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Hydrogen gas production from food wastes by electrohydrolysis using a statical design approach

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ABSTRACT

Hydrogen gas production was investigated by electrohydrolysis of food waste due to its high organic content. Different voltages generated by DC power supply were applied to food waste in order to produce hydrogen gas. Effects of the DC voltage, reaction time and initial solid content on cumulative hydrogen gas production, hydrogen gas content in the gas phase and total organic carbon (TOC) removal were investigated by using a Box-Behnken statistical experiment design approach. The most suitable voltage/reaction time/solid content values resulting in the highest hydrogen gas content (99%), the highest cumulative hydrogen gas formation (7000 mL) and total organic carbon removal (33%) were determined as 5 V/75 h/20%. The results indicated that food wastes constitute a good source for H_2 gas production by electrohydrolysis. Hydrogen gas produced by electrohydrolysis of food waste can be directly used in fuel cells due to its high putrity.

Introduction

In recent years, clean and high energy fuels have been searched and investigation on clean energy has gained significant attention because of energy limitations and green house gas emissions caused by the use of fossil fuels. Due to its high energy content (122 kJ g^{-1}), hydrogen gas is an effective and clean energy source with no green house gas emissions. When H_2 gas is used as a fuel only water vapor is produced without any other emissions. Besides H_2 gas is an important electron carrier which can be used in fuel cells for production of electrical energy [1]. Easy transportation in form of metal hydrides is another advantage of H_2 to be used in motor vehicles for electrical power generation.

Hydrogen gas is not readily available in nature and is produced by energy intensive, costly methods such as steam reforming of hydrocarbons or electrolysis of water [2]. The photocatalytic hydrogen production from glucose degradation under visible light were also investigated [3]. As an alternative for these processes, hydrogen gas production by fermentation (dark and photo fermentation) has been considered as a viable approach. Renewable organic wastes or materials containing carbohydrates can be used for H_2 gas production by fermentation. However, some obstacles in bio-hydrogen production were observed such as low hydrogen gas content and formation rates because of slow bacterial metabolisms in fermentation process. In order to overcome negative effect of photo/dark fermentation processes, different hydrogen gas production methods were investigated. Electrohydrolysis of organic wastes may be used for effective hydrogen gas production [4–7]. Based on literature reports electrohydrolysis may be used as a pretreatment at the hydrolysis stage in anaerobic digestion of organic wastes such as lignocellulosics to

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improve the rate and extent of hydrolysis [8,9]. However, in this study, electrohydrolysis was directly applied to organic waste to produce hydrogen gas but not for the pretreatment. Electrohydrolysis is the chemical process to decompose the organic matter by breaking the bonds between polymers provoked by application of current through electrodes. When electrodes connected to direct current, one electrode becomes positively charged and another electrode becomes negatively charged. This starts the movement of electrolyte towards electrodes i.e., positive ions moves to cathode and negative ions to anode.

Several studies on hydrogen gas production by application of direct current to organic wastes and effluents of fermentation were reported [10–12]. Microbial electrolysis cells were also used for H_2 gas production from organic wastes [13–16]. In one study, the effects of nutrient ratios on hydrogen gas production by batch dark fermentation of waste peach pulp was investigated using statistical experiment design. The effluent of dark fermentation experiments were used for H_2 gas production by electrohydrolysis [17]. In our previous studies, raw organic wastes such as leachate, olive mill wastewater, anaerobic sludge were used to produce hydrogen gas by electrohydrolysis [4,5,18,19]. In some studies, PVC panels were used as electrical energy source for H_2 gas production by electrohydrolysis from organic wastes [6]. Different electrodes were tested in electrohydrolysis studies and aluminum electrodes were found as the most effective one due to its high electrical conductivity [7]. Based on literature reports, hydrogen gas production from food wastes by electrohydrolysis was not investigated.

Electrohydrolysis of food waste with high organic content to produce hydrogen gas is a novel and promising method. A Box-Behnken statistical experiment design approach was used in this study to investigate the effects of important operating variables (applied voltage, solids content of the waste and operation time) on the rate and extent of hydrogen gas production and also on total organic carbon (TOC) removal from the food waste.

Design of experiments

The effects of variables on the response are a complicated and observed by means of the mostly known approach which is altering one factor at a time for multivariable systems. However this technic is not usable for estimation of responses. So, some experimental statistical design should be used for optimization of the reaction conditions. For this aim, several significant parameters are determined by response surface methodology. This method as called as RSM. This design contains 3-level factorial design, central composite design (CCD) [20,21], Box-Behnken design [22] and D-optimal design [23]. Between all the RSM designs, Box-Behnken design needs fewer runs than the other RSM designs. This design allows and shows to efficiency at intermediate levels not experimentally studied [24,25].

The mathematical relationship which is offered by Box-Behnken design application between the dependent variables (Y) and the independent variables (X) can be approximated by a (second-order) polynomial equation as follows:

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 \quad (2)$$

This approach was selected to predict a potential response function. A total of 15 experiments are demanded to determine 9 coefficients of the quadratic equation. This regression model includes one block term, three linear terms, three quadratic terms, and three interaction terms.

The main aim of this study is to observe and interpret the effects of the applied voltage, reaction time and initial solid content on percent hydrogen gas production, cumulative hydrogen gas production and percent total organic carbon removals from food wastes by electrohydrolysis method which is arranged by Box-Behnken design approach.

Materials and methods

A power supplier and two aluminum electrodes were used as shown in Fig. 1. Food waste obtained from the university kitchen was filled into bottles. Aluminum electrodes were immersed inside the bottles and connection of power supply to the system was done by wires. The bottles were closed very tightly using silicone rubber stoppers and screw caps. In addition silicon was used to seal the bottles and to eliminate any gas leakage from the bottles. Aluminum electrodes were pure aluminum with diameters of 4 mm, lengths of 20 cm and weight of 30 g each. Distance between the electrodes was 2 cm.

Experiments were performed at room temperature using 300 mL food waste. Water content of food waste was 75%. Food waste was homogenized by using a mixer. Water added in food wastes to adjust the solid content. Solid content value in food waste was arranged by different kind of foods. The raw food waste contained 43 mg/g TOC, 23.5 g/L total solids with a pH of 4.67 and ORP of 66 mV.

The voltage which is applied to system was nearly kept stable throughout experiment. However, during experiments the current intensities (mA) altered due to variations in the reaction mechanism and changes in the waste composition. These changes caused the corrosion on the electrodes. So, current intensities were continuously reported by the power supply unit and were also recorded by using a multimeter

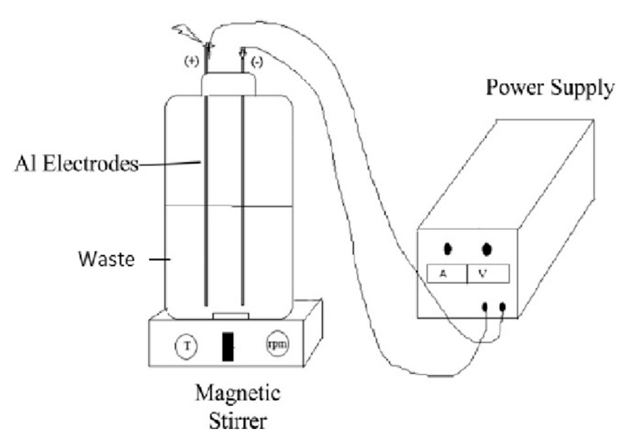

Fig. 1 – The experimental set-up.

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