Dairy Wastewater Treatment and Simultaneous Electricity Generation Using Microbial Fuel Cell Technology

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Introduction

Population growth, increasing consumption of natural energy sources, the increasing use of fossil fuels, especially the oil and gas industry in recent years with the energy imbalance management has led to emergence of global energy crisis. Moreover, rapid urbanization and industrialization have substantially increased the amount of high-strength wastewater being produced, which in turn increases the amount of pollution in receiving waters. Dairy industries which have a high percentage of organic substrates in their wastewater are considered to be one of the most contaminated food industries. Organic compounds existing in milk as (proteins, carbohydrates and fats) account for a large amount of the chemical oxygen demand (COD) found in dairy industries wastewaters and can have important effects on municipal waste treatment plants. With regard to the discharge of dairy industries wastewater in the environment, as a result of the presence high level of nitrogen and phosphor, the eutrophication occurs in receiving waters especially in lakes and rivers with small waves. Usually, different biological systems such as activated sludge system, anaerobic pond, oxidation pond, trickling filter and combined trickling filter/activated sludge system are used in order to treat the wastewater of these industries. But these systems have weaknesses such as the consumption of a high level of energy, the production of much of a biomass, the requirement of vast land and substantial expenses. As compared to common processes of treatment, microbial fuel cells (MFCs) are a new concept in the biological treatment technology of wastewater. Using it, it is possible to treat wastewater and generate electricity simultaneously. MFCs are bio-electrochemical transducers which are capable to converting stored energy in chemical bonds in organic compounds to electrical energy by the catalytic actions of microorganisms. In light of the fact that dairy industries' wastewater is rich in biodegradable organic substrates, the purpose of this study is to investigate the treatability of this industry's wastewater and determining the amount of electricity generation using the dual chamber microbial fuel cell technology without catalyst and mediator.

Materials and methods

Dairy industries wastewater was collected from the equalization basin of Pegah dairy factory in Kerman's and maintained until the time of usage at a temperature of 4 C in refrigerator. In order to provide required microorganism in MFC reactor, an amount of active sludge being treated by active sludge system was collected from wastewater's treatment of Kerman. In the study, the dual chamber microbial fuel cell (model H) which made of methyl methacrylate was used. MFC reactor was built having two anode and cathode chambers with equal volume (1.5 liter) which are separated from each other by proton exchange membrane. To increase porosity before using, the membrane were placed into the distilled water, Sulfuric acid solution 0.5 molar and Hydrogen Peroxide 30%.

Two electrodes made of carbon graphite ($12\times4\times0.5$cm) were placed in each of the two chambers and connected to digital multimeter by a copper wire with 8 cm long and 100 ohm of external resistance. Before using, the electrodes were placed into Deionized water within a period of 24 hours.

The cathode chamber was loaded with phosphate buffer 100mM (Na2Hpo4.H2o:2.75gl-1, NaH2Po4.H2o:4.2gl-1) as catalyst.

The anode chamber was anaerobic and contained the wastewater as substrate.

Wastewater was continuously injected into it through a peristaltic pump with 40 ml min-1. First, the reactor was set to work by the injection of active sludge only. After 12 hours, the dairy industry wastewater was injected gradually to the chamber, in such a way that after 24 hours, more than 90 percent of the anode chamber contained dairy wastewater. The fixed amount of COD and produced voltage showed that when the reactor got to the stable condition, the Anode chamber's wastewater must be replaced with fresh one. Substrate degradation rate and current output parameters were considered to assessment the performance of MFC according to the treatment efficiency. Open circuit voltage (mV,

V) and current intensity (mA, I) (in 100 ohm of external resistance) were read by digital multimeter for 1 hour interval. COD, turbidity and PH of treatment wastewater were analyzed at the beginning and end of each cycle in accordance with standard method.

Results

The Maximum voltage and current intensity were obtained as 503.7mV and 2.02mA respectively. Maximum current density and power density were obtained in 100 ohm of resistance as 291.67mA/m2 and 81.43mW/m2. The experimental data showed that the highest percentage of COD removal and substrate degradation rate occurred in cycle 3 and were equal to 77.25% and1.63 kg COD/m3.Also, there's a good relationship between the substrate degradation rate and power generation (R2=0.7412) and the amount of organic loading and power generation (R2=0.6467). This shows that generating electricity is done through substrate degrading. Also, the highest power generation is observed in cycle 1. (0.7946w).

During the operation of MFC reactor, with COD removal also observed the removal of carbohydrate that the efficiency of carbohydrate removal was variable between 69.37 to 89.39 %.A good relationship was observed between carbohydrate removal and power generation (R2=0.7396).The minimum percent of protein removal (70.8%) was observed in second cycle and loading OLR=2.095 and the maximum removal (78.93%) in the first cycle and loading OLR=2.28.The turbidity removal shows a good relationship with COD removal (R2=0.8965).

Discussion and conclusion

After the injection of active sludge to the MFC reactor, the microorganism entered the lag phase and the voltage reached 344.3 MV during 12 hours. This could be due to the difference of the potential between the two electrodes in accordance with the biological and chemical factors and the presence of component that are easily utilized by existing microorganism in the wastewater. Similar sudden increase in voltage has been reported for microbial fuel cell with different sources of substrate. The results showed that according to previous studies, the active sludge was a suitable biocatalyst for generating electricity. . In the first stage, the maximum voltage generation started from 12th hours and remained fixed until 58 hours. After that, because of degrading substrate and decreasing carbon source in the anode chamber, the voltage and current generation decreased. Because of the enrichment and forming processes of electrically active bacteria biofilms on the anode surface, the ascending phase in its first cycle was longer as compared to its other cycle. The second cycle was started by the replacement of wastewater to the reactor. In this stage we observed the rapid increasing of voltage and current in reactor. These rapid increasing showed that the attached Bactria on anode as compared to suspended Bactria had a more effective role in generating electricity. This procedure was continued in the third and fourth cycle by injecting fresh wastewater. The reason for small differences which are observed in the amounts of produced voltage and current in different studies can be attributed to factors such as used electrode surface, the distance between electrodes, the microbial fuel cell's construction and proton exchange membrane. In order to determine the effects of resistance on microbial fuel cell's performance and determining the optimum resistance for maximum power density, the polarization curve is used. In one stage, when the reactor's voltage reaches to a fixed amount, the polarization Curve is obtained by changing the external resistance From 100 ohm to 30 kilo ohm and recording the voltage. According to the V=IR equation, by the increasing of resistance the produced current intensity decreases and the fixing Of voltage is observed relatively in higher resistances. The fixing of voltage at one point shows that the reactor gets to a stable condition and can generate electricity from treating of wastewater. The experimental data showed that anode chamber of reactor, like common anaerobic treating systems could Perfectly remove the wastewater COD and besides generating electricity, had good substrate degradation rate. This showed that the function of existing wastewater's microorganism in metabolizing the carbon source as electron donors. Decreasing in the carbohydrate concentration shows the effective functioning of microbial collection as electron donor, in dairy industries wastewater. The dairy industries wastewater contains high concentration of protein that during the operation of MFC a good reduction was observed in its concentration. With increasing the amounts of loading in each cycle and following it increasing the amount of carbon in reactor, the efficiency of protein removal also increases. Because of the presence of proteins, lipids and insoluble organic matters, the dairy industries wastewater contains turbidity. The turbidity removal might be as a result of colloidal organic matters like casein and other milk's

compositions that are biologically degraded. Result of this study show that electricity generation is possible by using dual chamber microbial fuel cell technology without mediator and catalyst and dairy industries wastewater as the substrate and the reactor operation showed that it was perfectly used in order to treating dairy industries wastewater.

Keywords: Microbial Fuel Cell, wastewater Treatment, Dairy industry, Electricity generation, Organic matter removal