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# Semi-pilot scale production of hydrogen from Organic Fraction of Solid Municipal Waste and electricity generation from process effluents

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The production of hydrogen from Organic Fraction of Solid Municipal Waste (OFSMW) was studied on a semi-pilot scale. The potential of generating electricity using the process effluents was further assessed using a two-chambered Microbial Fuel Cell. A maximum hydrogen fraction of 46.7% and hydrogen yield of 246.93 ml $H_2$ $g^{-1}$ Total Volatile Solids was obtained at optimum operational setpoints of 7.9, 30.29 °C and 60 h for pH, temperature and hydraulic retention time (HRT) respectively. A maximum electrical power density of 0.21 W $m^{-2}$ (0.74 A $m^{-2}$) was recorded at 500 Ω and the chemical oxygen demand (COD) removal efficiency of 50.1% was achieved from the process. The process economics of energy generation from organic wastes could be significantly improved by integrating a two-stage process of fermentative hydrogen production and electricity generation.


## 1. Introduction

The effects of climate change, increased global demands for oil and natural gas are intensifying the search for alternatives to fossil fuels [1]. Hydrogen gas is an attractive future energy carrier due to its clean, efficient and renewable properties [2] and can be generated from various organic wastes. The feasibility of hydrogen production in dark fermentation with the Organic Fraction of Solid Municipal Waste (OFSMW) in laboratory scale experiments has been reported in various studies with yields of 76 ml $g^{-1}$ VS [3], 122.9 ml $g^{-1}$ COD [4] and 134 ml $g^{-1}$ COD [5]. These were achieved under different optimal flask operational conditions. The industrial production of hydrogen from these wastes requires further understanding of the process dynamics at semi-pilot or large scale.

OFSMW is highly considered as substrate of choice for hydrogen production partly due to waste disposal problems and also its rich content of carbohydrate, biodegradability, and a high hydrogen potential [6,7]. South Africa generated 7.88 Mt of organic waste in 2011, and only 35% of these were recycled. The rest were mostly burnt or disposed on landfills [8]. Hydrogen production from these waste materials will not only contribute to sustainable energy but also assists to alleviate environmental hazards.

Hydrogen production from organic waste materials is more efficient, but much of the organic matter remains in solution. Current fermentation processes can only produce 2–3 mol

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$H_2$ $mol^{-1}$ glucose, and results in 80–90% of initial chemical oxygen demand (COD) remaining in solution in the form of various volatile organic acids and solvents [9]. To improve the economics of hydrogen production from substrates, additional processes are therefore needed to recover the remaining energy [10]. Recently, there has been an upsurge of interest in using MFC technology for harnessing electricity generation from wastewaters and organic wastes while facilitating complete energy recovery and reducing the waste treatment costs [11,12]. MFCs are biochemical catalyzed systems that generates electrical energy through the oxidation of biodegradable organic matter in the presence of fermentative bacteria [13]. The bacteria present in the anode chamber of fuel cell generate electrons and protons, and the potential between the respiratory system and electron acceptor generates electricity. Hence, bacterial energy is directly converted to electrical energy. Protons migrate through a proton exchange membrane from anode to cathode [12]. MFC processes have been reported for an effective energy recovering from wastewater [9,14,15].

This work describes a semi-pilot scale production of hydrogen from OFSMW, then investigates the electricity generation potential from the process effluents using MFC.

## 2. Materials and methods

### 2.1. Hydrogen production in a semi-pilot scale reactor

#### 2.1.1. Inoculum development

The hydrogen-producing mixed consortia was obtained from the anaerobic sludge collected from the Darvill wastewater treatment plant, Pietermaritzburg, South Africa. The sludge was heated at 100 °C for 30 min to deactivate the methanogenic bacteria, thus enabling the survival of hydrogen producing endospore-forming clostridia which were confirmed in our previous studies (unpublished results).

#### 2.1.2. Substrate pre-treatment

Organic wastes were collected from food stores in Pietermaritzburg, South Africa and the OFSMW was simulated according to the method of Gomez et al. [16]. It was made up of 10% apple, 10% orange, 35% cabbage, 35% potatoes, 8% bread, and 2% paper. The total volatile solids content of OFSMW was determined according to Equation (1).

$$\text{Total Volatile Solids} = \frac{\text{Weight of dried waste} - \text{Weight of ash}}{\text{Weight of dried waste}} \times 100\% \qquad (1)$$

#### 2.1.3. Intermediate fermentation process phase

Prior to the pilot-scale process, an intermediate fermentation stage was carried out in a 1000 ml modified Erlenmeyer flask reactor, inoculated with 50 ml of pre-treated sludge. The reactor was fed with OFSMW at concentration of 40.45 g $l^{-1}$, supplemented with inorganic salts (in g $l^{-1}$): $NH_4Cl$ 0.5, $KH_2PO_4$ 0.25, $K_2HPO_4$ 0.25, $MgCl_2.6H_2O$ 0.3, $FeCl_3$ 0.025, $ZnCl_2$ 0.0115, $CuCl_2$ 0.0105, $CaCl_2$ 0.005 and $MnCl_2$ 0.015. The working volume was made up to 500 ml with distilled water. Anaerobiosis was created by flushing the reactor with nitrogen gas for 3 min. The setpoints of initial pH, temperature and stirring speed were 7.9, 30.29 °C and 1.66 $s^{-1}$ respectively and the process was carried out for 60 h.

#### 2.1.4. Fermentation process

The semi-pilot hydrogen fermentation process was conducted in 10 L bioreactor (Labfors Infors HT bioreactor, Switzerland). Prior to use, the reactor was sterilized by autoclaving at 121 °C for 15 min. It was fed with 4500 ml medium of OFSMW and inorganic salts stated above, followed by inoculation at 10% with the previous 60 h intermediate culture. The temperature was controlled at 30.29 °C and the stirring speed was maintained at 1.66 $s^{-1}$. The initial pH of the reactor was adjusted at 7.9 with no further pH control. Anaerobiosis was created by flushing the reactor with nitrogen gas for 10 min through the gas sparger.

#### 2.1.5. Process monitoring and analysis

The changes in the volume fractions of hydrogen and carbon dioxide of the evolving gas were continuously monitored using the F-Lab Biogas software previously described [17], running at 1 min sampling frequency and using the BCP-$H_2$, and BCP-$CO_2$ sensors (Bluesens GmbH, Germany). The measuring principle of the gas sensors was based on thermal conductivity detector and infrared technology, all with pressure compensation. The cumulative volume of these biogas was recursively software computed using their fractions in the evolving gas and the gas volume at each sampling interval according to Equation (2).

$$V_{H,i} = V_{H,i-1} + C_{H,i}(V_{G,i} - V_{G,i-1}) + V_H(C_{H,i} - C_{H,i-1}) \qquad (2)$$

where $V_{H,i}$ and $V_{H,i-1}$ are cumulative hydrogen gas volume at the current (i) and previous (i−1) time intervals, $V_{G,i}$ and $V_{G,i-1}$ the total biogas volumes in the current and previous time intervals, $C_{H,i}$ and $C_{H,i-1}$ the fraction of hydrogen gas in the headspace of the reactor in the current and previous time intervals, and $V_H$ the total volume of headspace in the reactor [18].

The pH was monitored with a pH sensor (Mettler Toledo GmbH 405-DPAS-SC-K8S/325, Germany).

### 2.2. Electricity generation from process effluent using MFC

#### 2.2.1. MFC structure and design

The MFC was constructed as described by Khan et al. [19] on a two-chambered design using glass material. The anodic and cathodic compartments were provided with inlets and sampling ports. A salt bridge made up of glass tube was used to connect the two chambers (length = 0.05 m, diameter = 0.012 m), and consisted of 10% agar, 5% KCl and 5% NaCl. The electrodes were made up of graphite rod (1.48 $m^2$ cross section), positioned at a distance of 0.05 m on either side of the salt bridge with equal projected surface areas of 2.19 $m^2$. Anaerobic conditions in the anode were achieved by sealing the flask with a rubber stopper. The cathode was operated under aerobic conditions. Prior to use, the electrodes were sterilized with 70% ethanol. The schematic diagram of MFC design is shown in Fig. 1.