," *Sep Sci Technol*, vol. 56, no. 10, pp. 1788–1801, Jul. 2021, doi: 10.1080/01496395.2020.1788596.

[22] J. P. P. B. Rech and A. T. Paulino, "Electroflocculation for the treatment of wastewater from dairy food industry: scale-up of a laboratory reactor to full-scale plant," *Clean Technol Environ Policy*, vol. 21, no. 5, pp. 1155–1163, Jul. 2019, doi: 10.1007/s10098-019-01682-4.

[23] G. Varank, S. Yazici Guvenc, and A. Demir, "A comparative study of electrocoagulation and electro-Fenton for food industry wastewater treatment: Multiple response optimization and cost analysis," *Sep Sci Technol*, vol. 53, no. 17, pp. 2727–2740, Nov. 2018, doi: 10.1080/01496395.2018.1470643.

[24] I. Chakchouk, N. Elloumi, C. Belaid, S. Mseddi, L. Chaari, and M. Kallel, "A COMBINED ELECTROCOAGULATION-ELECTROOXIDATION TREATMENT FOR DAIRY WASTEWATER," *Brazilian Journal of Chemical Engineering*, vol. 34, no. 1, pp. 109–117, Jan. 2017, doi: 10.1590/0104-6632.20170341s20150040.

[25] S. Sharma and H. Simsek, "Treatment of canola-oil refinery effluent using electrochemical methods: A comparison between combined electrocoagulation + electrooxidation and electrochemical peroxidation methods," *Chemosphere*, vol. 221, pp. 630–639, Apr. 2019, doi: 10.1016/j.chemosphere.2019.01.066.

[26] M. Barbera and G. Gurnari, "Wastewater Treatments for the Food Industry: Biological Systems," 2018, pp. 23–28. doi: 10.1007/978-3-319-68442-0_3.

[27] G. Research Online, M. Abdulgader, Q. J. Yu, P. Williams, and A. A. L Zinatizadeh, "A review of the performance of aerobic bioreactors for treatment of food processing wastewater Author Copyright Statement Link to published version A review of the performance of aerobic bioreactors for treatment of food processing wastewater." [Online]. Available: http://hdl.handle.net/10072/17070http://www.cemepe.prd.uth.gr/invitation.htm

[28] T. I. Tatoulis, A. G. Tekerlekopoulou, C. S. Akratos, S. Pavlou, and D. V. Vayenas, "Aerobic biological treatment of second cheese whey in suspended and attached growth reactors," *Journal of Chemical Technology & Biotechnology*, vol. 90, no. 11, pp. 2040–2049, Nov. 2015, doi: 10.1002/jctb.4515.

[29] A. Ashraf, R. Ramamurthy, and E. R. Rene, "Wastewater treatment and resource recovery technologies in the brewery industry: Current trends and emerging practices," *Sustainable Energy Technologies and Assessments*, vol. 47, p. 101432, Oct. 2021, doi: 10.1016/j.seta.2021.101432.

[30] J. B. van Lier, F. P. van der Zee, C. T. M. J. Frijters, and M. E. Ersahin, "Celebrating 40 years anaerobic sludge bed reactors for industrial wastewater treatment," *Rev Environ Sci Biotechnol*, vol. 14, no. 4, pp. 681–702, Dec. 2015, doi: 10.1007/s11157-015-9375-5.

[31] Y.-T. Hung, P. Kajitvichyanukul, and L. K. Wang, "Advances in anaerobic systems for organic pollution removal from food processing wastewater," in *Handbook of Water and Energy Management in Food Processing*, Elsevier, 2008, pp. 755–775. doi: 10.1533/9781845694678.5.755.

[32] B. Abbassi, S. Dullstein, and N. Räbiger, "Minimization of excess sludge production by increase of oxygen concentration in activated sludge flocs; experimental and theoretical approach," *Water Res*, vol. 34, no. 1, pp. 139–146, Jan. 2000, doi: 10.1016/S0043-1354(99)00108-6.

[33] G. Carucci, F. Carrasco, K. Trifoni, M. Majone, and M. Beccari, "Anaerobic Digestion of Food Industry Wastes: Effect of Codigestion on Methane Yield," *Journal of Environmental Engineering*, vol. 131, no. 7, pp. 1037–1045, Jul. 2005, doi: 10.1061/(ASCE)0733-9372(2005)131:7(1037).

[34] J. D. Edwards, *Industrial wastewater treatment*. CRC press, 2019.

[35] L. Deng *et al.*, "Recent advances in circular bioeconomy based clean technologies for sustainable environment," *Journal of Water Process Engineering*, vol. 46, p. 102534, Apr. 2022, doi: 10.1016/j.jwpe.2021.102534.

[36] K. Obileke, H. Onyeaka, E. L. Meyer, and N. Nwokolo, "Microbial fuel cells, a renewable energy technology for bio-electricity generation: A mini-review," *Electrochem commun*, vol. 125, p. 107003, Apr. 2021, doi: 10.1016/j.elecom.2021.107003.

[37] D. Cecconet, D. Molognoni, A. Callegari, and A. G. Capodaglio, "Agro-food industry wastewater treatment with microbial fuel cells:

Energetic recovery issues," *Int J Hydrogen Energy*, vol. 43, no. 1, pp. 500–511, Jan. 2018, doi: 10.1016/j.ijhydene.2017.07.231.

[38] K. Rabaey and W. Verstraete, "Microbial fuel cells: novel biotechnology for energy generation," *Trends Biotechnol*, vol. 23, no. 6, pp. 291–298, Jun. 2005, doi: 10.1016/j.tibtech.2005.04.008.

[39] V. Sharma and P. P. Kundu, "Biocatalysts in microbial fuel cells," *Enzyme Microb Technol*, vol. 47, no. 5, pp. 179–188, Oct. 2010, doi: 10.1016/j.enzmictec.2010.07.001.

[40] Y. Song, L. Xiao, I. Jayamani, Z. He, and A. M. Cupples, "A novel method to characterize bacterial communities affected by carbon source and electricity generation in microbial fuel cells using stable isotope probing and Illumina sequencing," *J Microbiol Methods*, vol. 108, pp. 4–11, Jan. 2015, doi: 10.1016/j.mimet.2014.10.010.

[41] W.-W. Li, H.-Q. Yu, and Z. He, "Towards sustainable wastewater treatment by using microbial fuel cells-centered technologies," *Energy Environ. Sci.*, vol. 7, no. 3, pp. 911–924, Nov. 2013, doi: 10.1039/C3EE43106A.

[42] D. A. Jadhav, A. K. Mungray, A. Arkatkar, and S. S. Kumar, "Recent advancement in scaling-up applications of microbial fuel cells: From reality to practicability," *Sustainable Energy Technologies and Assessments*, vol. 45, p. 101226, Jun. 2021, doi: 10.1016/j.seta.2021.101226.

[43] R. J. Marassi, L. G. Queiroz, D. C. V. R. Silva, F. T. da Silva, G. C. Silva, and T. C. B. de Paiva, "Performance and toxicity assessment of an up-flow tubular microbial fuel cell during long-term operation with high-strength dairy wastewater," *J Clean Prod*, vol. 259, p. 120882, Jun. 2020, doi: 10.1016/j.jclepro.2020.120882.

[44] P. S. Parihar, S. Keshavkant, and S. K. Jadhav, "Electrogenic potential of Enterococcus faecalis DWW1 isolated from the anodic biofilm of a dairy wastewater fed dual chambered microbial fuel cell," *Journal of Water Process Engineering*, vol. 45, p. 102503, Feb. 2022, doi: 10.1016/j.jwpe.2021.102503.

[45] A. Faria, L. Gonçalves, J. M. Peixoto, L. Peixoto, A. G. Brito, and G. Martins, "Resources recovery in the dairy industry: bioelectricity production using a continuous microbial fuel cell," *J Clean Prod*, vol. 140, pp. 971–976, Jan. 2017, doi: 10.1016/j.jclepro.2016.04.027.

[46] B. Farizoglu and S. Uzuner, "The investigation of dairy industry wastewater treatment in a biological high performance membrane system," *Biochem Eng J*, vol. 57, pp. 46–54, Nov. 2011, doi: 10.1016/j.bej.2011.08.007.

[47] A. E. Franks, N. Malvankar, and K. P. Nevin, "Bacterial biofilms: the powerhouse of a microbial fuel cell," *Biofuels*, vol. 1, no. 4, pp. 589–604, Jul. 2010, doi: 10.4155/bfs.10.25.

[48] V. B. Oliveira, M. Simões, L. F. Melo, and A. M. F. R. Pinto, "Overview on the developments of microbial fuel cells," *Biochem Eng J*, vol. 73, pp. 53–64, Apr. 2013, doi: 10.1016/j.bej.2013.01.012.

[49] J. Jayapriya and S. N. Gummadi, "Scaling up and applications of microbial fuel cells," in *Scaling Up of Microbial Electrochemical Systems*, Elsevier, 2022, pp. 309–338. doi: 10.1016/B978-0-323-90765-1.00017-4.

[50] Y. Ruan, R. Wu, J. C. W. Lam, K. Zhang, and P. K. S. Lam, "Seasonal occurrence and fate of chiral pharmaceuticals in different sewage treatment systems in Hong Kong: Mass balance, enantiomeric profiling, and risk assessment," *Water Res*, vol. 149, pp. 607–616, Feb. 2019, doi: 10.1016/j.watres.2018.11.010.

[51] S. M. Henkanatte-Gedera, T. Selvaratnam, N. Caskan, N. Nirmalakhandan, W. Van Voorhies, and P. J. Lammers, "Algal-based, single-step treatment of urban wastewaters," *Bioresour Technol*, vol. 189, pp. 273–278, Aug. 2015, doi: 10.1016/j.biortech.2015.03.120.

[52] K. W. Chew, S. R. Chia, P. L. Show, Y. J. Yap, T. C. Ling, and J.-S. Chang, "Effects of water culture medium, cultivation systems and growth modes for microalgae cultivation: A review," *J Taiwan Inst Chem Eng*, vol. 91, pp. 332–344, Oct. 2018, doi: 10.1016/j.jtice.2018.05.039.

[53] K. B. Satyan, M. V. L. Chhandama, and D. V. Ranjit, "Usage of Microalgae: A Sustainable Approach to Wastewater Treatment," in *Biotechnology for Zero Waste*, Wiley, 2022, pp. 155–169. doi: 10.1002/9783527832064.ch11.

[54] P. Gani *et al.*, "Outdoor phycoremediation and biomass harvesting optimization of microalgae *Botryococcus* sp. cultivated in food processing wastewater using an enclosed photobioreactor," *Int J Phytoremediation*, vol. 24, no. 13, pp. 1431–1443, Nov. 2022, doi: 10.1080/15226514.2022.2033688.

[55] R. Sirohi, J. Joun, J. Y. Lee, B. S. Yu, and S. J. Sim, "Waste mitigation and resource recovery from food industry wastewater employing microalgae-bacterial consortium," *Bioresour Technol*, vol. 352, p. 127129, May 2022, doi: 10.1016/j.biortech.2022.127129.

[56] G. Yadav, I. Sharma, M. Ghangrekar, and R. Sen, "A live bio-cathode to enhance power output steered by bacteria-microalgae synergistic metabolism in microbial fuel cell," *J Power Sources*, vol. 449, p. 227560, Feb. 2020, doi: 10.1016/j.jpowsour.2019.227560.

[57] K. K. Jaiswal *et al.*, "Microalgae fuel cell for wastewater treatment: Recent advances and challenges," *Journal of Water Process Engineering*, vol. 38, p. 101549, Dec. 2020, doi: 10.1016/j.jwpe.2020.101549.

[58] A. Ferreira *et al.*, "Valorisation of microalga Tetradesmus obliquus grown in brewery wastewater using subcritical water extraction towards zero waste," *Chemical Engineering Journal*, vol. 437, p. 135324, Jun. 2022, doi: 10.1016/j.cej.2022.135324.

[59] N. Hamidian and H. Zamani, "Biomass production and nutritional properties of Chlorella sorokiniana grown on dairy wastewater," *Journal of Water Process Engineering*, vol. 47, p. 102760, Jun. 2022, doi: 10.1016/j.jwpe.2022.102760.

[60] A. Maalej, I. Dahmen-Ben Moussa, F. Karray, M. Chamkha, and S. Sayadi, "Olive oil by-product's contribution to the recovery of phenolic compounds from microalgal biomass: biochemical characterization, anti-melanogenesis potential, and neuroprotective effect," *Biomass Convers Biorefin*, Apr. 2022, doi: 10.1007/s13399-022-02640-9.

[61] A. W. Mohammad, C. Y. Ng, Y. P. Lim, and G. H. Ng, "Ultrafiltration in Food Processing Industry: Review on Application, Membrane Fouling, and Fouling Control," *Food Bioproc Tech*, vol. 5, no. 4, pp. 1143–1156, May 2012, doi: 10.1007/s11947-012-0806-9.

[62] S. Mallakpour and E. Azadi, "Nanofiltration membranes for food and pharmaceutical industries," *Emergent Mater*, vol. 5, no. 5, pp. 1329–1343, Oct. 2022, doi: 10.1007/s42247-021-00290-7.

[63] H.-B. Liu *et al.*, "Current and Future Use of Membrane Technology in the Traditional Chinese Medicine Industry," *Separation & Purification Reviews*, vol. 51, no. 4, pp. 484–502, Oct. 2022, doi: 10.1080/15422119.2021.1995875.

[64] A. Morelos-Gomez *et al.*, "Graphene oxide membranes for lactose-free milk," *Carbon N Y*, vol. 181, pp. 118–129, Aug. 2021, doi: 10.1016/j.carbon.2021.05.005.

[65] C. Baldasso, W. P. Silvestre, N. Silveira, A. P. Vanin, N. S. M. Cardozo, and I. C. Tessaro, "Ultrafiltration and diafiltration modeling for improved whey protein purification," *Sep Sci Technol*, vol. 57, no. 12, pp. 1926–1935, Aug. 2022, doi: 10.1080/01496395.2021.2021424.

[66] E. Díaz-Montes and R. Castro-Muñoz, "Analyzing the phenolic enriched fractions from Nixtamalization wastewater (Nejayote) fractionated in a three-step membrane process," *Curr Res Food Sci*, vol. 5, pp. 1–10, 2022, doi: 10.1016/j.crfs.2021.11.012.

[67] C. Garnier, W. Guiga, M.-L. Lameloise, L. Degrand, and C. Fargues, "Treatment of cauliflower processing wastewater by nanofiltration and reverse osmosis in view of recycling," *J Food Eng*, vol. 317, p. 110863, Mar. 2022, doi: 10.1016/j.jfoodeng.2021.110863.

[68] H. Kyllönen, J. Heikkinen, J. Ceras, C. Fernandez, O. Porc, and A. Grönroos, "Membrane-based conceptual design of reuse water production from candy factory wastewater," *Water Science and Technology*, vol. 84, no. 6, pp. 1389–1402, Sep. 2021, doi: 10.2166/wst.2021.326.

[69] J. Rubio, M. L. Souza, and R. W. Smith, "Overview of flotation as a wastewater treatment technique," *Miner Eng*, vol. 15, no. 3, pp. 139–155, Mar. 2002, doi: 10.1016/S0892-6875(01)00216-3.

[70] R. T. Rodrigues and J. Rubio, "DAF–dissolved air flotation: Potential applications in the mining and mineral processing industry," *Int J Miner Process*, vol. 82, no. 1, pp. 1–13, Feb. 2007, doi: 10.1016/j.minpro.2006.07.019.

[71] R. T. Rodrigues and J. Rubio, "DAF–dissolved air flotation: Potential applications in the mining and mineral processing industry," *Int J Miner Process*, vol. 82, no. 1, pp. 1–13, Feb. 2007, doi: 10.1016/j.minpro.2006.07.019.