EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2023, 24(1), 264–271
https://doi.org/10.12912/27197050/154921
ISSN 2719-7050, License CC-BY 4.0

Received: 2022.09.15
Accepted: 2022.10.19
Published: 2022.11.01

Reduction of Contaminants from Municipal Wastewater of Salori Sewage Treatment Plant Using Electrochemical Membrane Bioreactor and Bioelectricity Generation

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ABSTRACT

Membrane bioreactor (MBR) is stable and rising wastewater treatment reactor though membrane fouling and energy expenditure remain operational impediments and challenges for the wider deployment of the MBR technology. The majority of municipal wastewater contains low quantities of suspended, dissolved inorganic and organic particles. Proteins, carbohydrates, synthetic detergents, lignin, soaps, lipids and their decomposition products, along with many natural and synthetic organic chemicals from industrial processes, are also examples of impurities present in water. In addition, municipal wastewater contains a variety of inorganic chemicals, such as heavy metals, which might have phytotoxic and health consequences, limiting its usage in agriculture. In this study, an electrochemical membrane bioreactor (EMBR) has been developed to reduce several impurities from real municipal wastewater; moreover bioelectricity was also generated simultaneously. The maximum removal of biological oxygen demand (BOD), chemical oxygen demand (COD) and total dissolved solid (TDS) were 35.57%, 31.55%, and 32.84 %, respectively, after a 5-day experimental run.

Keywords: electrochemical membrane bioreactor, municipal wastewater, COD, BOD, TDS.

INTRODUCTION

The primary concerns confronting the globe now are environmental pollution and water, food, energy scarcity. Humans use natural resources irresponsibly and its over-exploitation has resulted in energy and resource crisis (McCarty et al., 2011; Vorosmarty et al., 2010). Human health and social development are also jeopardised by water contamination and the ensuing scarcity of water resources (Grant et al., 2012; Mo et al., 2013). As a result, it is crucial to recycle energy and materials from trash while producing new energy. While removing contaminants from contaminated water and getting tidy and recycled water, recuperating energy and other chemicals (like phosphorus and nitrogen) mixed in wastewater is in line with existing circumstances and requirement for attaining long-term development (Baker, 2010; Logan et al., 2012). Biological treatment method of wastewater treatment that depended on activated sludge has become extensively applied wastewater treatment technique after decades of development, owing to its steady process and excellent removal of organic pollutants (Shannon et al., 2008; Meng et al. 2009). However, due to their complicated procedure and disposal of sludge, huge energy consumption, low quality effluent and deficiency of nitrogen and phosphorus regaining processes, such conventional wastewater treatment processes still have severe techno-economic and sustainability constraints (Abegglen et al., 2008; Abels et al., 2013). As a result, in order to accomplish resource and energy recovery during treatment of wastewater, it is required to modify the recent wastewater biological treatment procedure from the standpoint of sustainable development (Agana et al., 2012; Ahmed et al., 2008).

The rapid advancement of membrane separation processes (MSP) and bioelectrochemical systems (BES), as well as their widespread usage in wastewater treatment, opens up the possibility of recovering water and other usable resources from wastewater (Akamatsu et al., 2010). However, various issues must be addressed before membrane separation technique can be widely used, such as high membrane material costs, relentless membrane fouling and high aeration energy utilization (Akamatsu et al., 2012).

At the same time, due of their restricted biomass retention, bioelectrochemical systems typically have low effluent quality and poor treatment efficiency for wastewater treatment, necessitating extra treatment with additional operating expenses (Al-Malack et al., 1996). It is possible that combining membrane separation technology with BES could provide a compelling choice for treatment of wastewater and nutrient, energy recuperation (Al-Malack et al., 1998; Ali et al., 2004). Such a coupling system may be able to address the disadvantages of MBR and BES for wastewater treatment, like BES's low organics and biomass removal efficiency, as well as MBR's expensive membrane cost and substantial membrane fouling (Alibardi et al., 2014; Asatekin et al., 2006). Figure 1 shows typical EMBR assembly and possible materials that can be used for its components (Ma et al., 2015). In this work, an EMBR has been designed for treatment of wastewater and simultaneous energy recovery, combining the benefits of membrane separation technology and bioelectrochemical systems.

MATERIAL AND METHODS

Reactor construction and operation

The reactor (as shown in Figure 2) in this study has cathodic and anodic chambers, each with a capacity of 100 mL. A square shaped carbon sheet (2 × 2 cm) was used as anode in the anodic chamber and a platinum mesh was used as cathode in the cathodic chamber using electrode holders, separated by nafion membrane as shown in Figure 3. Moreover, the work station of electrochemical system for this investigation is depicted in Figure 4. The municipal wastewater was collected from the inlet of the salori sewage treatment plant (STP) in Prayagraj (Uttar Pradesh, India). Nitrogen purging was done at regular intervals after the sample of wastewater was placed into the anodic chamber.

Analysis of water samples

The process consists of entirely filling a BOD bottle that has been sealed with para film polymer with water. This sealed BOD bottle will be kept in an incubator for 5 days at a particular temperature (20°C). A typical method for analysing water, the 5-days BOD test, is used to

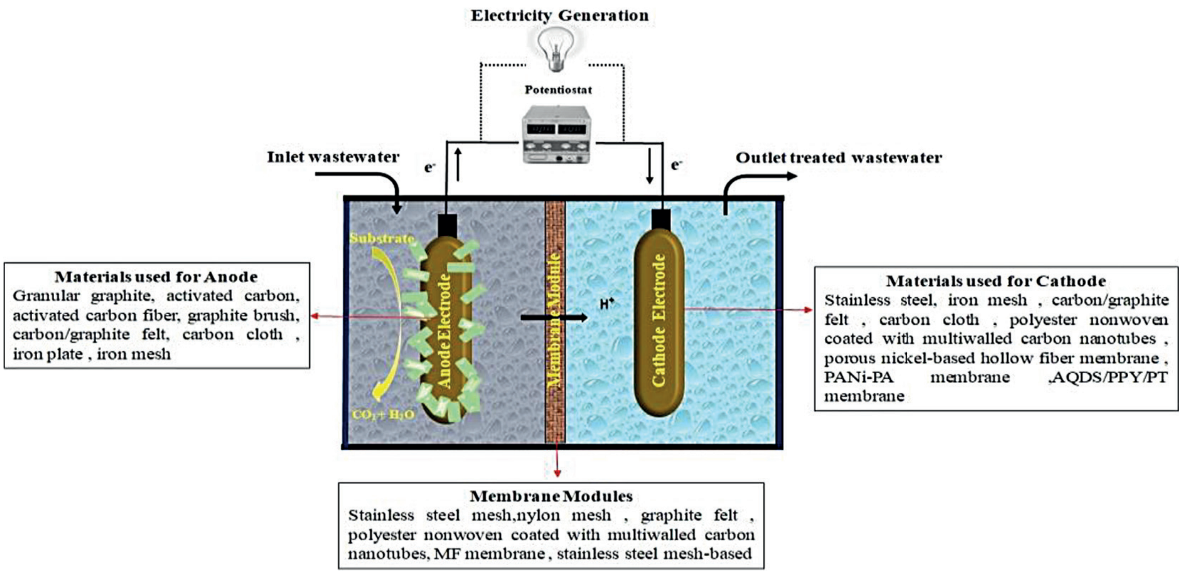

Figure 1. Schematic diagram of EMBR system

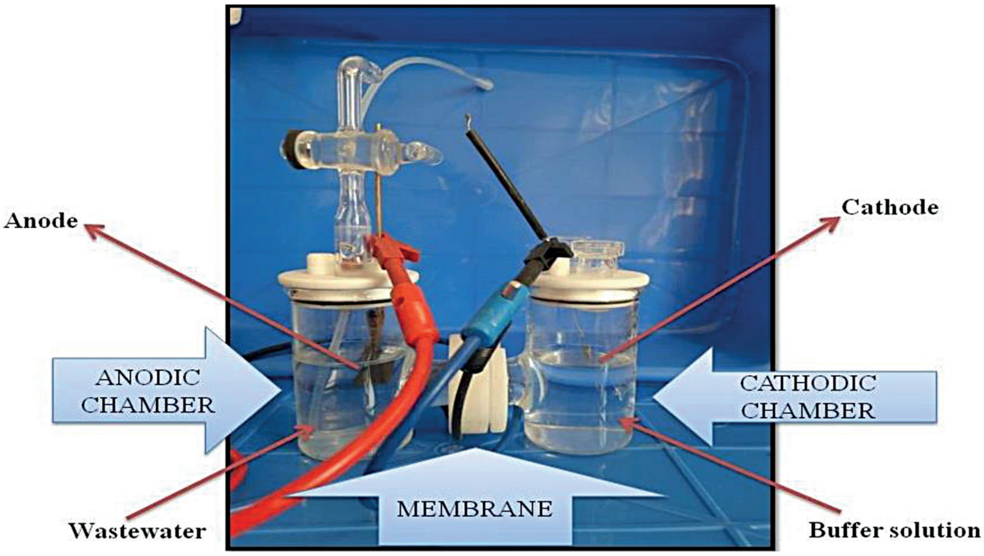

Figure 2. Experimental set-up of EMBR system

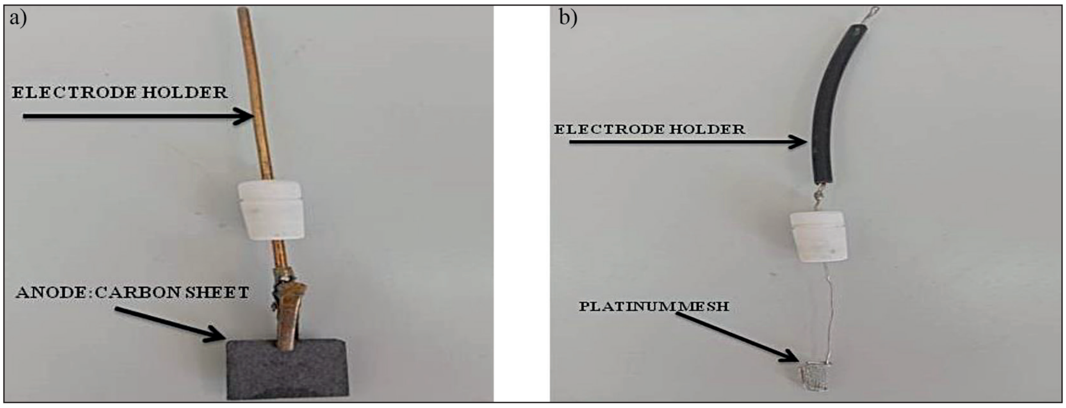

Figure 3. The component of EMBR system: (a) anode (carbon sheet) and (b) cathode (platinum mesh)

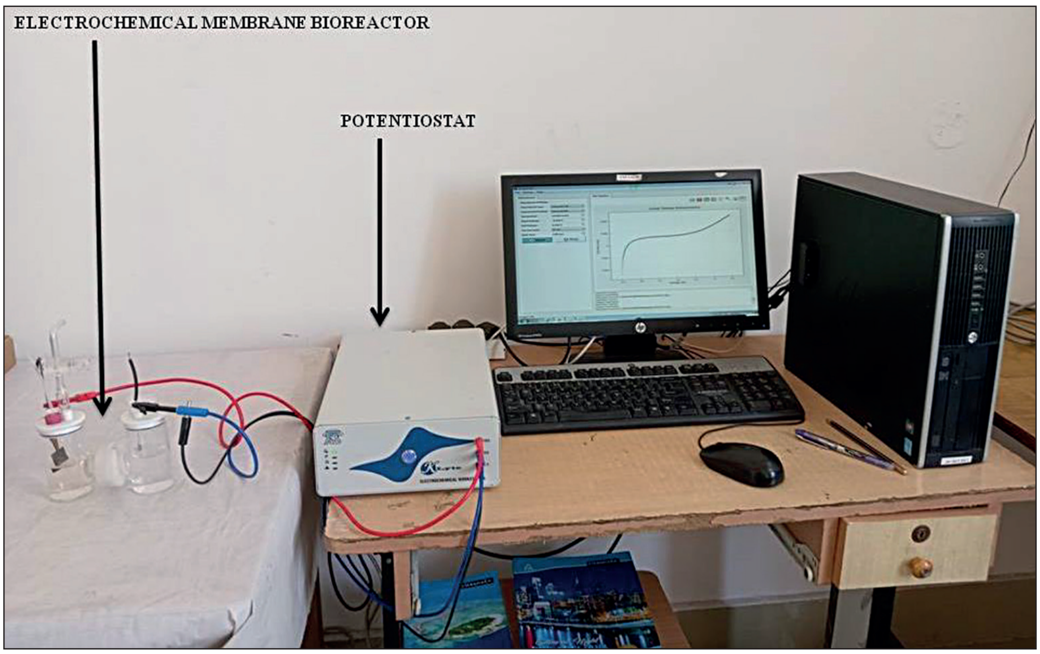

Figure 4. Experimental set up with EMBR and electrochemical potentiostat

determine the biological oxygen demand (BOD) for five days. To carry out this activity BOD incubator of M.K. Scientific Instrument was used. The technique of identifying that aerobic bacteria in water that act as decomposers of organic material can only do so if there is enough oxygen is done by the oxidation of organic compounds by K_2CrO_7 to reach 95–100%. Because oxygen serves as an organism's food source, the degradation process is hindered or simply leads to fouling when there is a lack of accessible oxygen as presented in equation 1.

$$(CH_2O)n + nO_2 \rightarrow nCO_2 + nH_2O + \text{microorganism biomass} \quad (1)$$

As more oxygen is removed from the water, the amount of oxygen in the environment decreases, disturbing the survival of aquatic species. The BOD value was determined using the following equation 2:

$$\text{BOD} = \frac{(\text{Initial DO} - \text{Final DO}) \times 300}{5 \text{ mL of sample}} \quad (2)$$

For carrying out COD analysis to preserve the test sample, concentrated H_2SO_4 is added until the pH is less than 2, and the sample is then kept in a cooler at 4°C for a maximum storage period of 7 days. 2.5 mL of distilled water and 5 mL of $K_2Cr_2O_7$ 0.1N were added to an Erlenmeyer flask, which was then allowed to cool to room temperature. Ferric ammonium sulphate (FAS) solution was titrated after 2–3 drops of ferroin indicator were added to the solution. COD level determination as per SNI 6989.73: 2009. A test tube containing 2.5 mL of sample, 1.5 mL of potassium dichromate, and 3.5 mL of sulfuric acid reagent solution was then filled. Once the sample is homogeneous, tightly seal the tube and shake it briefly. After being heated at 150 °C for two hours, the reaction tube was titrated with a 0.05 M FAS solution and three drops of ferroin indicator until a distinct colour change from green to reddish-brown occurred. To carry out digestion COD digester of Merck (TR 320) was used and UV-VIS single beam spectrophotometer (LMSPUV 1200) was used for measuring dichromate consumption during the process. The COD value can be calculated by the following equation 3:

$$\text{COD} = \frac{(A - B) \times M \times 8000}{V} \quad (3)$$

where*:* A – volume of FAS solution needed for blank (mL), B – volume of FAS solution needed for the test sample (mL), M – molarity of FAS solution, V – sample volume (mL).

TDS level was measured between 889 mg/l to 597 mg/l in this experiment using Labman multiparameter measurement device (LMMP 30) and the generated bioelectricity was determined using electrochemical potentiostat (KLyte 1.0) with start voltage of -0.5V and end voltage of 0.1V with sweep rate of 10 mV/s.

RESULTS AND DISCUSSION

The concentration levels of BOD, COD, and TDS were estimated based on standardised procedures utilising conventional analysis methods in order to evaluate the quality of wastewater collected from the STP. Based on the initial reading of the obtained water sample, the percentage elimination of contaminants was calculated at regular intervals during the experimental process. Figure 5 depicts a comparison of BOD, COD, and TDS reduction levels. Figures 6, 7, and 8 show the level of BOD, COD, and TDS reduction day by day, as well as the percentage of BOD, COD, and TDS removal, respectively.

Effect on BOD

BOD concentrations in municipal wastewater sample collected from STP was initially 319 mg/L. To reduce BOD level, the experiment was run in a batch reactor for 5 days. For 24 hours of testing, the BOD level was reduced to 291 mg/L (i.e. 6.73 % reduction of BOD), as shown in figure 6. After 48 hours of experimental run, the BOD level was dropped to 249 mg/L, indicating that 20.19 % of the BOD has been removed. Similarly, water samples were tested at 72, 96, and 120 hours, and BOD levels was reduced to 219 mg/L, 211 mg/L, and 201 mg/L, respectively resulting in day-by-day BOD removal percentages of 29.80 %, 32.37 %, and 35.57 %, respectively. The organic and inorganic materials present in the wastewater as pollutant get consumed by the bacteria that colonise the EMBR's anode, hence causing reduction in BOD value (Pierangeli et al.,2021). It was observed that the BOD removal efficacy of the current set-up was on lower side as compared to the other studies (Matsubara et al.,2020; Ragio et al.2021) that might be due to low concentration of refractory compounds in wastewater, that causing

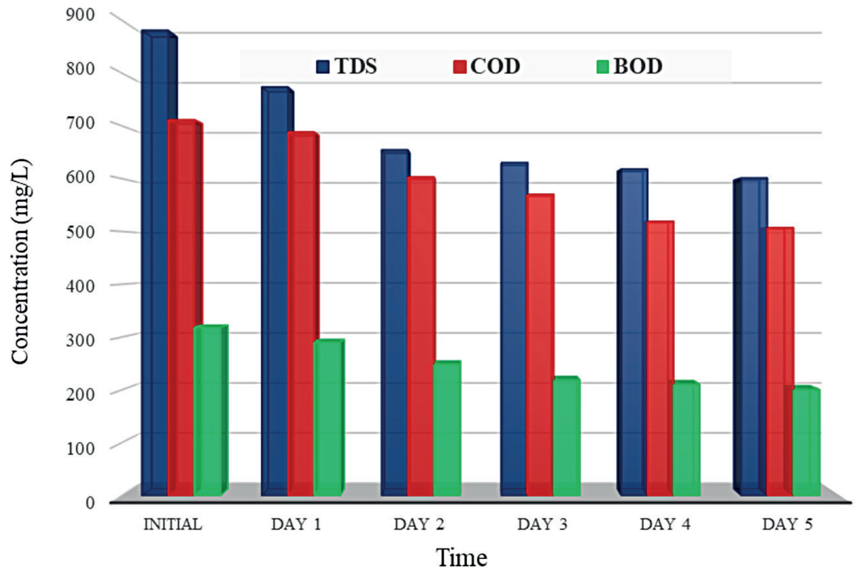

Figure 5. Comparative chart for removal of BOD, COD and TDS from municipal wastewater collected from STP Salori

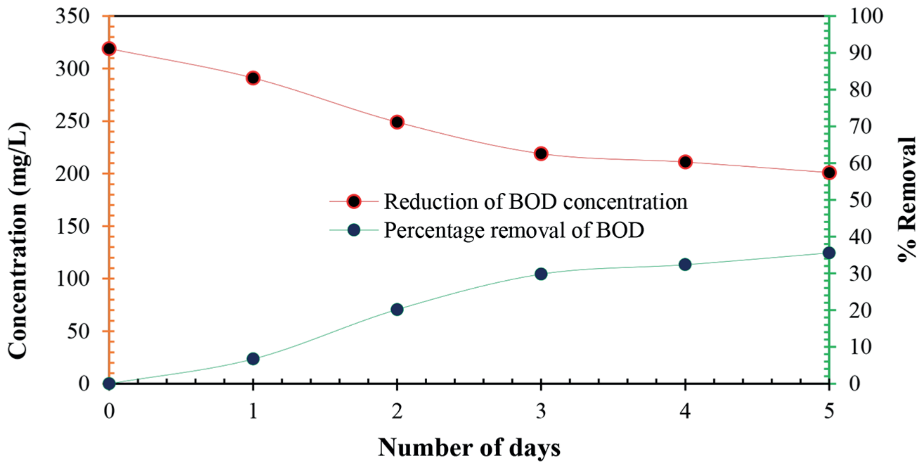

Figure 6. Effect on BOD concentration in EMBR system

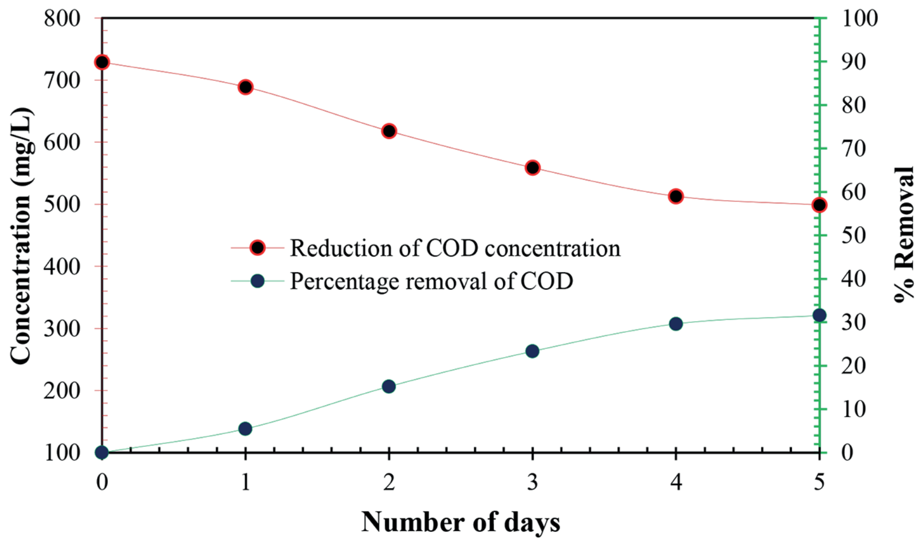

Figure 7. Effect on COD concentration in EMBR system

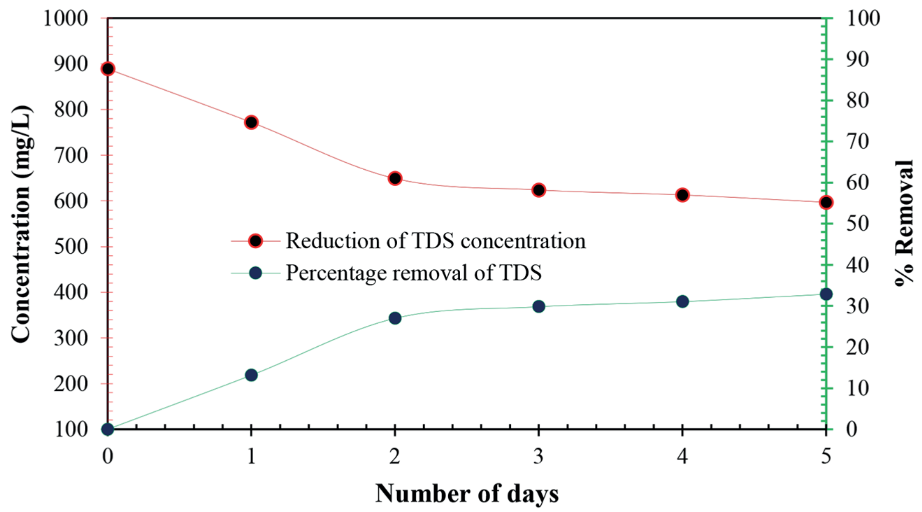

Figure 8. Effect on TDS concentration in EMBR system

inhibition of organic matter by bacterial species (Gabrielle et al.,2022). Although the BOD removal efficacy of the EMBR was on lower side concentration expected at for a MBR, which is ≤ 5 mg/L (Guowang et al., 2015).

Effect on COD

The COD level in the municipal wastewater sample collected was 729 mg/L. Figure 7 shows that after performing the experiment for 24 hours, 5.48% of COD was removed, resulting in a COD level of 689 mg/L. After 48 hours, a water sample was taken and the COD level was found to be 618 mg/L (15.23% removal of COD). The bacteria that inoculates at the EMBR's anode consumes organic debris, lowering COD. Similarly, after 72, 96, and 120 hours of experimental run, COD levels were found to be 559 mg/L, 513 mg/L, and 499 mg/L, respectively, resulting in day by day percentage removal of 23.32%, 29.63%, and 31.55%, respectively (Ma et al., 2015). Similarly, up to 31.4% COD removal was observed in the anodic chamber of overflow type EMBR at shorter HRT of 4.2 h. It was observed that electroactive bacteria was responsible for COD metobolization along with formation of electricity (0.41–1.03%) (Guowang Zhou 2015; Su et al., 2013).

Effect on TDS

TDS was 889 mg/L in the wastewater sample that was collected from STP. After running the experiment in EMBR for 24 hours, it was reduced to 772 mg/L, indicating a 13.16% reduction. After 48 hours, a water sample was examined for TDS level, which was found to be 649 mg/L (i.e., 26.99% removal of TDS). The consumption of pollutants by bacteria present at the anode is the reason for TDS reduction,since BOD and COD are reduced TDS is also reduced. As indicated in figure 8, samples were examined at 72, 96, and 120 hours, with lower TDS levels of 624 mg/L (29.80% removal), 613 mg/L (31.04% removal), and 597 mg/L (32.84% removal), respectively.

Generation of electricity

Electrochemical membrane bioreactors (EMBRs) has been developed using a combination of electrochemical and membrane technologies to recuperate energy from contaminated water while collecting treated water for reuse. The bacteria consumes the substrates, leading the anode to transfer electronsr. Electrons are carried to the cathode by the electrodes and external circuit, where they were mixed with oxygen from the air and protons diffused from the anode. A potentiostat KLyte 1.0 was used to measure the electricity generated by the movement of electrons created by bacteria's metabolic activities (Wang et al. 2013). Figure 9 depicts the generation of electricity using a linear sweep voltammetry (LSV) graph from day 1 to day 5. Bioelectricity generation was found to be 0.00286 mA at 24 hours, 0.00303 mA at 48 hours, 0.00336 mA at 72 hours, 0.00334 mA at 96 hours, and 0.0029 mA at 120 hours, respectively. Comparision of day to day generation of electricity and it rise and fall because of metabolic activity of bacterium as shown in Figure 9.

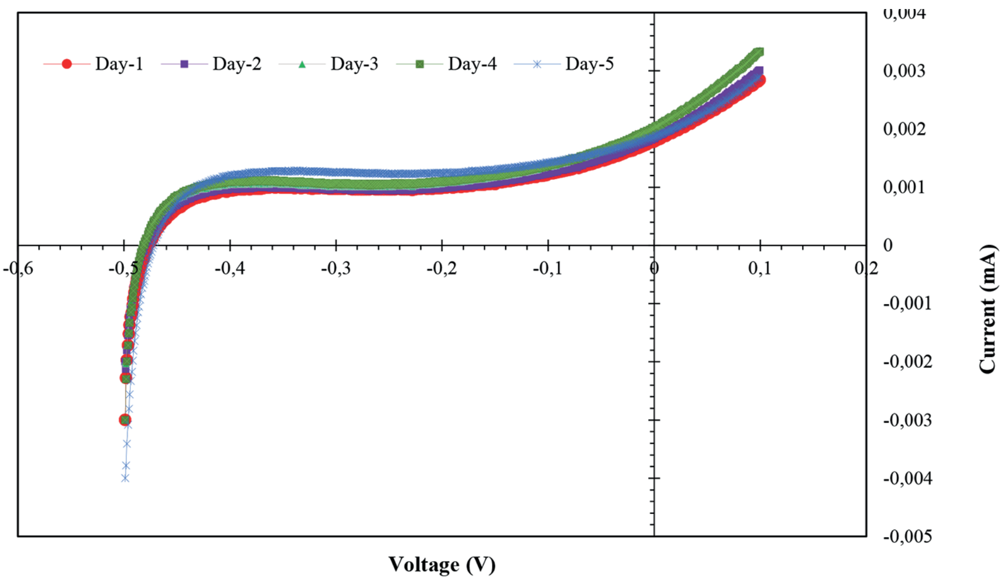

Figure 9. Comparison of bioelectricity generation from municipal wastewater collected from STP Salori

CONCLUSIONS

In a batch procedure, municipal wastewater was treated with an electrochemical membrane bioreactor (EMBR). The experiment was run continuously for 5 days, with a sample taken every day for analysis. The maximum elimination after 5 day of experimental run BOD, COD and TDS were 35.57%, 31.55%, and 32.84%, respectively, according to the experimental data obtained. Furthermore, the maximum current value of 0.00336 mA was generated as a result of the metabolic activities of bacteria present in municipal wastewater, which gradually decreased day by day as the bacteria decayed. Hence, EMBR system is a potential technology for wastewater treatment and bioelectricity generation at the same time.

Acknowledgements

This study is reported in part and partial of the Science and Engineering Research Board (SERB) sponsored research project title "Development of a novel electrochemical membrane bioreactor (EMBR) for the treatment of low strength municipal wastewater and generation of sustainable bioelectricity simultaneously". The authors would like to express their gratitude to SERB, India (Sanction order no. EEQ/2019/000395 dated 19/12/2019) for their financial support and assistance in carrying out this research work.

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