Nutrient recovery from industrial waste water using microbial fuel cell technologies

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The disproportionate and accelerated growth of the population has led to the development of various sectors of industry and with it the discharge of waste water resulting from the different processes implemented, which has triggered pollution problems associated with the increase of nutrients in water bodies and soils, especially the presence of phosphorus and nitrogen. Excess nutrients promote eutrophication processes, which cause alterations in the biota, affecting biological diversity; as well as inhibiting photosynthesis processes and in turn, the decrease in free oxygen increases metabolic activity leading to an anaerobic environment that affects water quality.

However, within the industrial sector, phosphorus is a very important nutrient in the agricultural sector, since according to Kataki *et al.* (2016) it is used for the production of fertilisers, about 80 % of the phosphorus extracted globally is used for its production, 12 % is used in the detergent industry, 5 % in animal feed and the remaining 3 % in special applications such as in the technology industry, which is used in the form of phosphoric acid.

Considering that phosphorus is one of the most important nutrients for the growth of various organisms, but that its presence in substantial quantities in bodies of water such as lakes and rivers can stimulate the growth of algae and photosynthetic aquatic organisms causing eutrophication phenomena in these surface sources, phosphorus is also a non-renewable natural resource with a limited reserve (Huang *et al.*, 2017).

Therefore, research has focused not only on nutrient removal, but also on nutrient recovery, especially recovery from municipal and industrial waste water, which brings benefits such as alleviating the burden of increased fertiliser production and reducing the occurrence of eutrophication caused by excessive phosphate concentration in the released effluent (Ye *et al.*, 2017).

Among all the nutrient recovery technologies, Microbial Fuel Cell (MFC) technology is gaining importance due to the results obtained in early and initial stages of its development.

MFC utilise microorganisms to convert organic compounds into electrical power. MFC is currently considered a promising technology in the waste water treatment due to its production of electricity and waste water purification generation (Deng *et al.*, 2018). Generally, the MFC consists of an anode and a cathode chambers with a cation-exchange membrane (CEM) which is installed to separate them. In the anode chamber chemical energy stored in organics is directly converted into electricity by anaerobic microorganisms generation (Yang *et al.*, 2018). The ammonium ions can be transferred from the anode to the cathode chamber across the CEM through concentration-gradient-caused diffusion and current-driven migration. Regarding phosphate ions some options are available to transfer them: using the anode effluent as influent of the cathode chamber, different membranes and chambers configurations and/or photosynthetic organism application. As a result, ammonium salts are obtained in the cathode chamber through air stripping and later adsorption by acid solution in the cathode chamber after transformation of ammonium into ammonia due to cathode chamber pH increment. Moreover, phosphate ions could be recovered through chemical precipitation (Ye *et al.*, 2019). The precipitates are often found on the surface of the cathode electrode.

In recent years, various low-grade substrates are being treated in MFCs for energy generation (Khunjar *et al.*, 2012). Urban, industrial and agricultural waste water can be a potential resource of substrate as nutrient recovery for MFCs (Khunjar *et al.*, 2012). In the field of MFC research, a significant progress on the various aspects like understanding of electron exchange mechanisms and development of efficient biocompatible, low cost and robust electrode materials has already been done. However, there is a need for further development before using this technology to higher scales (Deng *et al.*, 2018). The main bottleneck of MFCs operation is the low power output due to high internal resistance, which limits the performance of MFCs generation (Logan *et al.*, 2006). Furthermore, high start-up time and costly materials used (membrane, electrode, and catalyst) in MFCs make them less economically viable (Yang *et al.*, 2018).

For improving the performance of the MFC system, it is imperative to distinguish the major influential factor that affects its efficiency, such as microbial community in the anodic chamber and the mediators, type of substrates and their concentration, electrode materials, type of CEM, operating conditions (pH, external resistance, temperature, ionic concentration, catholyte aeration flow rate, etc.) and MFCs design and configuration. In this regard, WalNUT will attempt to optimise those parameters from laboratory.

In this work a study of the nutrient recovery from waste water of different origin has been carried out with a double objective, on the one hand, to maximise the concentration of recovered nutrients and, on the other hand, to obtain a high quality final effluent.. The study of nutrient recovery and purification of the final effluent will be achieved using MFC technology. The design and construction of a lab-scale installation was performed by double chambers set-ups with 500 mL working volume of each one. Furthermore, different cylinder-shaped and brush electrodes was used. The influence of the main variables of the MFC process will be studied through this set-up. To this end, a DOE was defined and the effect of these variables (hydraulic retention time, electrode material, anaerobic conditions, electrode shape...) was quantified. The operating variables was optimised, not only to maximise the nutrient recovered and the quality of the final effluent, but also to ensure that the amount of energy generated by the MFC is as high as possible. Finally, the output effluent was characterised to quantify the main physical-chemical parameters and therefore its quality.

Results

After studying different configurations, nutrient recovery (both phosphorus and nitrogen) has been achieved using MFC technology. However, for the moment, the recovery yields obtained are lower than other microbiological processes (e.g. microalgae production). On the other hand, in all cases, the organic load of the waste water (COD) was significantly reduced, thus demonstrating that MFC is a valid technology not only for the recovery of nutrients but also for the treatment of waste water itself. Of the different types of waste water on which the MFC technology was tested, the one with the best results was the waste water from the dairy industry, specifically the one with a graphite electrode configuration at the anode and a platinum electrode at the cathode.

MFC is therefore a promising technology in the field of nutrient recovery and waste water treatment, although more knowledge and research is needed to make the technology competitive on a larger scale with other microbiological-based nutrient recovery processes.

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