Parchmentization process for low cost novel separator for whey protein treatment in microbial fuel cell

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Abstract

This study compared the performance of microbial fuel cells (MFCs) using parchment paper as a separator to a CMI7000 proton exchange membrane. The MFCs were operated in two chambers with whey solution as the substrate. Parameters such as COD removal, internal resistance, power density, current density, and Columbic efficiency ratio (CE) were evaluated. The CMI7000 membrane exhibited the highest COD removal at 92%, while the parchment paper achieved removal percentages ranging from 72–91%. The internal resistance was lower for the parchment paper separator for the first run, the internal resistances were 68 and 84 for parchment paper and CMI7000, respectively. The maximum energy densities were 219 mW/m (5.74 mA/m) and 421 mW/m (8.24 mA/m) for parchment paper and CMI7000 membrane, respectively. The CE values for parchment paper were 36.32 and 33.5, while for the CMI7000 membrane, they were 42.73 and 32.0, for the two runs. Overall, the study demonstrated that the parchment paper separator performed reasonably well in terms of COD removal, internal resistance, energy density, and Columbic efficiency ratio compared to the CMI7000 membrane in microbial fuel cells.

Introduction

Assuming an average energy content of 2 kWh m^{-3}, the 300 billion m^3 of domestic wastewater produced annually throughout the world contains about 600 billion kWh of organic matter. Thus, the recovery of the energy contained in these waste streams is an attractive opportunity to achieve a sustainable economy and lower the energy cost of wastewater treatment (Vivas et al. 2021). By generating power and oxidising organic materials in wastewater, microbial fuel cells (MFCs) have the potential to minimise the amount of energy needed for wastewater treatment. In an MFC, exoelectrogenic bacteria oxidise biodegradable organic matter at the anode in conjunction with an oxygen reduction reaction at the cathode to generate electricity (Abdulwahhab, Najim, and Abdulwahhab 2023)(Rossi et al. 2022). Direct one-step power may be recovered from wastewater for onsite usage through the MFC wastewater-treatment technology (Sovik Das et al. 2019)(Pérgola et al. 2023). Protons, electrons, CO_2, and a tiny amount of biomass are produced in the anodic chamber of MFCs through the anaerobic electrogenic bio-electrochemical oxidation of organic materials present in wastewater. Protons migrate across the proton-exchange membrane (PEM) towards the cathode in membrane-based MFCs owing to the proton gradient and combine with electrons in the cathodic chamber when oxygen or other terminal electron acceptors are present (Swati Das, Das, and Ghangrekar 2019). Electrons are caught by the anode. Challenges related to the sustainable field-scale deployment of MFCs include lower electricity-recovery efficiency(Penteado et al. 2018), expensive PEM and electrode materials like platinum, and nonlinear performance variation upon scaling up. In an effort to enable the practical field-scale deployment of MFCs, several studies have been conducted to identify low-cost electrode materials (Pasupuleti et al. 2016) and PEMs (Behera, Jana, and Ghangrekar 2010), which may bring the effective field-scale implementation of MFCs one step closer to fulfilment. (I. Das et al. 2020)

The increase in the types and amounts of organic contaminants in water has been of concern in recent decades (Abd-almohi, Alismaeel, and M-Ridha 2022). Whey is a by-product of the dairy industry and wastewater. Whey proteins and whey are well known for their great nutritional benefits, but they are also frequently discussed because of their high chemical oxygen demand (COD), which poses risks to the environment. Notably, treating huge amounts of sewage costs a substantial amount of money and energy, and the majority of the world's energy comes from fossil fuels, which pollute the environment and are rapidly running out of sources. Whey is produced on a global scale every year in quantities of around 1.1 million metric tons. Accordingly, scientists and researchers worldwide are seeking innovative techniques for treating wastewater and creating renewable energy given the limitations of using fossil fuels for electricity and the high capital costs of conventional wastewater-treatment technologies. One way is to use MFCs to turn whey into less complicated components and mitigate their harmful effects on the environment (Ghasemi et al. 2016). Typically, the high organic-matter concentration of effluents form the dairy sector is their distinguishing feature. The most extensively researched dairy waste is cheese whey. Although troublesome, high-pollutant dairy wastewater including product losses and process effluents must be handled individually. Despite the relatively high effectiveness of physicochemical procedures, the removal of the contaminant load is usually insufficient, and a biological process is required to finish the treatment. Comparing anaerobic digestion with dark and/or photofermentation and MFCs with the traditional dairy wastewater-treatment paths has revealed significant advantages. The importance of microbial materials in bioconversion follows, and it must be performed in accordance with the goals of treatment. *Candida*, *Klyveromyces*, and *Saccharomyces* strains are frequently used to remove the contaminant load from dairy wastewaters. Considering their biotechnological advantages, lactic acid bacteria are used. Some mixed cultures have also been shown to be potentially effective and useful treatments (Kasmi 2018).

PEM-CMI7000 is an essential part of an MFC because it helps with the proton transfer between the aerobic cathodic and anaerobic anodic chambers, as well as with their separation. Charge separation between the anode and cathode occurs as a result of proton transport via PEM, which then produces electricity. Since it has outstanding proton conductivity and is one of the most extensively utilised PEMs as same as Nafion but lower in cost, Nafion is regarded as one of the finest performing PEMs (Tota-Maharaj and Paul 2015). However, despite having a superior proton-transport capacity, this membrane cannot be scaled up owing to its extremely high cost, decreased proton selectivity, and anticipated fouling with time (Choi et al. 2011). Owing to their application in economic separation processes, research on different membranes has attracted considerable interest over the past three decades (Elsherif et al. 2014). Ion-exchange membranes have become the most sophisticated and cost-effective separation membranes in this area. These membranes are extensively utilised in the pharmaceutical field, sugar processing, beverage, and electrodialysis of seawater or brackish water, as well as in the separation of inorganic hazardous metal ions. Owing to their durability under various environmental conditions, inorganic precipitate membranes are frequently used as a model to study transport processes (Elsherif et al. 2014). Several types of membranes have been made utilising inorganic precipitates and supports/binders. These membranes are then used as models to examine the mechanism of ion transport and to check the accuracy of recently created membrane-potential equations (Elsherif et al. 2014). Vegetable paper, parchment paper, papyrus, or butter paper are some of the different names for this product, which has been around for over 150 years (Hubbe and Pruszynski 2020). Finest butter and cheese products are still packaged with parchment paper. Given that parchment paper lacks a nonstick surface, which is one of its distinguishing qualities, its use in baking is not advised. The Food and Drug Administration has authorised parchment paper for use at 232°C, but it can also be made with a silicone coating on both sides and has other physical qualities such as being water resistant, nonstick, and heat resistant. Additionally, it may be used in microwaves, ovens, refrigerators, and freezers (Report 2019).

The present study aimed to manufacture parchment-paper membranes for use as a separator in MFCs and to assess their properties. The novelty of this work focuses on the fabrication of prepared parchment paper (PPP) and its application in a two-chamber tubular MFC reactor and further comparison with PEM CMI7000 under identical operating conditions in the two reactor at the same time. MFC performance in terms of power density, internal resistance, ohmic resistance, COD elimination, and the percentage of coulombic efficiency (CE) were examined using the membranes as separators.

Materials and Methods

Construction and Reactor Design of MFC

Two reactors of the TTMFC were constructed as concentric cylinder MFCs with two chambers: an inner anode chamber and an outer cathode chamber, as shown in Fig. 1-B. These tubes were made of acrylic. The two identical reactor surfaces measured 1130.4 cm^2 (L = 30 and D = 12) and 1695 cm^2 (L = 30 and D = 18) for the anode and cathode chambers, respectively. Thirty long slots with dimensions of L = 18 cm and W = 0.6 cm were added to create more than

28% perforated area between the anode and cathode chambers. The first reactor's anode was covered in two layers of PPP as a separator, whereas the second reactor's anode was wrapped in one layer of leftover CMI (CMI7000) as a membrane. The anode and cathode electrodes were made of the four carbon fibre brushes; two of them served as cathodes and the other two served as anodes for the two chambers (Mill-Rose Lab Inc., OH, USA). All carbon fiber materials were organic polymers with lengthy chains of molecules joined by carbon atoms (Bhatt and Goe 2017). The projected surface area for both cathodes was double of the anode electrode, which was approximately 0.4 m^2. Carbon fibre brushes were pre-treated by soaking in 5% diluted HCl overnight, followed by 2.5 h of heat treatment at 450°C (Feng et al. 2010).

A stainless-steel wire 304 was used as a current collector from the anode to the cathode. Two equal-sized circular holes for perforated acrylic tubes were cut on one side of two acrylic sheets (12 and 18 cm in diameter). Once the tubes were placed in the grooves, they were glued with silicone gum to prevent leakage between anode and cathode. A rubber ring was used in the form of a rubber circle to close it appropriately from the top to prevent air leakage to the anode and for anaerobic digestion to proceed well. The tubes were connected to the sides of the reactor with screws and acrylic sheets, as shown in Fig. 1-A. All experiments were performed in the laboratory at room temperature of (25 ± 3°C).

Biofilm description and Culture inoculation

A biofilm is an accumulation of bacteria in a microbial community with many layers of intricate micro-colonies. By adhering to the glue-like material they emit, biofilms enable one or more bacteria species to coexist. A slime-like matrix made of polysaccharides and proteins holds biofilms together (Saeed et al. 2015)(Garbini, Barra Caracciolo, and Grenni 2023). The appropriateness of the surface and local climatic factors such as temperature and moisture content (Saeed et al. 2015) limit the colony's capacity to develop. After locating the ideal surface conditions, the cells attach and begin to divide into new cells, as shown in Fig. 2 (Abd-almohi, Alismaeel, and M-Ridha 2022).

Bacteria present in wastewater may directly create electrons without the aid of a third party because they transform the organic components in the wastewater into electrical energy. Their capacity to transmit electrons to the anode electrodes without the aid of an electron acceptor is another feature of these microorganisms. One of the most significant elements affecting the generation of electrical energy and the treatment of wastewater is the age and thickness of biofilms because they may stop the substrate from penetrating. The development of microorganisms on the electrode in the anode chamber is shown in Fig. 3. The adhesion of microorganisms to a mucilage-like material generated by bacteria is the initial step in the accumulation of germs on the electrodes. Owing to the suitability of the surface and the chamber's environmental factors, where the cells initially cling to one other before adhering to the electrodes, colonies develop bound structures on the electrode surface. A separated stage leaves a hollow mound behind, causing the biofilm to dissolve. SEM analysis may be used to identify these steps in the correct order (Fuel et al. 2018).

in Al-Rustumia The bacterial source for the MFC was collected from anaerobic sludge in a wastewater-treatment plant City, Baghdad, Iraq. The biofilm was prepared for one month before the main circle started. In an MFC, the formation of a biofilm on the anode surface is necessary for better biocatalysis and effective electron transfer. Nevertheless, several genera such as *Geobacter, Shewanella* and *Pseudomonas* are frequently found in mixed-culture MFC anodes and are connected with current production because they can generate current under axenic circumstances(A et al. 2020). Many phylogenetic groupings have been shown to be prominent in MFCs. Nevertheless, extremely varied communities have been found on anodes, conferring difficulty in estimating electrical-power generation performance through a microbiological ecology study. Notably, a number of studies indicate that cheese whey may be used to generate energy in MFCs, often with low CE (Wenzel et al. 2017).

Parchmentized Paper

Parchment paper, also known as baking paper or silicone-coated paper, is a versatile material commonly used in culinary applications and various other fields. It is known for its unique surface properties, which contribute to its functionality and usability. Understanding the surface characteristics of parchment paper is crucial for its effective utilization and to explore its potential in different applications. It is created from cotton fibre or pure chemical wood pulps known as parchment. Parchment paper is a premium paper that actually becomes stronger when wet, it is either greaseproof or grease resistant and can be coated or waxed. In baking, parchment paper is mostly used as a pan liner or to wrap food before cooking. In the current work, parchment-paper sample was prepared by soaking normal paper in a 30% sulphuric acid solution for 15 s and then in a neutral water bath used many times to remove all remaining sulphuric acid, followed by drying at 20°C and coating with silicone oxide. The strong acid made the fibres swell, creating a uniform plate. A mild ammonia solution was occasionally used to neutralise the sulphuric acid solution before passing it over the water bath. The sulphuric acid solution was used at 15–20°C for 10–20 s (Hubbe and Pruszynski 2020). Figure 3 shows the steps of the parchment process to show the paper’s appearance before and after processing. Manufactured parchment paper in the local markets was used for its low cost and ease of use.

Synthesis of cheese whey solution

Cheese whey, a liquid by-product with a high amount of organic matter made mostly of lactose and proteins, is a significant contaminant created during cheese making. Due to its abundance and high organic content it was used as a substrate for the MDC cell (Wenzel et al. 2017).

Raw cheese whey was prepared using 150 g of powdered milk (Al-Mudhesh) were mixed with 2.5 L of water. The mixture was then heated to 50°C, 15 mL of date 5% acetic acid was added, and solution heating was continued until the cheese chunks agglomerated. These chunks were removed from the cheese whey solution with a Whatman filter paper the remaining liquid is the whey protein solution and was ready to use as a substrate (Tremouli et al. 2013). The substrates for the anode chambers were produced by diluting 1 L of cheese whey solution with 1.5 L of tap water to give 7600 mg/L COD and 750 mL of cheese whey solution with 2 L and 2.5 L of water to give 3582 mg/L 1764 mg/L of COD respectively.

Operation of TTMFC

Prior to operation, the system was set up and prepped by making parchment paper using the procedure previously indicated. After that, the CMI7000 membrane was cleaned and activated by soaking it for a whole day in a weak 5% HCL acid solution. To expand and moisturize the membrane, it was thoroughly rinsed with tap water and then thoroughly with distilled water. After thoroughly washing it with water and soaking the carbon electrode in a dilute solution of 5% HCL acid for a full day, it was heated for a period of two to three hours at a temperature of 450°C before being transformed into a brush form to increase the surface area of the electrode. Before beginning the initial trials under anaerobic circumstances, the biofilm needed to be prepared in the second phase. After a sample was collected from the station, it was grown using MFC experiments for 30 days. The bacteria were fed prepared cheese serum at low concentrations (600–500 ppm) using prepared parchment paper, and the voltage obtained proved that the separating membrane is responsible for transporting protons. To guarantee conditions of saturation and dissolved oxygen, airflow rate in cathode chamber was 4.5 L/min for all tests. To avoid the growth of fungus, 20 ml of methylene blue were injected to the cathode chamber every five days.

In a batch process, artificial cheese water was employed as a substrate to feed the anode. As shown in the Table 1 the first and second runs operated using cheese whey with COD content (3528, 3528) and (7600, 1764) mg/L, respectively. In comparison to the lower concentration, the high concentration of synthesized cheese water included a much larger proportion of salt, which favored the transportation of ions across a membrane separator and by driving force in the electrochemical system. When the COD conversion for the OCV linked to concurrent substrate consumption reaches roughly 95%, a cycle is said to have ended.

Table 1
shows the kind of separator and initial COD concentration for the first and second runs.

Kinds of process	No. of reactors	Kinds of separators	No. of Runs	COD (ppm) concentration
Batch	Double	P.P.	1st Run	3528
		CMI7000		
	Single	P.P.	1st Run	7600
			2nd Run	1764

Measurement and analysis

The voltage (V) was recorded every one day in an open and close circuit using a HP-90EPC Multimeter (Digital USB Multimeter). Current (I) with respect to the applied external resistance (R_{ext}) was calculated using Ohm's law ($I = V/R_{ext}$). Anolyte samples were collected every single day to determine analyse COD by using the standard method (Jafary et al. 2020). CE was calculated for each cycle using the following equation for batch cycle (Kosanke 2019):

$$CE = \frac{Ms\int_{t1}^{t2} Idt}{Fzv\mathrm{An}\varDelta\mathrm{COD}} \ldots\ldots\ldots\ldots(1)$$

where M.wt is the molecular weight of the substrate; t_1 and t_2 are the initial and final times of each cycle, respectively; I is the current; F is Faraday's constant; v is the volume of anode z and is equal to 4 for the number of electrons exchanged per mole of oxygen (Ghasemi et al. 2017); and ΔCOD is the change in COD over a cycle. The electrical conductivities (ECs) and pH of the solutions in anode and cathode chambers were measured daily using an EC and pH meter (VIVOS PH and TDS meter Combo, 0.05ph High Accuracy Pen Type pH Meter ± 2% Readout Accuracy 3-in-1, UL-certified TDS EC Temperature Meter for Aquaculture, Household Drinking, and Hydroponics). Polarisation and power analyses were performed by applying seven different external resistances (100 000, 28 000, 1000, 565, 168, 51, and 10 Ω), and power density was calculated using Eq. 2.

$$P = (I.V)/A \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

where A is the geometric surface area, V is the cell voltage, and I is the current.

The power density of the MFC was calculated using the power-density peak method, which states that at the maximum power output, the internal resistance equals the external resistance, or R_{in} equals the external resistance (load), or R_{ext}, that must be connected to the MFC to achieve maximum power output (Kosanke 2019). The internal resistance of the system was calculated using the plot tangent for polarisation curve, and the slope of straight line from the inclined point to the end point was equal to the internal resistance (Jafary et al. 2020).

Results and discussion

Voltage and biofilm generation

Four acclimation cycles were performed during the MFC's start up to inoculate the anodic electrode with electrogenic bacteria in the two identical reactors. Each of the two cycles (Run) worked at the same time. same substrate concentration with a different membrane in first run and different substrate concentration with the same membrane in second run. All cycles utilised cheese whey as bacterial nutrient. An external resistance $R_{\mathbf{ext}} = 1000\ \Omega$ was connected to the MFC throughout each cycle after 16 days of open-circuit voltage (OCV). In the two MFC system cycles, the biofilm had one month to prepare before the main circle began. In the first run, the OCV started to increase gradually from the first day to the 6th day, then voltage stabilized and reached maximum values of 575 mV and 625 mV for the PPP and CMI7000 intervals on the 16th day, respectively. Likewise, in the second run using the same PPP separator and for the OCV, the low concentration curve started levelling up quickly in voltage until reaching 8th days, as results for the low resistance of anolyte concentration, while the high anolyte concentration curve started levelling up gradually and eventually reached 500 mV and 595 mV for COD levels of 1764 ppm and 7600 ppm, respectively, within 16 days, as indicated in Figs. 4, 5 and 6.

For the first run CMI7000 had higher voltage, due to its performance of proton transfer compared to parchment paper. Consequently, the voltage increased consistent with the results of many previous studies on dairy products using CMI7000 in batch operation. while in the second run for the same separator (P.P.) the higher concentration had higher voltage, this finding was due to the biofilm's growth with more substrate, i.e., more biofilm corresponded with faster digestion. (Munoz-Cupa et al. 2021) and (Khaled 2017).

SEM Observations

Micrographs were taken with a SEM system (FEI-company, Netherlands, inspect S50 (Model)). SEM were taken for parchment paper before and after the processes and for the carbon fiber after 30 days of preparing for bacteria growth and at the ends of the two runs. MFC fed with dairy products as nutrient the results for SEM for carbine fiber are shown in Figs. 7 and 8, after 30 days of preparing and 16 days of operation and by SEM noticed the carbon fibres were fully and unevenly colonised by bacteria, dense microbial clusters that were often exclusively found at the external electrode surface of fiber and have apparent formation materials. As indicated by Wenzel J. et al. (Wenzel et al. 2017), bacteria appeared to be in mixed cultures that were mostly *Geobacter* and *Pseudomonas* shaped. Notwithstanding the bio-anodes' characteristics, colonisation overall seemed to have produced positive consequences. As observed in MFCs with single or mixed cultures, MFC performance could still be substantially enhanced by inducing biofilm colonisation onto anodes. Figures 7 and 8 shows the different resolution images for bacterial growth on the outer surface of the carbon fibre, while Figs. 9 and 10 shows the different resolution images for parchment paper before and after MFC processes.

MFC Performance

For the MFC performance, the maximum power output comparison was higher for reactor with CMI7000 membrane (421.8 mV/m^2) than with parchment paper separator (219.6 mV/m^2), for the first run. For the second run with parchment paper separators for two different concentrations substrate (7600 and 1764 ppm), the MFC-PPP for the higher concentration provided more than double value of in power output for the lower one (Munoz-Cupa et al. 2021). It produced 364.4 mW/m^2 while the lower concentration 148.32 mW/m^2 (6.11 and 3.37 A/m^2, respectively$^)$. This finding was consistent with that of Bibiana C. et al., who studied three different types of waste, namely, apple juice, wine lees, and dairy wastewater. Anaerobic sludge was selected for the test because it is frequently used as an MFC inoculum, and it was used herein to examine each waste for its potential ability to create electroactive biofilms from its indigenous flora. When operating at peak efficiency, an MFC that had been compost-leachate infected and fed dairy waste produced a consistent power density of 44 mW/m^2 (with a maximum value of 92 mW/m^2 at 404 mA/m^2) (Cercado-Quezada, Delia, and Bergel 2010). This finding was related to the longer contact times between substrates and microorganisms, resulting in greater metabolic performance, which lowered the COD content and improved electron transfer. Consequently, the power output increased in the second run. Table 2 shows the maximum results for the first and second runs for two types of separator.

Figures 11 and 12 show the polarisation and power–current curves of the MFC using various membranes and at various concentrations for the first and second run, respectively.

For all comparison figure 13 shows the whole power curves and polarization curves for the two runs.

The polarization curve revealed to batch operation MFC-internal resistance for CMI7000 for the first run was 84.11 Ώ while for parchment paper it was 68.01 Ώ, While the internal resistance for the second run for the two reactors (7600 and 1764 ppm) was 69.10 Ώ and 61.03 Ώ respectively, as shown in Table 2. The increase in internal resistance in the second run was due to the high substrate concentration, where high concentrations of solution molecules formed from amino acids caused fouling on the surface of the membrane or separator, and this molecule obstructed the ion transport. Moreover, thinner membranes increased the permeability to oxygen and substrate, which significantly reduced the CE of MFCs as shown in Table 1,these results has been compared with another thinner membrane (Min et al. 2005). And CMI7000 had highest internal resistance due to its thickness compared to the thickness of parchment paper. As compared with other separators such as salt bridges (Min et al. 2005), CMI7000 (CEM) and Nafion 117 membranes frequently generate higher power densities and have lower internal resistance but these had approximately same thickness. However, because they provide nearly identical power densities, Nafion 117 and CMI7000 membranes operate similarly (Leong et al. 2013).

Table 2. shows the maximum results for the first and second runs using two kinds of separator and different concentrations of substrate.

	Rectors NO.	*Type of membrane*	*substrate concentration*	*max. voltage*	*max. power density*	*max. current density*	*max. COD removal*	*Columbic efficiency*	*Internal resistance*
			mg/l	**(mV)**	**mW/m^2**	**mA/m^2**	**%**	**%**	Ώ
1st run	1st reactor	P.P	3528	575	219.67	5.74	89.51	36.32	68.01
	2nd reactor	CMI7000	3528	625	421.84	8.24	92.06	42.73	84.11
2nd run	1st reactor	P.P	7600	595	364.41	6.11	76.32	33.50	69.10
	2nd reactor	P.P	1764	500	148.32	3.37	91.50	32.00	61.03

COD removal and CE

The first run of the second reactor, which used CMI7000 membrane and had a feeder amount of 3528 ppm, produced the highest removal of COD and CE in these experiments, yielding 91.06% and a CE of 42.73%, because of its superior ionic transport, CMI7000 has been shown to have a higher cell efficiency compared to the first reactor (Rahimnejad et al. 2014), While used P.P. as a separator and produced 89.51% and 32.36%, respectively. Regarding the second run, where the concentrations were different for the first and second reactors while using the same separator (parchment paper), the results with the lower primitive concentration (1764 ppm) gave more COD removal (91.50%/) and a lower CE 32.00, whereas for the first reactor, which had a concentration of 7600 ppm, the COD removal was 76.32 and a higher CE 33.5, all results shows in table 2 and Fig. 14. As the concentration of whey increases, there is an observed increase in Coulombic Efficiency (CE). However, when the whey concentration becomes excessively high, there is a decrease in CE due to blockage caused by the density of particles present in the liquid. This impedes the movement of protons across the membrane causing increasing in the internal resistance and slowing the removal of organic waste. Additionally, contamination on the surface of the membrane or separator can lead to increased acidity in the anode chamber. The acidic environment can negatively effect of bacteria the growth and keep it a life, which play a crucial role in the microbial fuel cell system. These results agree with previous research (Cecconet et al. 2018), (Nevin et al. 2008) and (Marassi et al. 2020).

Conclusions

MFCs with different membranes were tested and compared between a CMI7000 membrane and an inexpensive separator.

- The MFC results showed that the new produced waterproof parchment paper has a good energy density (364 MW/m^2) for the high concentration substrate, while the expensive CMI7000 membrane was the highest value for all experiments due to its high ability to conduct protons and all its results were high but for its thickness compared to parchment paper, the internal resistance was high.
- In addition, the PPP cost was 95% less expensive than the PEM-CMI7000.
- The results showed that MFC-PPP was a promising membrane for use in MFC and capable of further optimization for expanded use in other types of pollutant handling. Although the contaminants of dairy products yield relatively low efficiencies, the mixture of cultures may help to raise the energy density and CE, consistent with the results shown.
- A higher contaminant concentration of whey is consistent with a lower CE produced for the two types of membranes used.
- In conclusion, although there are obstacles to address, it is undeniable that parchment separator will play a significant role in the next generation of selective membranes, particularly in areas such as MFC, desalination, and water treatment.

Abbreviations

COD: chemical oxygen demand

MFCs: Microbial fuel cells

CE: columbic efficiency

Declarations

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Figures

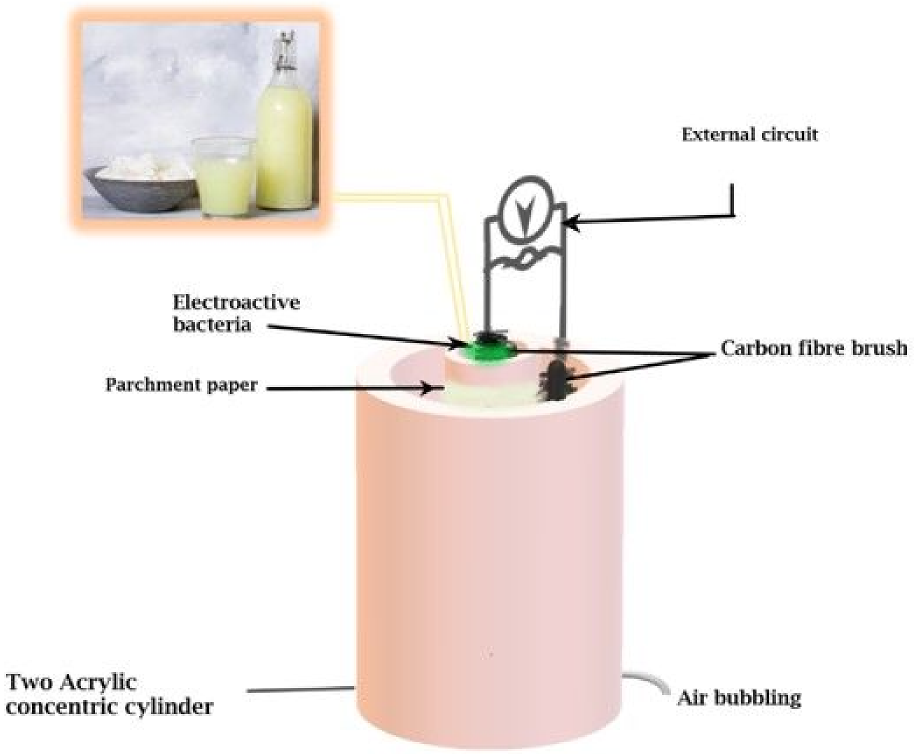

Figure 1

A) Construction of two reactors, B) schematic diagram of MFC reactor

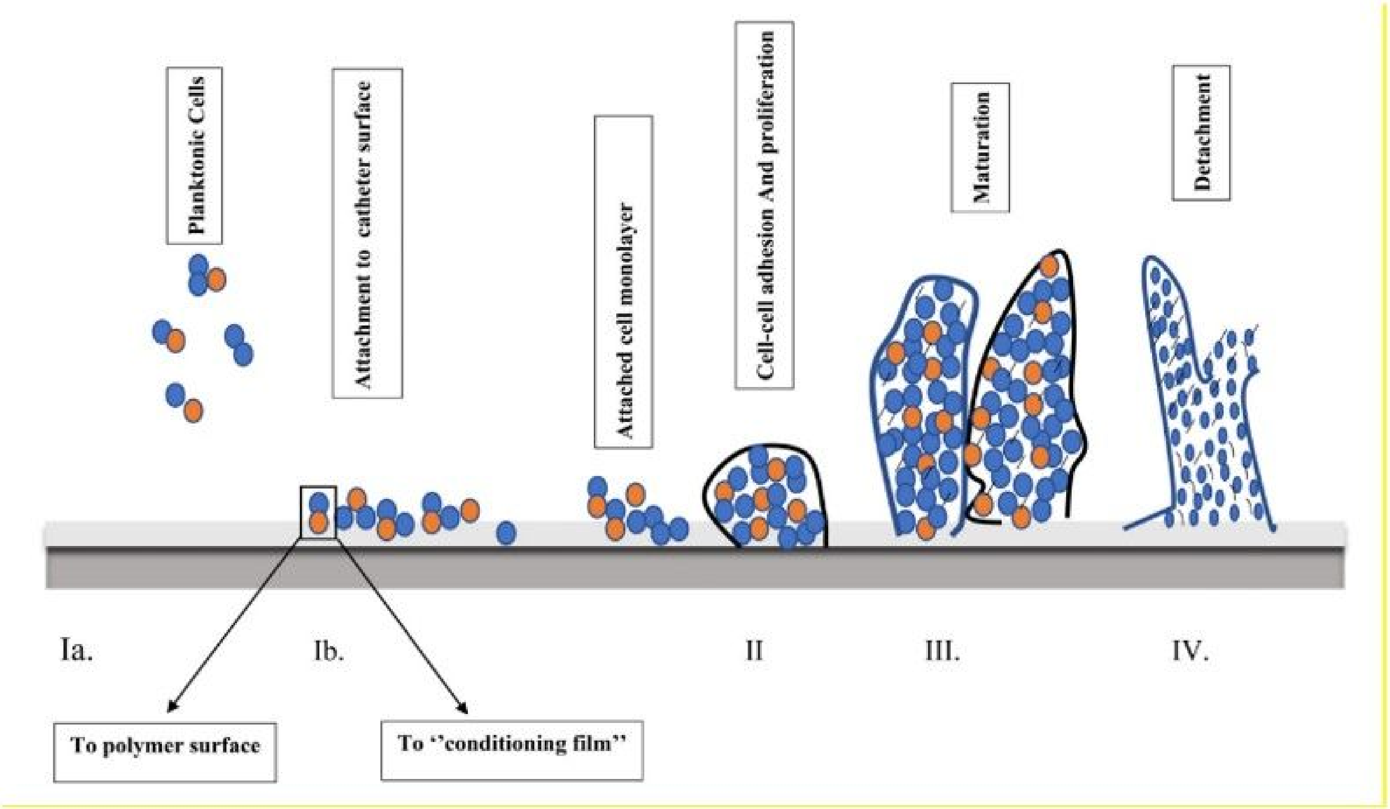

Figure 2

Biofilm stage formation onelectrodes surface (Abd-almohi, Alismaeel, and M-Ridha 2022)

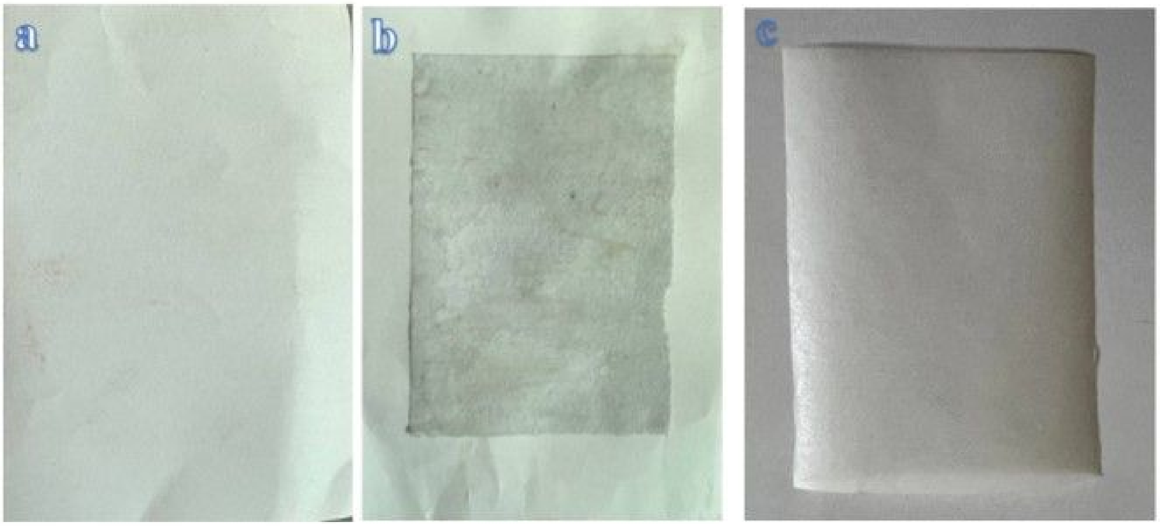

Figure 3

Parchmentizing Process for sheet of paper a) before using sulfuric acid b) after using sulfuric acid c) after coating with silicone oxide.

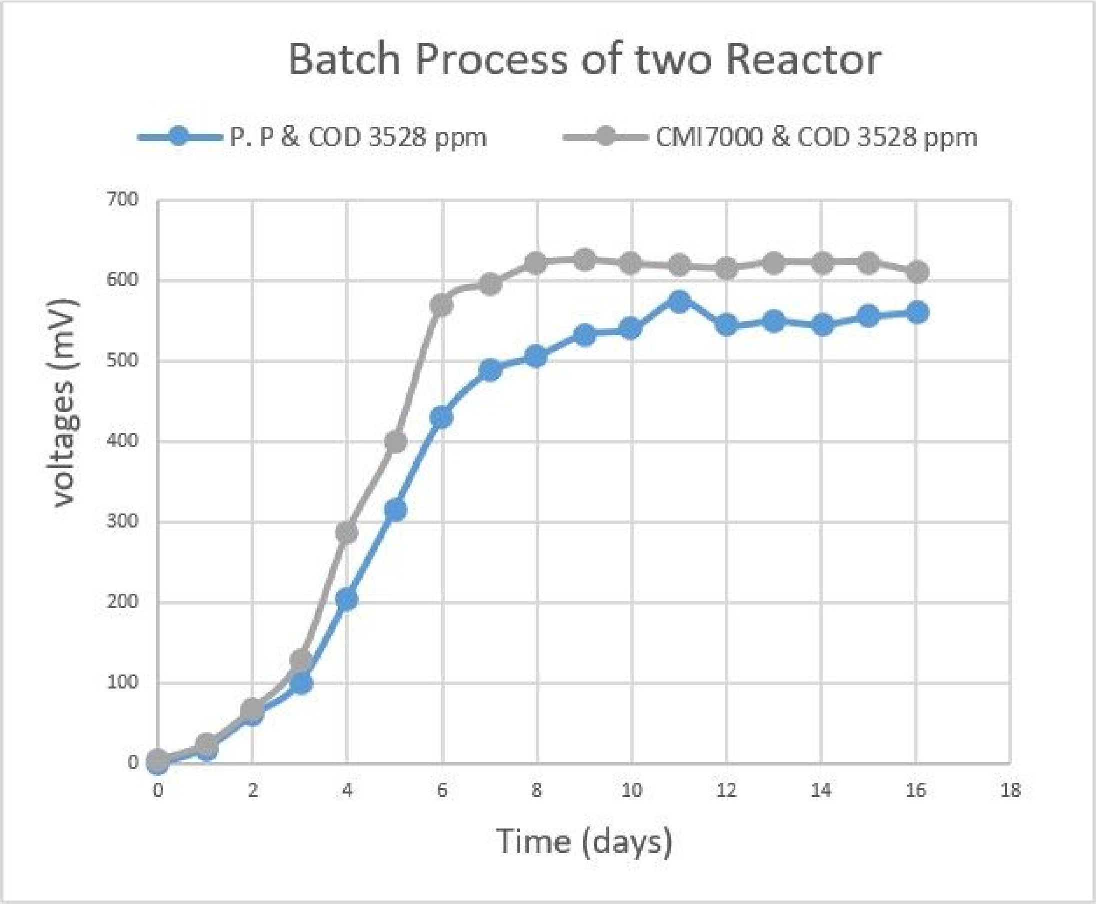

Figure 4

Response of potential with time for the first run of MFC in two reactors at the same substrate concentration and different membrane

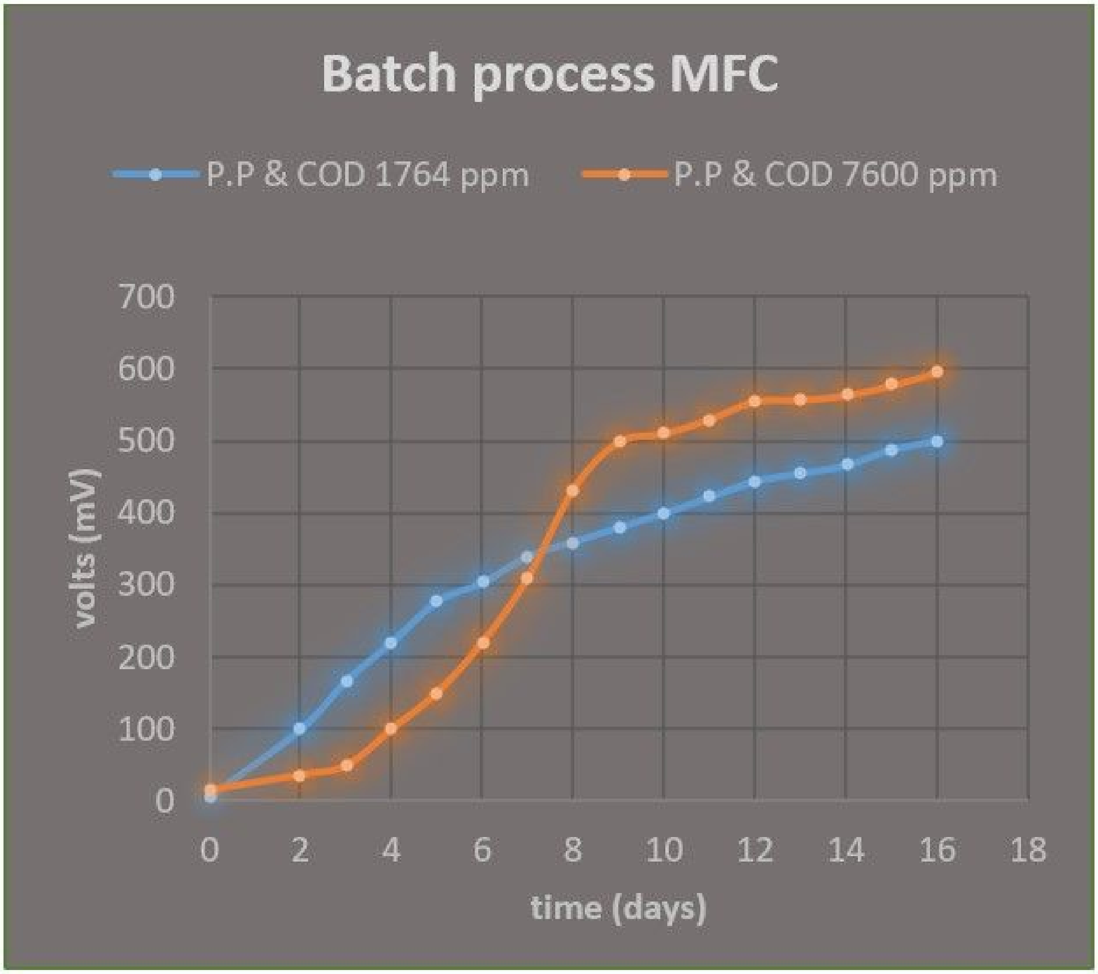

Figure 5

Response of potential with time for the second run of MFC in two reactors at the different substrate concentration and same separator

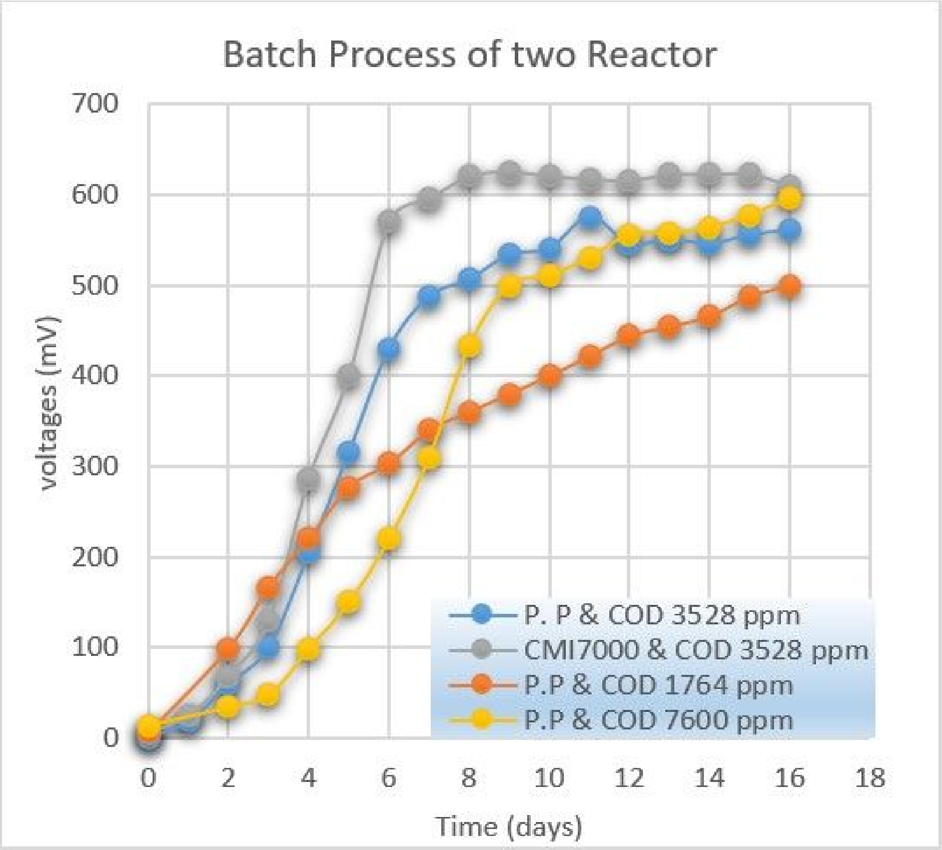

Figure 6

Response of potential with time for the first and second run of MFC

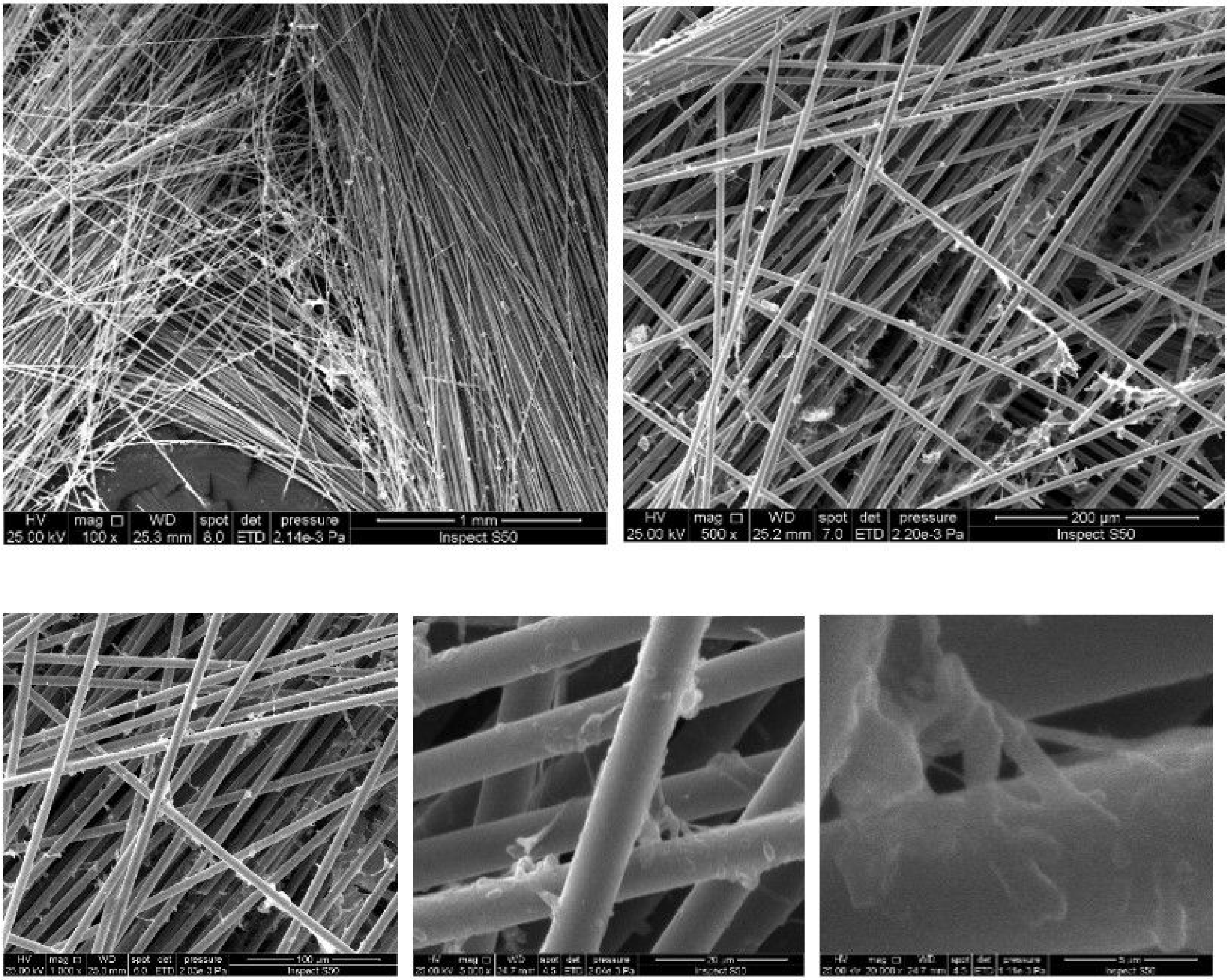

Figure 7

SEM images in different resolution for growth of bacteria on carbon fibre after 30 of preparation.

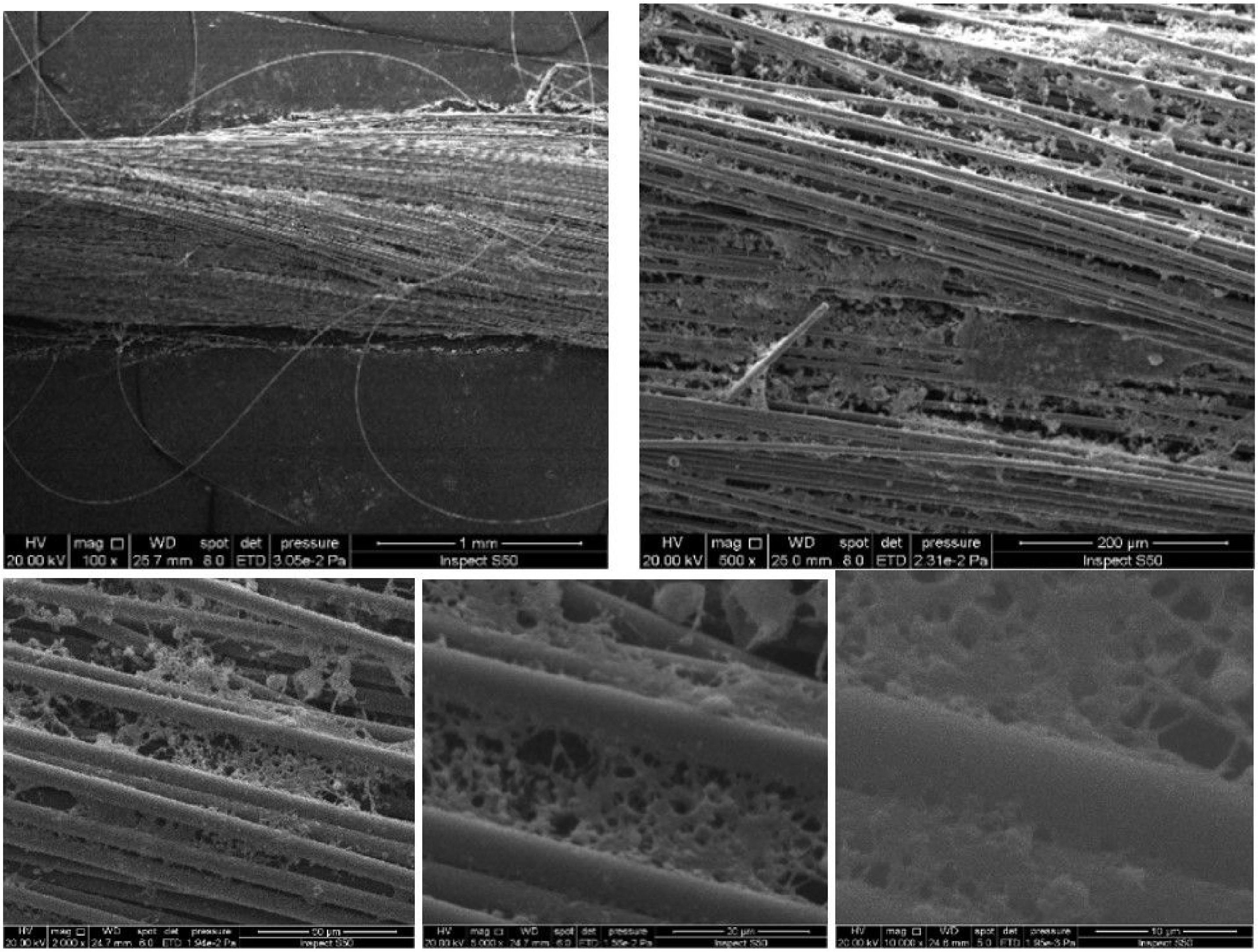

Figure 8

SEM images in different resolution for growth of bacteria on carbon fibre at the end of processes.

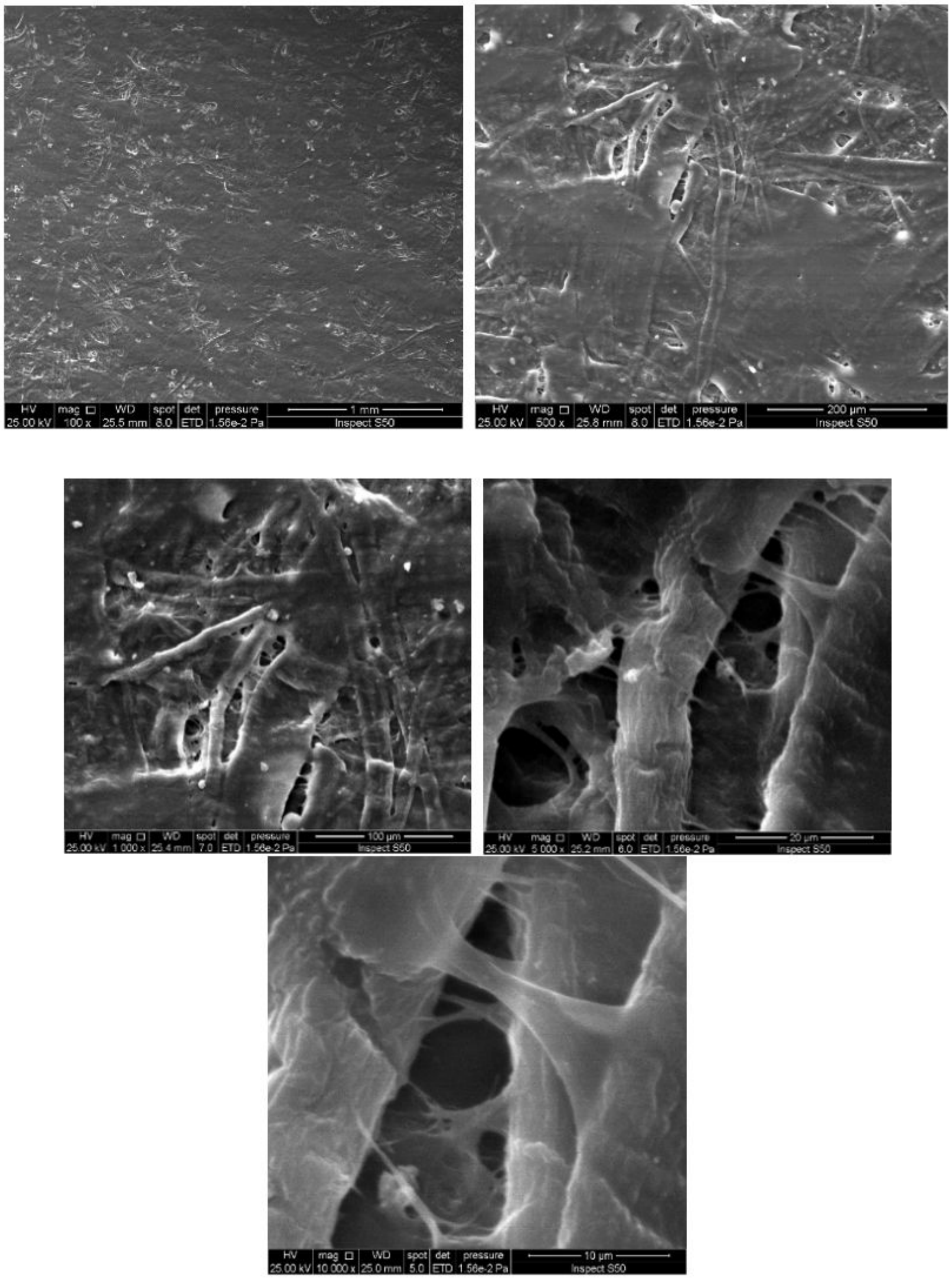

Figure 9

SEM images in different resolution for parchment paper before operation process.

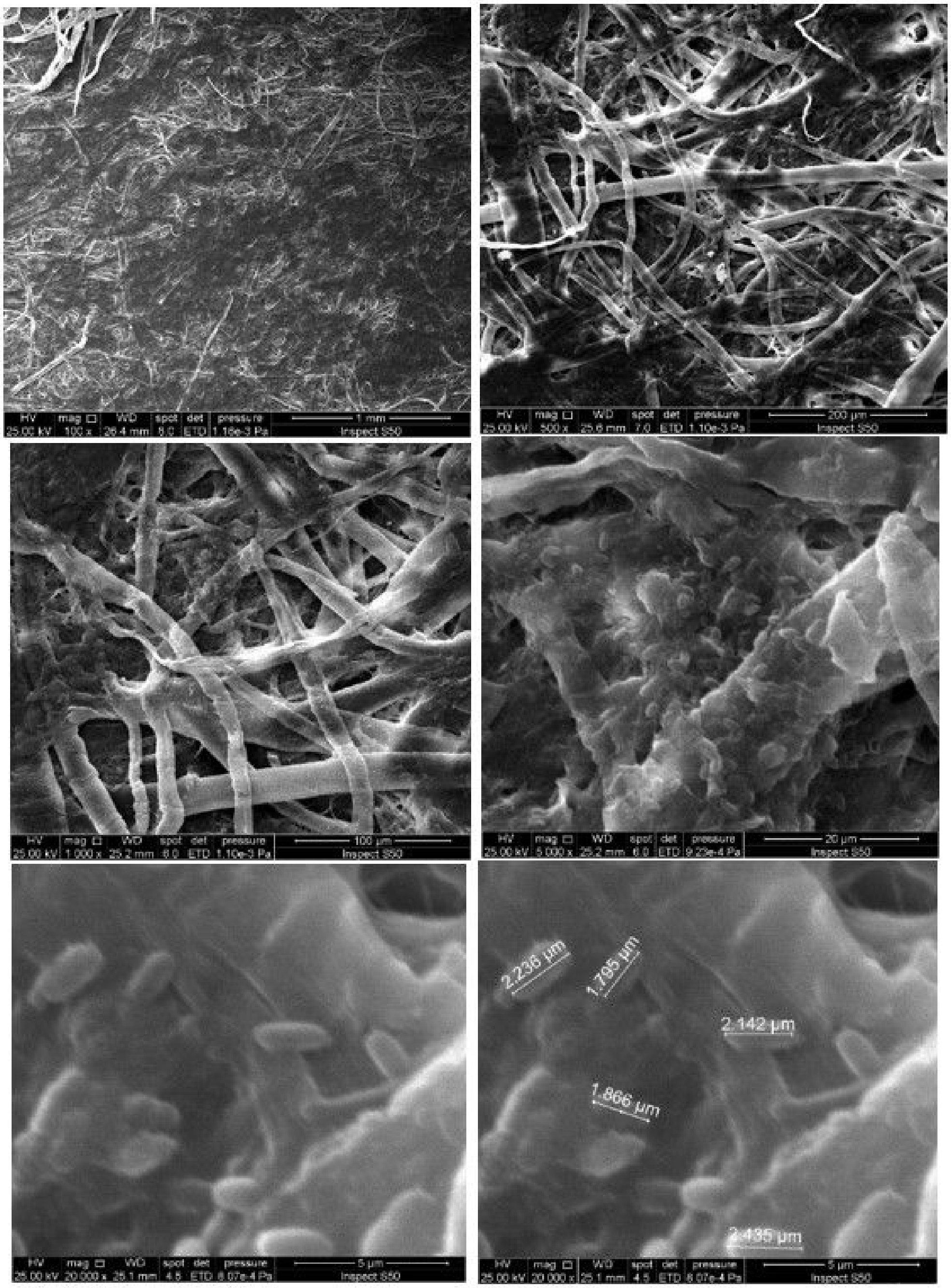

Figure 10

SEM images in different resolution for parchment paper after operation process.

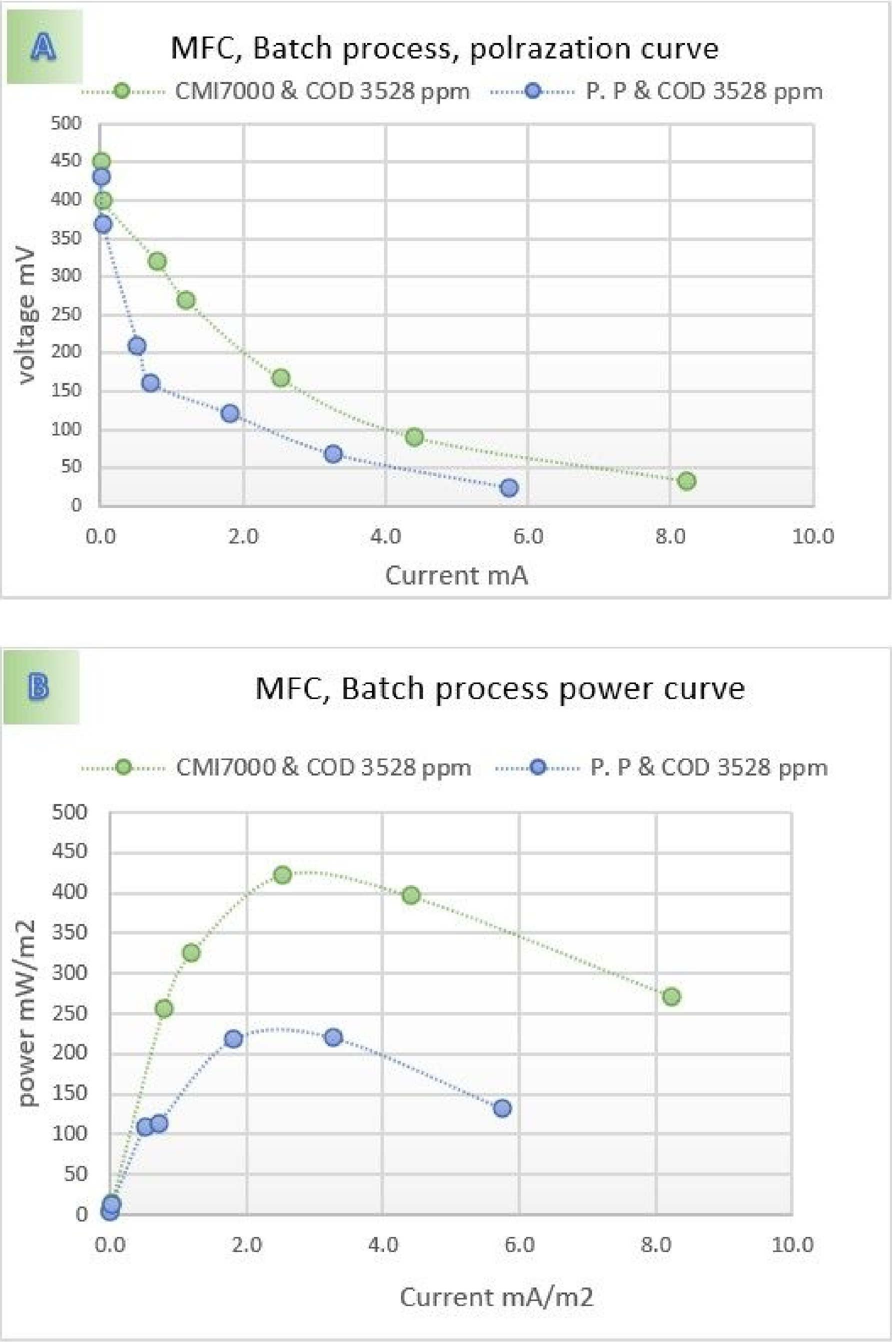

Figure 11

A) polarization curves B) MFC power density using CMI7000 and Parchment paper for first cycle when operated in batch mode

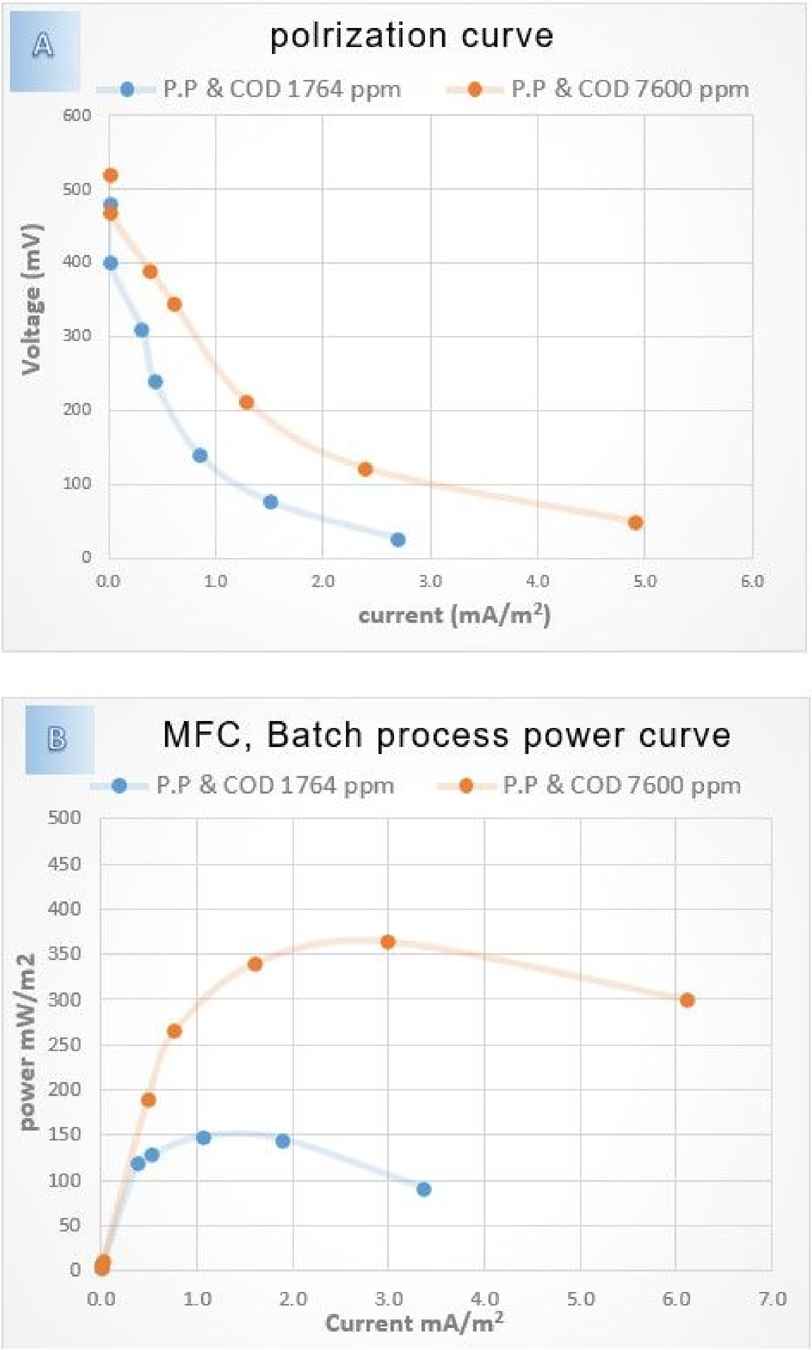

Figure 12

A) polarization curves B) MFC power density using Parchment paper as a separator for second cycle when operated in batch mode.

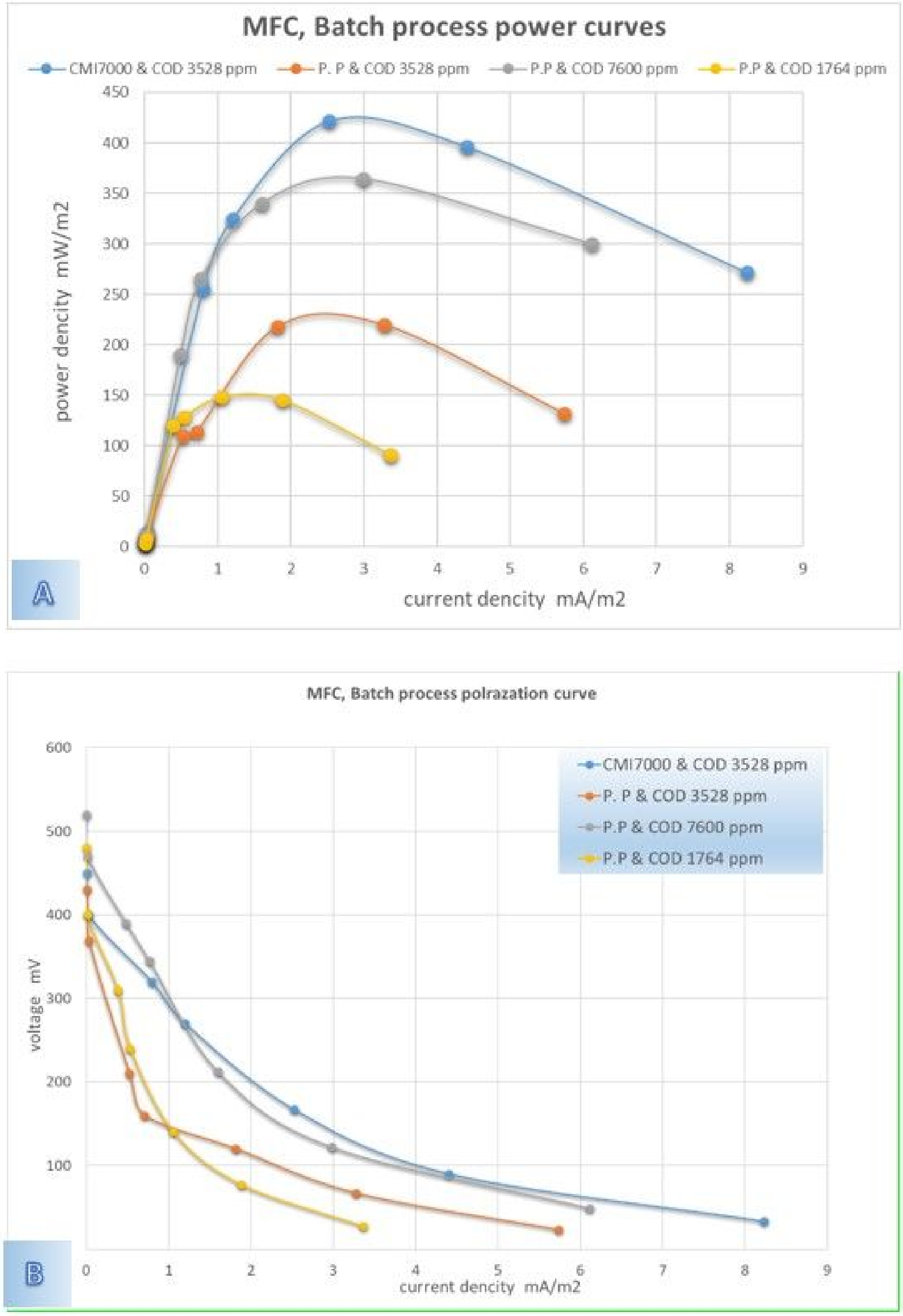

Figure 13

A) polarization curves B) MFC power density curves for two runs and for all comparison figure 13 shows the whole power curves and polarization curves for the two runs

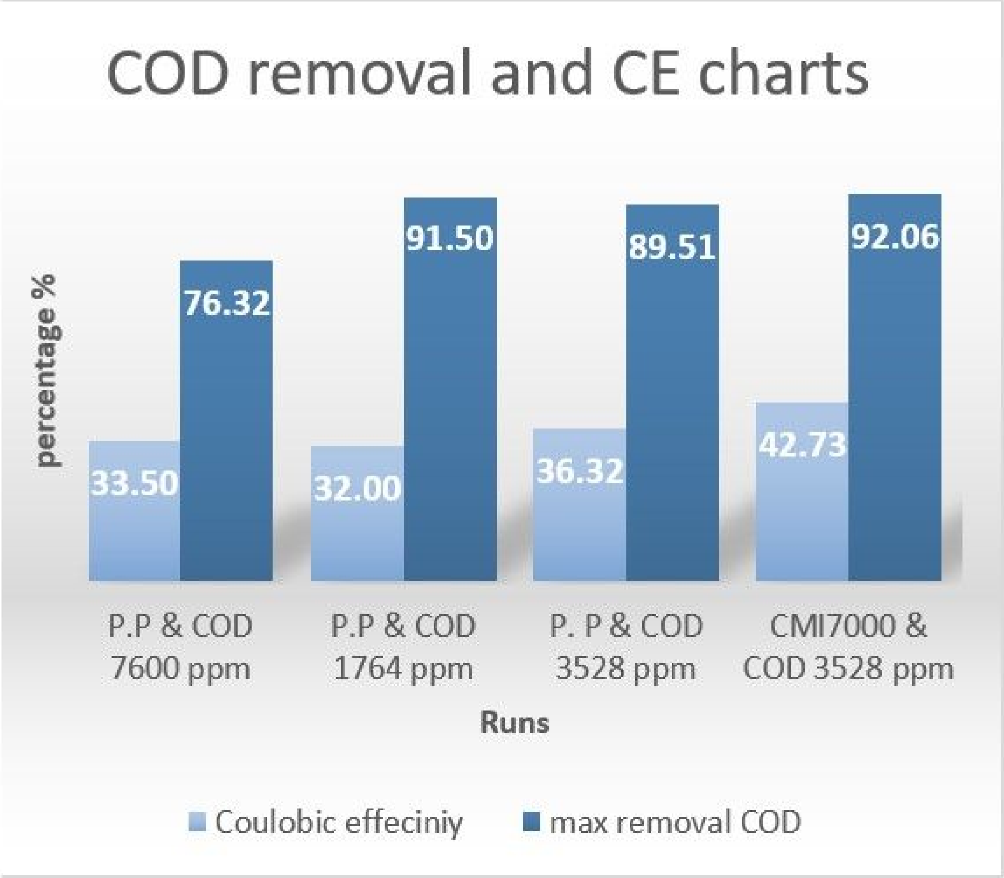

Figure 14

COD removal and CEs efficiency for two runs using CMI7000 and Parchment paper as separators.