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Biotreatment of Actual Potato Chips Processing Wastewater with Electricity Generation in Microbial Fuel Cell

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ABSTRACT

This study aimed to investigate the feasibility of treatment actual potato chips processing wastewater in a continuously operated dual chambers microbial fuel cell (MFC) inoculated with anaerobic sludge. The results demonstrated significant removal of COD and suspended solids of more than 99% associated with relatively high generation of current and power densities of 612.5 mW/m^3 and 1750 mA/m^3, respectively at 100 Ω external resistance.

Keywords: Microbial fuel cell, biodegradation, food processing wastewater, power generation

المعالجة الحيوية لمياه الصرف الصناعية من معامل انتاج رقائق البطاطا مع توليد الطاقة الكهربائية في خلية الوقود الحيوي

الخلاصة

تهدف هذه الدراسة الى البحث في جدوى المعالجة الحيوية لنماذج حقيقية للمياه العادمة الصناعية المصرفة من معامل انتاج رقائق البطاطس وذلك بأستخدام خلية الوقود الحيوية المتكونة من حجرتين والتي تعمل بأسلوب الضخ المستمر وبأستخدام الحمأة اللاهوائية. برهنت نتائج الدراسة كفاءة إزالة عالية للطلب الكيميائي للاوكسجين و المواد الصلبة العالقة تصل إلى اكثر من 99٪ مع توليد طاقة وتيار كهربائي بقيمة 612.5 ملي واط / م^3 و 1750 مللي أمبير/ م^3 ، على التوالي بأستخدام مقاومة خارجية بقيمة 100 اوم .

الكلمات الرئيسية: خلية الوقود الحيوي، التحلل الحيوي، مياه الصرف للصناعات الغذائية، انتاج الطاقة

1. INTRODUCTION

The fossil fuels were formed thousands of years ago by natural processes. Due to the high efficiency of these fossil fuels to generate power, their utilization by human civilization was significant during the last few decades. However, these fossil fuels levels are depleting at a very fast rate, therefore they cannot be considered as a sustainable renewable energy. Moreover, many of these fossil fuels could no longer be available in the coming few decades. Accordingly, it is

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necessary to start looking for alternative sources of energy to sustain the modern societies, **Bergmann, et al., 2006.**

In recent years, the focus on the eco-friendly renewable sources of energy has been clearly increased, and has been given a priority as an alternative to conventional energy sources. Energy generated from natural processes which cannot be exhausted and are continuously replenished is known as renewable energy, including sunlight, tides, geothermal heat, wind, water, and different types of biomass, **Lund, 2007, Hanjra and Qureshi, 2010 and Chu and Majumdar, 2012.**

On the other hand, the effluents produced from domestic and industrial activities composed of the major sources of water pollution including organic matters, heavy metal, cyanide, toxic refractory organics, suspended solids, nitrogen, phosphorous, color, and turbidity, **Arao, et al., 2009 and Hu, et al., 2013.**

Updated legislation and regulation on the quality of wastewater released into the natural streams has become stricter and wastewater recycling and reuse become more widespread. Based on this fact, more efforts are being made to develop non-conventional technologies to treat wastewater and remove new and emerging pollutants, **Arévalo, et al., 2009.**

Wastewater discharged from potato chips processing plants is a significant source for environmental pollution. It is collected from a series of potato chips production processes including; raw potato collecting, storing, cleaning, shelling, cutting and slicing, washing, frying, salting, picking, coating and packing. It includes high concentrations of different organic compounds including carbohydrates, starches, proteins, and sugars which are the source for high chemical oxygen demand (COD), and suspended solids (SS), **Kobya, et al., 2006.**

There are two sources for potato chips wastewater, which are silt wastewater and processing wastewater. The silt wastewater results from washing and fluming operations for raw potato. Normally, contains large amount of clay and silt removed from the raw potato. The process wastewater results from potato processing operations including consequence operation of peeling, cutting, blanching, and packing. Also, processing wastewater includes discharges from caustic-potato peeler and barrel washer, as well as all other liquid wastes generate from the processing operations, including cleanup water, **Hung, et al., 2006.**

Microbial fuel cell (MFC) is a device that can generate the electrical energy through using microorganisms. MFC is one of sustainable and renewable practical approach to produce electricity, **Hao, et al., 2007 and ElMekawy, et al., 2017.** MFC considered as a biochemical reactor in which chemical energy is being converted to electrical energy by using bacteria as a biocatalyst which oxidize the available biodegradable substrates. Accordingly, the MFC can be used for treatment of wastewater and production of energy. Production of electrical energy from wastewater by using MFC suggest a cost-effective and reliable solution for controlling the environmental pollution and energy crisis issues in the future years, **He, et al., 2016 and Qin, et al., 2017.**

Very limited studies have been reported regarding the application of MFC for the treatment of food processing wastewater, in particular potato processing wastewater. **Durruty, et al., 2012;** studied the feasibility of supplementing methanogensis in tubular MFC for simultaneous treatment of synthetic potato processing wastewater and electricity production. The MFC consisted two anodic chambers located on both sides of concentric cathodic chamber. The anodic chambers were filled with particulates of graphite. The results revealed that the combination of the energetic yield of methanogensis improved the COD removal and electricity generation. On the other hand, **Du and Li, 2016;** studied the effect of changing the ratio of cooked (boiled) to uncooked potato (waste potato) on the efficiency of potato waste treatment in MFC. They used four MFCs which were fueled with different ratios of cooked to uncooked potato including 0, 48.7, 67.3 and 85.6%, resulted in COD reduction by 86.6, 83.9, 84.1 and 86.3%, respectively.

As given above, none of the previously reported studies concerned of the real potato chips processing wastewater treatment in MFC. The present study deals with the simultaneous biodegradation of real potato chips processing wastewater and electricity generation in a rectangular shaped dual-chambered MFC inoculated with anaerobic aged sludge.

2. MATERIALS AND METHODS

2.1 Complete System Description

An anaerobic complete system consisted of holding-neutralization tank, sedimentation tank, followed by dual-chamber MFC was used to treat wastewater. All components were made of Plexiglas material. A schematic diagram is given in **Fig.1**.

The microbial fuel cell was designed as horizontal dual-chambers MFC. The dimensions of each compartment were 20 cm x 10 cm x 10 cm, using uncoated plane graphite electrodes as the anode and cathode. Both electrodes were of size 8 cm x 8 cm x 0.25 cm, with a subjected area of 128 cm^2. These electrodes were connected to an external electrical circuit by copper wires, through which the transportation of electrons were occurred and then passed through resistance box. The graphite electrode was scratched by a knife blade to enhance bacterial attachment.

The cation exchange membrane CEM class CMI-7000s (obtained from Membrane International INC., NJ, USA) was placed between the anode and cathode. This was arranged by sandwiching the CEM between two perforated Perspex sheets, the perforated sheets had 72 holes, each hole of 5 mm diameter, and the effective area of membrane was 14.14 cm^2.

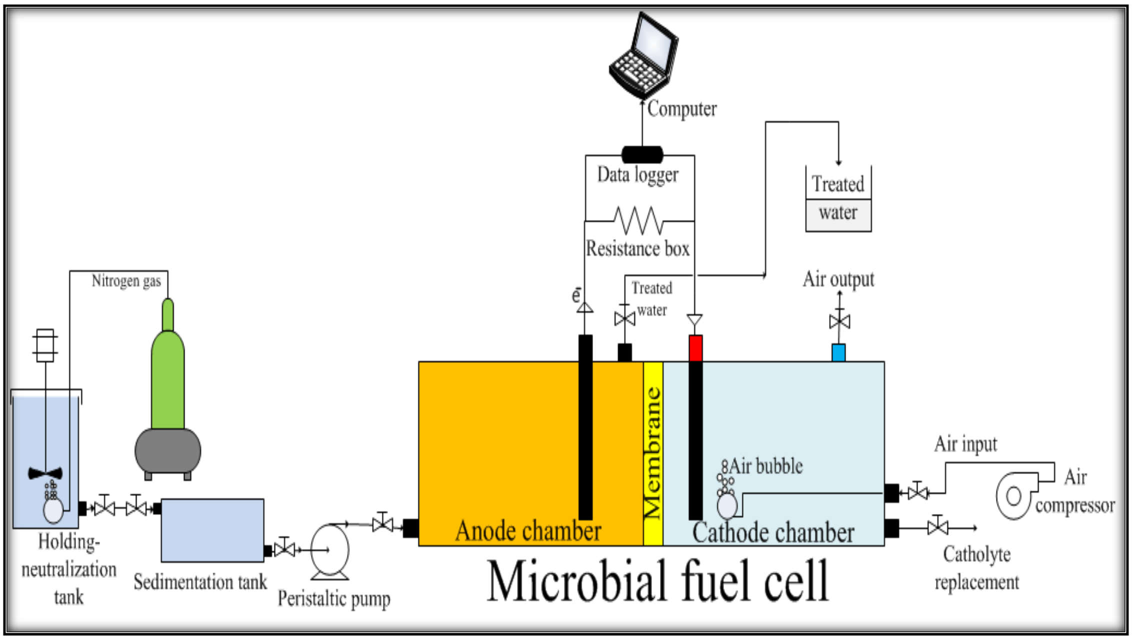

Figure 1. Schematic diagram of MFC-system.

2.2 Substrate

Real-field potato chips factory wastewater was freshly collected from a small local factory named "Salah Al-din Bakery & Pastry" in Tikrit city. The quality and average concentrations of wastewater are given in **Table 1**.

Table 1. Quality of Real-field potato chips factory wastewater.

Constituents	Units	Average concentration
COD	mg/L	7830
Total dissolved solids (TDS)	mg/L	2490
pH	-	5.80
Electrical conductivity (EC)	µS/cm	4990
Suspended solids	mg/L	2580

2.3 Inoculum (Biocatalyst)

Anaerobic aged sludge was collected from a bottom of local septic tank in Tikrit city. The biocatalyst preserved in a closed plastic container until used to inoculate the anodic section of the microbial fuel cell. The anaerobic sludge was black having thick texture and unpleasant sharp odor.

2.4 Start Up and Operation of MFC Complete System

Before operating the MFC system, 500 ml of the collected anaerobic aged sludge was placed on the anodic electrode surface. Then after, the electrode was placed in closed incubator. In order to maintain anaerobic conditions, the incubator was purged with nitrogen gas for 10 min. The bacterial cells were incubated for seven days and fed with desired nutrients for enrichment of cells.

Then after, the enriched anodic biofilm was transferred to the MFC. The real wastewater was fed in a continuous mode to the anodic chamber of the MFC via a peristaltic pump with a flow rate of 1 ml/min to obtain hydraulic retention time (HTR) of 33 h. Nitrogen gas was released into the holding-neutralization tank and anodic chamber to drive out oxygen content and provide anaerobic environment in the wastewater. Oxygen was the electrons accepter in cathodic chamber and supplied by an air compressor.

2.5 Analytical Analysis and Methodologies

The chemical oxygen demand (COD) concentrations were determined by using COD reactor (model RD 125, Lovibond, Germany) and COD test (model MD 200 COD vario, Lovibond, Germany) on a daily basis. Dissolved oxygen (DO), pH, TDS, suspended solids (SS) and electrical conductivity (EC) tests also were measured on a daily basis. The tests were accomplished according to the procedure mentioned in the ***standard methods*** (**APHA**, **2005**).

Voltage was continuously measured by a voltage data logger (model: Lascar EL-USB-3, USA), with a data acquisition system and a multimeter (model MT1233C, pro'skit, Taiwan) of high accuracy (0.001mV),then the data converted to power according to $P = I * V$, where P is the power, I is the current, and V is the voltage. Then, the power was calculated as a function of the surface area of the anode. All data was obtained at 100Ω external resistance.

Polarization curves were accomplished by changing the external resistances within a range from 5 to 60000 Ω.

3. RESULTS AND DISCUSSIONS

3.1 Chemical Oxygen Demand (COD) and Suspended Solids (SS) Removal

MFC was continuously operated for 30 days achieving a maximum COD removal efficiency of 99.6% as given in **Fig. 2**. Fast removal of COD was observed after 1 day of MFC start up and high removal after 10 days. This could be concluded that the type of substrate fed to MFC was favorable to the bacteria despite it contains cellulosic compounds that result from peeling and washing the chips raw materials. This observed maximum removal efficiency of COD in the current study was higher than the previously reported values synthetic potato processing wastewaters which was studied by **Durruty, et al., 2012** and **Du and Li, 2016**, and this affected by the source and type of substrate, type of growth and type of biocatalyst, geometric design of MFC, type of electrodes and surface area of attaching as mentioned by **Ismail and Jaeel, 2015**.

The profile of suspended solids removal is given in **Fig.3**. Significant removal efficiency higher than 99% was achieved by the suggested MFC system.

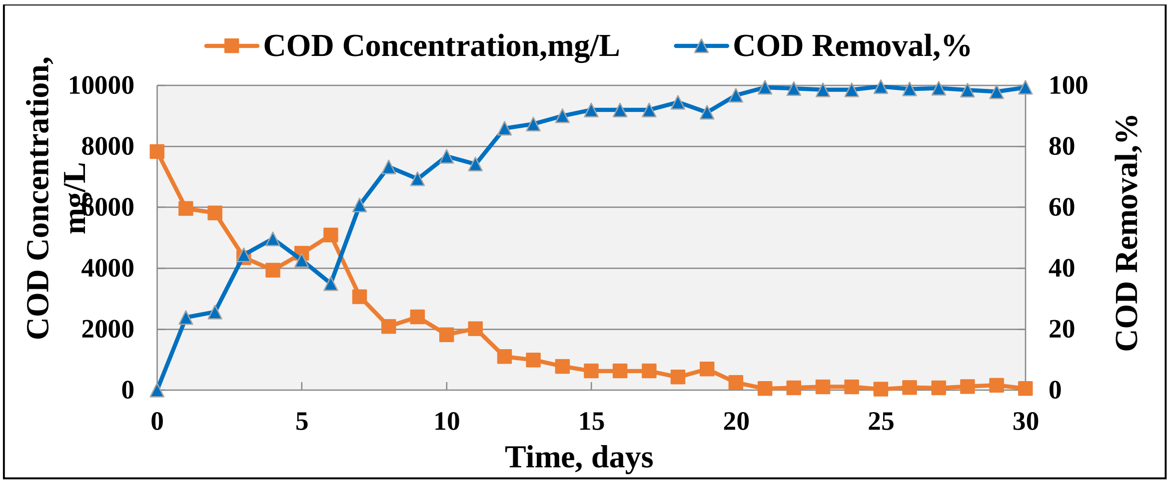

Figure 2. Profile of COD removal efficiency.

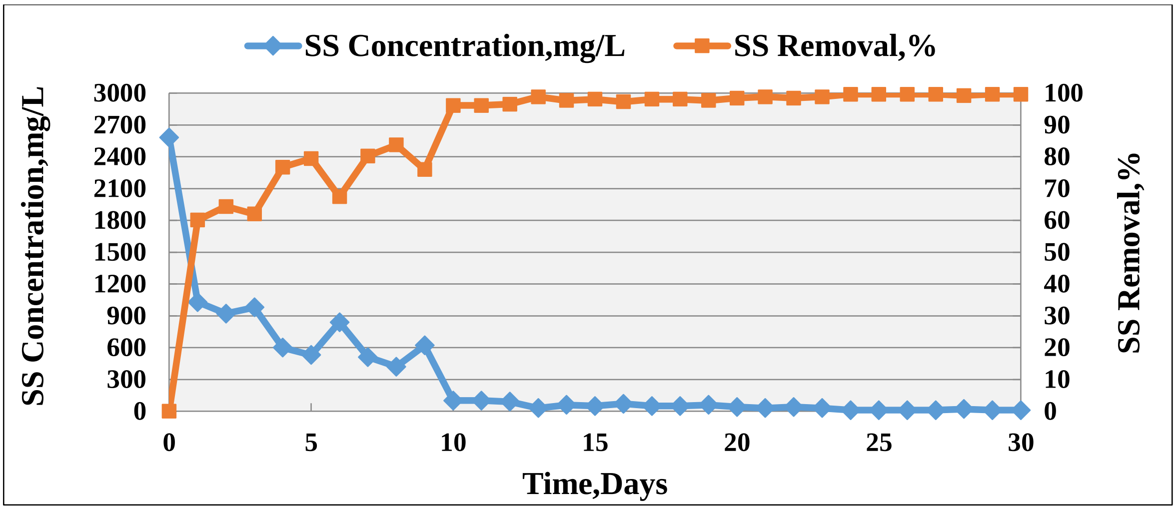

Figure 3. Profile of suspended solids removal for whole complete system.

3.2 Current and Power Generation

Power and current production started on the first day of operation followed by a fluctuated up and down for a period of 5 days, **Ismail and Jaeel, 2013** suggested that this variation could be attributed to the fact that some types of microbes in the mixed culture which may not be electrochemically active species could compete with active microorganisms for the available substrate and limit their electrochemical activity until became a dominant species in the mixed culture. Then an increase in the generated current and power were observed until the end of 30 days, with a maximum power density and current density of 612.5 mW/m^3 and 1750 mA/m^3, respectively as shown in **Fig.4.** Maximum power and current density of the MFC-system suggest that electron transfer was also improved due to efficient oxidation of substrate. The high power densities could be due to the better electrochemically active bacteria at high ionic strength.

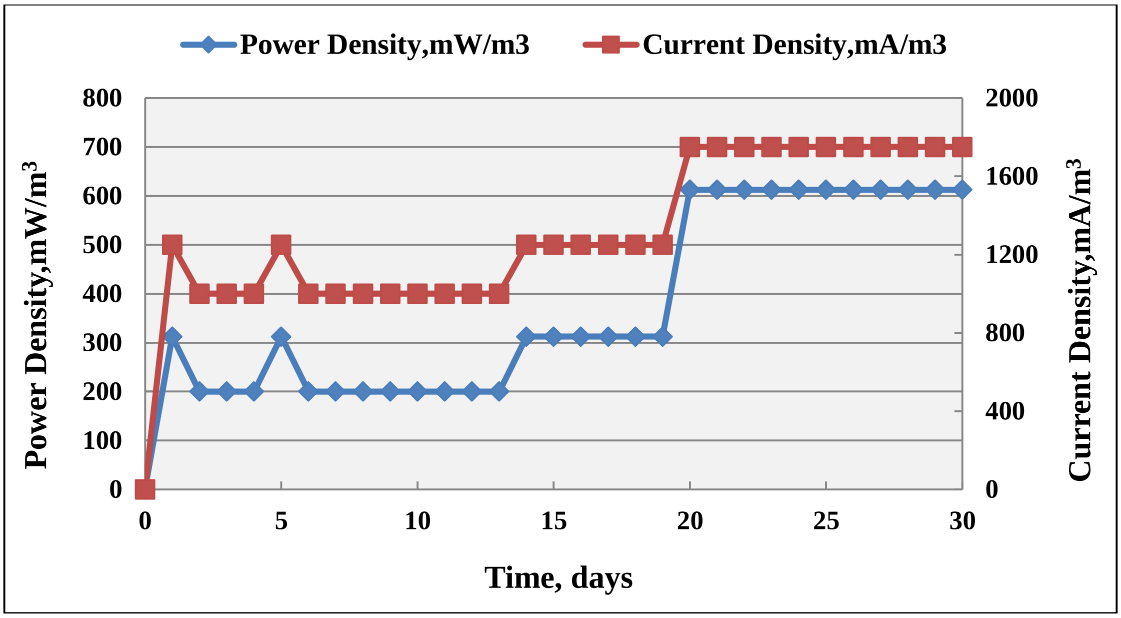

Figure 4. Profile of power generation and current.

3.3 Biosensor for COD removal

One of the potential applications of MFC technology is using it as a sensor for pollutants concentrations and in situ process controlling and monitoring, **Chang, et al., 2004.** In this study a relationship proposed between average current generation within range (2-3.5) mA (depending on data measured by multimeter of high accuracy (0.001mV) and average COD removal efficiency at this range. The result given in **Fig.5** showed high correlation of determination value (R^2 =0.99) gave an equation that could be used to determine COD residual concentration depending on using measured current values.

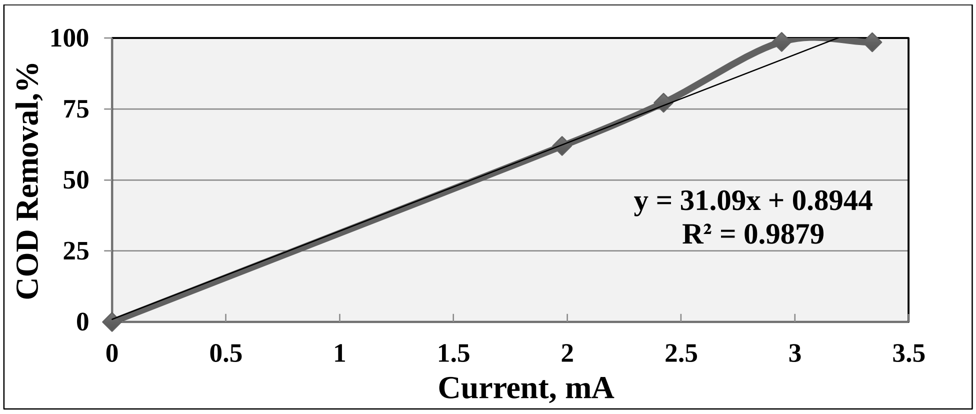

Figure 5. Biosensor based on current-COD removal relationship.

3.4 Polarization Curves

The polarization curve is a useful gadget for the analysis and description of MFC; it describes voltage as a function of current. A maximum power with available maximum current can be produced when the internal and external resistances are equal, **Liu and Li, 2007.**

As shown in **Fig.6**, the plots present the power output from the MFC as a function of external circuit loads, using a periodical increase in the external variable resistor and record the data by using Multimeter when it is stable. A maximum power density of 238.05 mW/m^2 and maximum current 862.5 mA/m^2 at external resistance of 25Ω was achieved, this result proved that the design of this MFC had a lowest value of internal resistance compared to other geometric designs of MFCs fed with food processing wastewater such as cylindrical graphite MFC designed by **Mohanakrishna, et al. 2018**, which had internal resistance of 750 Ω, and an annular single chamber MFC with spiral anode designed by **Mardanpour, et al., 2012**, which had an internal resistance of 55 Ω.

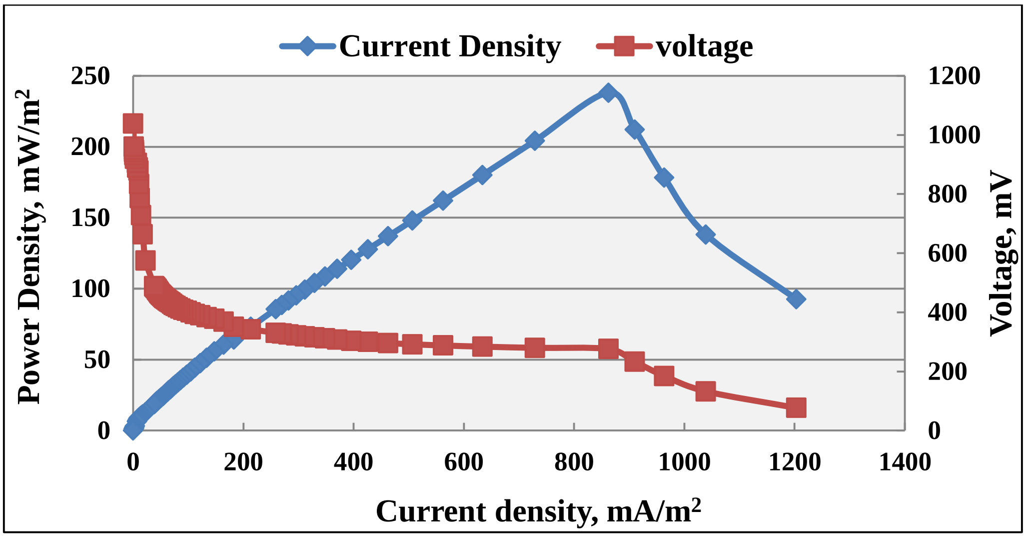

Figure 6. Polarization curve for MFC.

4. CONCLUSION

This study described the availability of using the MFC-system preceded by primary sedimentation tank fed with real wastewater collected from potato chips processing industry, for simultaneous biotreatment and power generation,

The results demonstrated the high removal efficiency up to 99% for major pollutants (COD, SS) in actual potato chips processing wastewater accompanied with highly current and power generations of 612.5 mW/m^3 and 1750 mA/m^3. This study suggested a sustainable approach for clean energy production associated with biotreatment of food processing wastewater represented by potato chips processing wastewater.

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