Article

Developing and testing lab scale microbial fuel cell for energy harvesting from wastewater

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Abstract

Bioelectricity can be harvested from organic substrates using Microbial Fuel Cells (MFC) that operate on the principle of oxidation reduction (redox) reactions. MFCs are devices which convert chemical energy into electrical energy by oxidation process of various organic wastes. MFCs produce electricity in the presence of microorganisms from biodegradable substances. This research explores the application of double chamber MFC in generating electricity using tab water and waste water mixed with slurry. Salt NaCl, egg and tomato were used as protein exchange membrane in salt bridge and voltage was recorded at the interval of 16hr with the help of multimeter. Maximum voltage recorded at 32hr using salt NaCl, tomato and egg was 154 mV, 195 mV and 240 mV. Based on the result of different types of exchange membranes it was found that the average voltage generated with egg as exchange membrane was 1.35 mV and 1.25 mV times greater as compared to tomato and salt NaCl. This study suggested that microbial fuel cell is applicable for energy harvesting.

Keywords microbial fuel cell; voltage; salt bridge; electrodes.

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1 Introduction

Recent rise in energy costs, rapidly dwindling crude oil supplies and concern over the negative effects of carbon emissions have reignited both public and private interest in finding cheap alternative renewable energy sources. Different types of alternatives technologies are being discovered to solve this issue with the consideration that they are sustainable. There are many environmental concerns connected with fossil fuel burning which after oxidation processes release greater amount of carbon contents in atmosphere. Now the trends are shifting towards the exploration of renewable energy options, such as bio hydrogen, bioethanol, biogas, biodiesel and bioelectricity. Microbial fuel cell (MFC) is considered to be a promising sustainable technology which generates electricity from wastewater and accomplishes wastewater treatment simultaneously, thus may offset the operational costs of wastewater treatment plant. Nowadays these system not only used for energy production abut also for wastewater treatment (Reddy et al., 2009). The use of natural resources for electricity production not only meet energy demand but also reduce pressure on environment (Arshad, 2017).

MFCs are devices which convert chemical energy into electrical energy by oxidation process of various organic waste (Aelterman et al., 2008; Angenent et al., 2004; Logan, 2009; Lovley et al., 2011). Chamber of MFC can be manufactured using different material such as glass, polycarbonate and Plexiglas (Rhoads et al., 2005). MFC is made up of two electrolytic chambers, i.e., anodic and cathode chamber. MFC chambers are separated using proton exchange membrane (PEM), along with an external circuit (Fig. 1). Electrically active bacteria in anodic chamber oxidizes substrates under anaerobic conditions to produce electrons and protons (Rabaey and Verstraete, 2005). The electrons move towards anode and travel through a circuit towards cathode (Wang and Ren, 2013). The protons directly transfer to the cathode plate through solution. At the cathode plate protons, electrons and oxygen react with another to create water. Some oxygen transfers through a proton exchange membrane towards anode section and be used by bacteria in this section to degrade biological organic matter (Liu et al., 2005; Liu et al., 2004; Min et al., 2005; Sharma and Li, 2010).

Many research have been conducted in which researchers have used different type of substrates in MAF. Geobacter (Lovley et al., 2011; Nevin et al., 2008) and Shewanella (Gorby et al., 2006; Wang and Ren, 2013; Watson and Logan, 2010) species are considered as majority of the microbial population and being utilized in MFC technology. Photosynthetic bacteria can also be used effectively in MFC for electric power generation. Algal species of *Leptolyngbya* sp. JPMTW1 have used not only for coupled biofuel but also for bioelectricity production (Maity et al., 2014). Mixed cultures of microbial population, carbohydrates, organic substrate, natural microbial community, sediments from marine, domestic wastewater and brewery wastewater can be used in MFC to produce bioelectricity (Allen and Bennetto, 1993; Choi and Ahn, 2014; Feng et al., 2008; Jiang et al., 2013; Logan, 2005; Moon et al., 2006; Rabaey et al., 2005). Min et al. (2005) demonstrated that swine wastewater produces maximum power density in single chambered MFC. Sludge, Fruit and vegetable waste has also been used as an effective substrate in bioelectricity generation coupled with hydrogen production (Choi and Ahn, 2014; Ge et al., 2013; Logroño et al., 2015). Logan (2008) discussed the power production potential of glucose, acetate, butyrate, protein and domestic wastewater. Power production potential of glucose, acetate, butyrate, protein and domestic wastewater was 494 mW/m^2, 506 mW/m^2, 309 mW/m^2, 269 mW/m^2, and 146 mW/m^2 respectively.

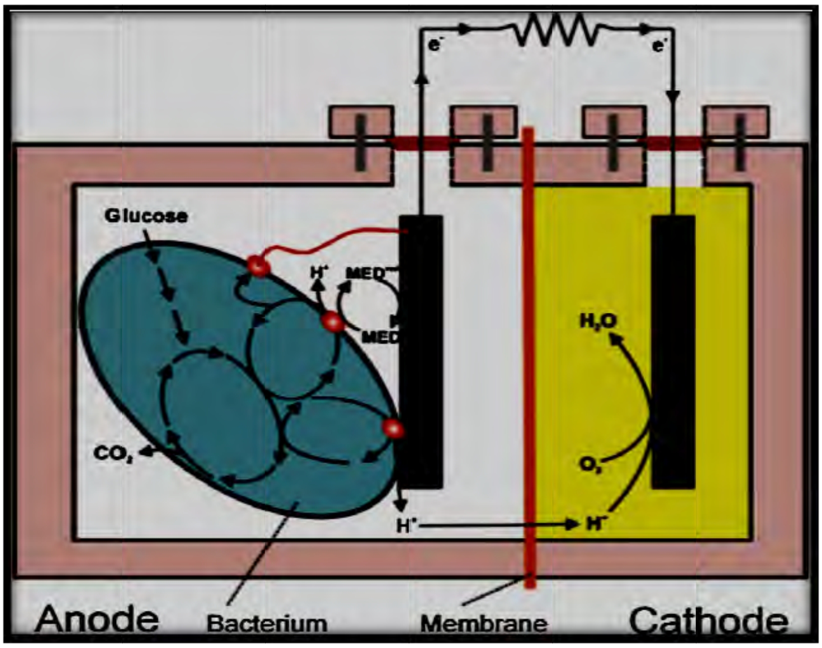

Fig. 1 Shows configuration of MFC system.

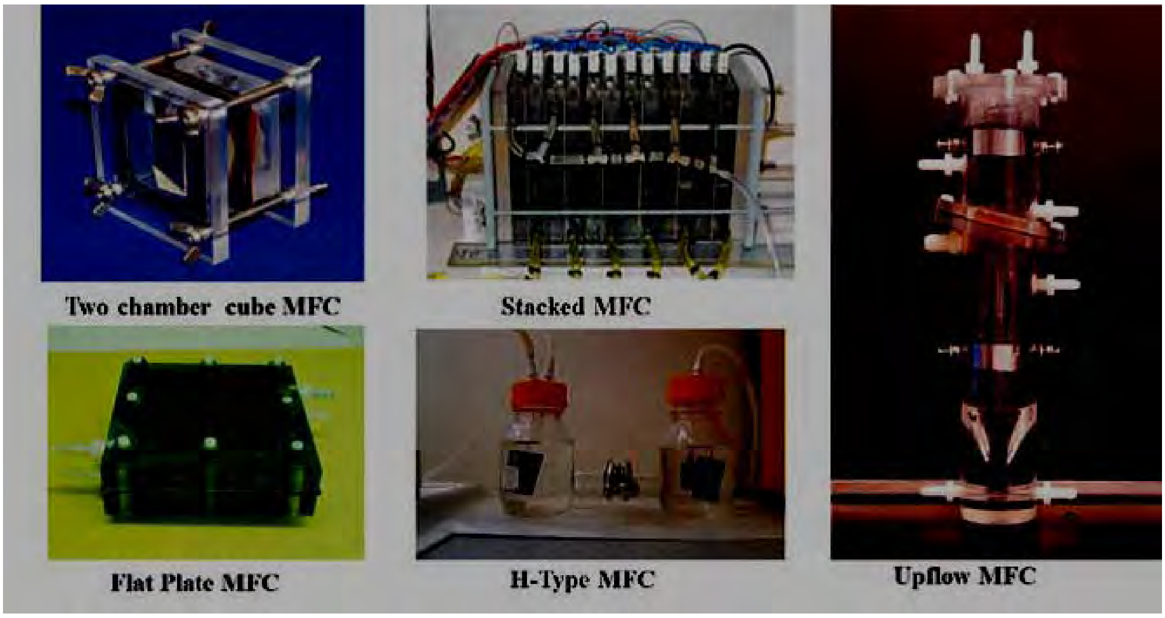

Fig. 2 Different types of microbial fuel cells (Logan, 2008).

Based on transfer mechanism of electron by active microorganisms from media to anode plate, MFCs could be divided into two categories: Double chamber MFC, single chamber and stacked MFC (Fig. 1). Double chamber MFC consists of dual chambers separated by an ion exchange membrane. These systems typically run in batch modes but can work in continuous mode as well and are currently used only in laboratories (Du et al., 2007). In single-chamber MFC anode chamber is connected with an air cathode to which electrons and protons are transferred. In stacked microbial fuel, different MFCs couple with each other in parallel or in series mode (Aelterman et al., 2006). All microbial fuel cell works on same principal but due to different substrates and power options, these systems have constructed in different shapes (Fig. 2). In this study double chamber MFC was developed to generate electricity using tab water and wastewater mixed with slurry as substrate. Salt NaCl, egg and tomato were used as protein exchange membrane in salt bridge and voltage was recorded at the interval of 16hr with the help of multimeter. The main objectives of this research are, (1) to develop a small scale MFC system (2) to evaluate the applicability of MFC system for electricity production.

2 Material and Methods

2.1 MFC components

Microbial Fuel Cell is composed of various components like electrodes, anode, cathode chamber and salt bridge. The substrate and the biocatalyst-microorganisms are part of the anodic chamber. The exchange of ions (protons) between cathodic and anodic chamber is aided by salt bridge. Graphite from pencils was used as anode and cathode. MFC system constructed in this research is shown in Fig. 3.

Fig. 3 Shows MFC system constructed for production of electricity.

2.2 Construction of MCF cell

2.2.1 Electrodes

Two 1.5 litter soda bottles were used in this experiment, one is known as cathodic chamber and other is known as anodic chamber. The bottle surface was sterilized by washing with 70% ethyl alcohol and 1% HgCl2 solution followed by UV exposure for 15 minutes. Two carbon electrode i.e. cathode and anode were placed in plastic soda bottles. Anode electrode was placed in anodic chamber while cathode was placed in cathodic chamber and both electrodes externally connected with multimeter through copper wire.

2.2.2 Exchange membrane

The protons transfer from anode to cathode affect the power output. As the transfer of protons from anode to cathode is a slow process that can result in high internal resistance. In most of the designs, MFCs need a salt bridge to separate the anode and cathode chambers. In this research plastic bottles were connected with each other by means of a small PVC pipe of 1inch diameter which acts as a bridge between two chambers and salt bridge was casted in PVC pipe. The connecting pipe having two segments, each of length of about 6-8inch, are connected by an adjustable union joint. Salt, tomato and egg were used as protein exchange membrane in bridge.

2.2.3 Substrates

Different types of substrates have been used for in MFC for electricity production. In this study two type of substrate were used. First substrate was tab water, collected from university of agriculture Faisalabad and second substrate was wastewater collected from drain. It contained organic matter like starch, glucose, and sucrose which used by bacteria for growth. Slurry was collected and mixed with substrates. Table 1 indicates the characteristics of substrate used in MFC system.

Table 1 Characteristics of substrates used in MFC.

Sr#	parameters	Domestic /tab water	Drain water
1	PH	7.04	8.35
2	salt	1 %	4%
3	EC	0.28 s/m	0.47
4	TDS	1300 mg/l	1970 mg/l
5	Turbidity	195 mg/l	330 mg/l

2.2.4 Circuit Assembly

Two chambers were internally connected by salt bridge and externally with wire and also multimeter was attached on other two ends. The potential difference generated by the Fuel Cell was measured by using multimeter.

2.3 MFC operation and voltage measurement

This research intends to utilize the waste water and tab water to generate electricity in double chamber Microbial Fuel Cell system. The experiment was setup for three types of proton exchange membranes (Fig. 4).

a. Salt (NaCl) a
b. Egg as proton
c. Tomato as proton

First of all salt NaCl was used as exchange membrane and small amount of NaCl was added into both chambers to make the solution eclectically conductive. Both chambers were sealed at the top to stop the entry of oxygen. The microorganisms are used as biocatalyst. The active bacteria present in waste water convert sugar components into Carbon dioxide. Small amount of potassium sulphate was also added in cathode chamber which allows the cathode plate to pick up electron from anode. All the components of MFC are connected via salt bridge internally and externally with wires to the multimeter. The substrates (waste water) mixed with slurry was added in the anodic chamber. The anodic chamber was completely sealed to maintain anaerobic condition. The samples were subjected into chamber for 64hrs and the voltage was recorded at every 16hr. The MFC set up was kept at static conditions. Multimeter was calibrated each time before use. Similarly experiment was repeated with egg and tomato as protein exchange membrane and voltage was recorded.

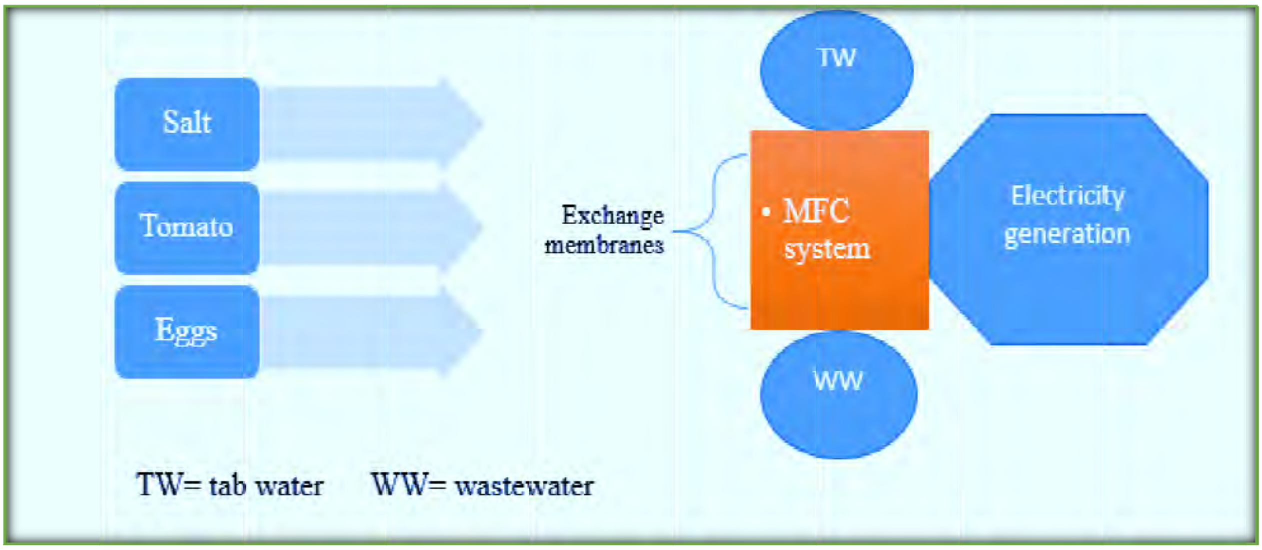

Fig. 4 Experimental setup of MFC.

3 Results and Discussion

MFC setup was adopted initially with salt NaCl as protein exchange membrane in PVC pipe. The voltage generation was recorded at 16hr basis for the period of 64 hrs for waste water sample of drain mixed with slurry. There was a definite increase in the voltage till 32hr and after that voltage has been decreased continuously. It was observed that for a whole experimental period of 64 hrs, the maximum potential was recorded as 154 mV to generate electricity at 32hr and minimum potential 98 mV at 64 hr (Fig. 5). Firstly addition of small amount of salt NaCl in both chamber made the solution electrically conductive. The sealing of anode chamber at the top stops the entry of oxygen into the chamber and decomposes the organic matter anaerobically. Secondly addition of small amount of potassium sulphate into cathode chamber enables the cathode plate to pick the elections and produce the current due to flow of electrons from anode plate towards cathode plate.

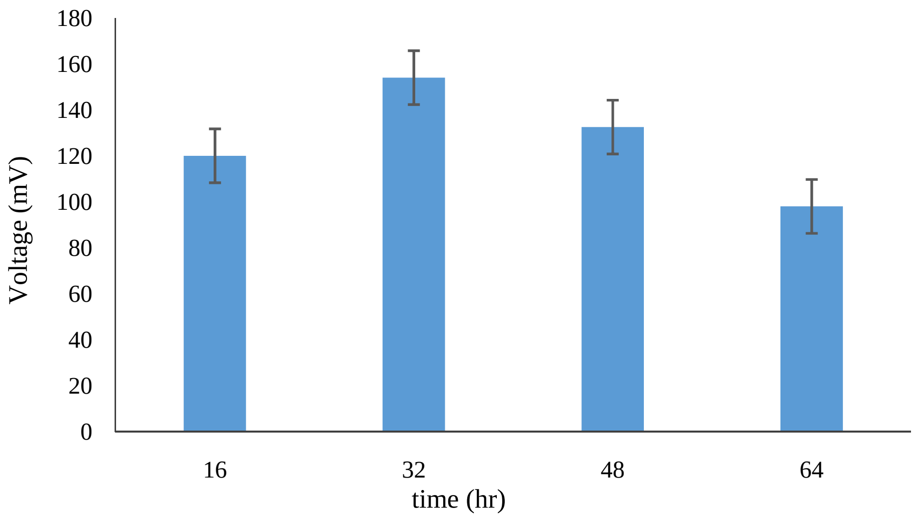

Fig. 5 Shows voltage generated with salt as exchange membrane.

Average amount of current produced during whole duration was 126.5 when salt NaCl was used as exchange membrane. Then, we use tomato instead of salt as a proton exchange membrane, again note the readings of multimeter and note the difference between both readings, i.e. readings with salt and readings with tomato. Minimum voltage of 95.5 mV was recorded at 16hr and maximum voltage was 195 mV at 32hr after that voltage was decreased gradually (Fig. 6). Average amount of voltage produced was 138.12 mV when tomato was used as exchange membrane. Again, we change the water in both container, and use egg as a proton exchange membrane in PVC pipe. The voltage generation was recorded 16 hr basis for the period of 64 hrs for the waste water sample of drain mixed with slurry. Maximum voltage generated with the use of egg was 240 mV at 48 hrs and minimum voltage was 108mV at 16hr (Fig. 7). Generation of electricity with the use of egg as protein exchange membrane was found 1.35 and 1.25 mV time greater as compared to tomato and salt.

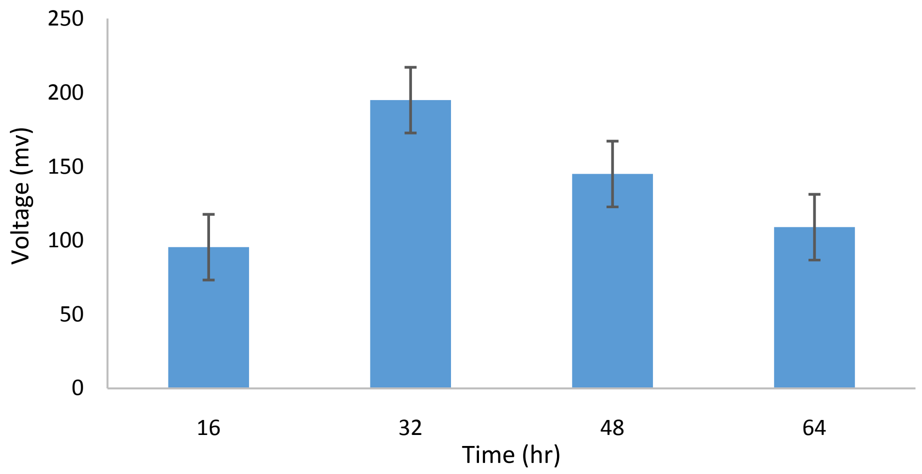

Fig. 6 Shows voltage generated with tomato as exchange membrane.

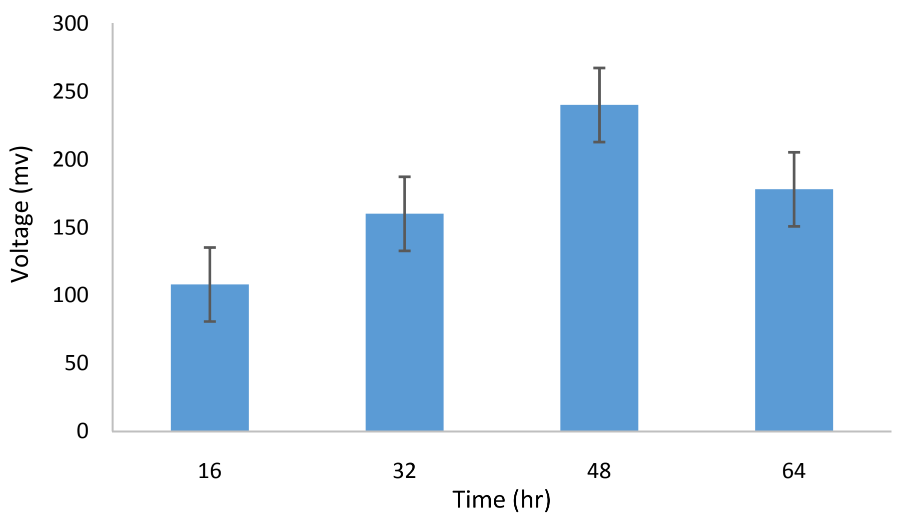

Fig. 7 Shows voltage generated with egg as exchange membrane.

Now we same experiment was tested with the use of tab water in both cathode and anode chamber and voltage was recorded at 16hr bases and no considerable voltage was produced with tab water during 64 hr (Fig. 8).

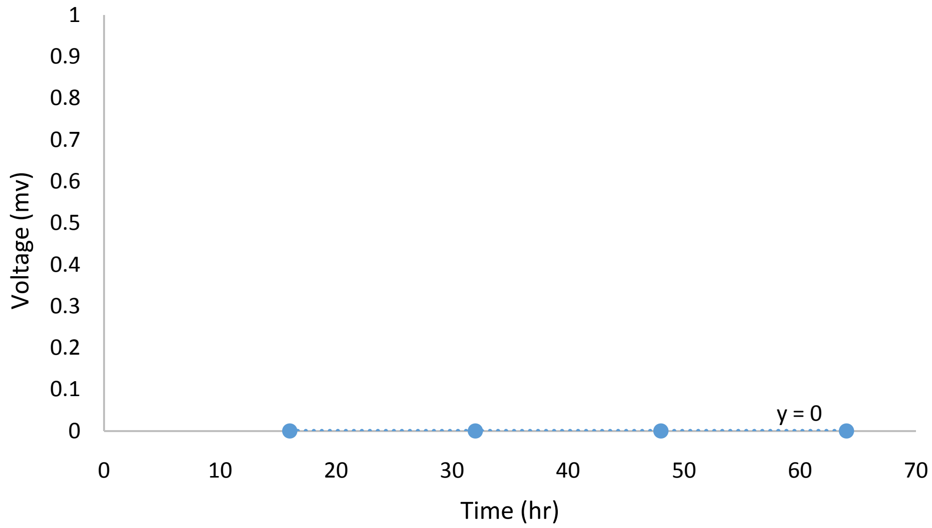

Fig. 8 Shows voltage generated using tab water**.**

4 Conclusions and Recommendations

Energy harvesting from waste-water using microbial fuel cells (MFC) appears to be an attractive option for sustainable energy. This peruse recognized the likelihood of bioelectricity generation from anaerobic wastewater treatment using a DCMFC fabricated with low-cost anode materials (pencil graphite as electrodes), without any toxic mediators. Moreover, power was generated utilizing low-cost and non-coated electrodes and mediator less anode. This system could be effectively integrated to wastewater treatment plant, wherein renewable energy could be generated from wastewater in addition to treatment. With habitual and stable improvements in microbial fuel cell, it will be possible to increase power generation and their production and operating cost can be lowered. Thus, the grouping of wastewater treatment along with electricity production may help in saving billions of money as a cost of wastewater treatment. On the basis of experiment following conclusions were drawn

1. Exchange membrane affects the transformation of proton from one chamber to another and thus affecting electricity production.
2. Organic things could be used as Exchange membranes.
3. Egg is more efficient media for exchange of proton.
4. Wastewater is a cheaper source of bioelectricity.

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