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Improvement on efficiencies of water electrolyzer using packed-bed electrodes

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ABSTRACT

In the present work, efforts have been made to increase the efficiency for electrolytic production of hydrogen from dilute acidic/alkaline water by increasing the surface area of electrodes using novel packed-bed electrodes instead of conventional plate electrodes. While aqueous 20–30% (w/v) KOH solution is normally used commercially, the feasibility of using dilute solutions has been studied. Acidic medium has been found to be unsuitable due to rapid corrosion and low current efficiency. In alkaline media, packed-bed electrodes have been found to exhibit better current and energy efficiencies compared to plate electrodes. Interestingly, solid packings exhibited higher efficiencies than hollow packings even though hollow packings have 25% greater surface area. Oxidation of electrode materials seems to be partially responsible for this drop in efficiency. Entrapment of produced gases inside the hollow packings may also play an important role.

Introduction

Hydrogen is a well known green fuel whose importance is rising. Among the processes for production of hydrogen, water electrolysis is the cleanest technology if the electrical source is renewable like solar, wind, hydro. However efficiency of electrolytic process is relatively low. Current efficiencies presently attained by commercial water electrolysis processes have been reported to vary between 80 and 95% [1] but no model or detailed explanation for this loss in current efficiency is available in literature. Surface area of electrodes may play a major role in deciding the current efficiency of the process as the increased surface area of the electrodes reduces the electrical resistance resulting in decrease of over potential required for production of hydrogen [2–4]. Flat plate electrodes are normally used for electrolysis of water. Sometimes electrodes with different geometries or configurations, like finned bodies, screens, perforated/porous structures, cylindrical/spherical, nano-scale coating on surface of electrodes have been used [2–11] primarily for increasing electrode surface area. Packed-beds can also increase surface area of electrodes if used as such, but have not been investigated. Investigations are also being carried out using different electrode materials like $NiCo_2O_4$, Ni–Co, Ni–Fe, Ni oxide [12], Raney-Ni, mixed metal oxides [13], etc. This work is therefore aimed at investigating the electrolysis of dilute acidic/alkaline water using different configurations of packed-bed electrodes made of stainless steel (SS 316).

Materials & methods

Cell components

The electrolytic cell consists of two major components: electrolytes and electrodes.

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Electrolytes

Dilute aqueous acidic/alkaline solutions were used as electrolytes. Following reagents (compositions are in wt%) were used for different media:

Acidic medium. Specifications of Hydrochloric acid (HCl) used has been given below:

Specific gravity: 1.18	HCl: ≥ 35.4%	Free chlorine (Cl): ≤0.002%
Sulfate (H_2SO_4): ≤0.02%	Sulphite (SO_3): ≤0.04%	Arsenic (As): ≤0.0002%
Heavy metals (Pb): ≤0.0005%	Iron compound (Fe): ≤0.0001%	

Alkaline medium. Compositions of Potassium hydroxide (KOH) used to prepare electrolytes are as follows:

KOH: ≥84%	Water: 10–15%	N compounds: ≤0.001%
K_2CO_3: ≤2.0%	Chloride (Cl^-): ≤0.01%	Phosphate (PO_4^{3-}): ≤0.05%
Sulfate (SO_4^{2-}): ≤0.003%	Ca: ≤0.005%	Fe: ≤0.001%
Mg: ≤0.002%	Na: ≤0.05%	Ni: ≤0.001%
Heavy metals (as Pb): ≤0.001%		

Electrodes

Two types of packing materials made of Stainless steel (SS 316) – Solid and Hollow cylinders were used to fabricate packed-bed electrodes as shown in Fig. 1(a) and (b), respectively. The specifications of solid and hollow cylindrical packing materials used in the investigation have been given in Table 1. Surface area of each hollow packing was higher than that of solid packing, being the ratio of surface area (Hollow: Solid) of 1.33:1. Packing materials were randomly packed in an electrically non-conducting cylindrical cage of polypropylene net as shown in Fig. 1(c) and (d). 250 pieces of packings were put in each electrode cage. The cages were closed at bottom and designed to hold the packing materials in an overall cylindrical shape. Average length and diameter of the packed-bed electrodes were 13.3 cm & 3.3 cm for Electrode I and 14.2 cm & 3.2 cm for Electrode II, respectively as given in Table 1. The void fraction of electrodes was about 77% using hollow packing while 57% using solid packing. The electrodes were connected to an external DC power source by conducting rods (diameter: 3.54 mm) of SS 316L which were inserted into the packed bed to serve as electrical contact.

Flat plate type electrodes made of SS 316 with length same as length of the packed-bed and width same as the diameter of the bed have also been used for comparison purpose. The thickness of the flat plate electrodes was 0.5 mm.

Methods

Experiments were performed in the setup shown in Fig. 2. The electrolytic cell made of electrically non-conducting Perspex

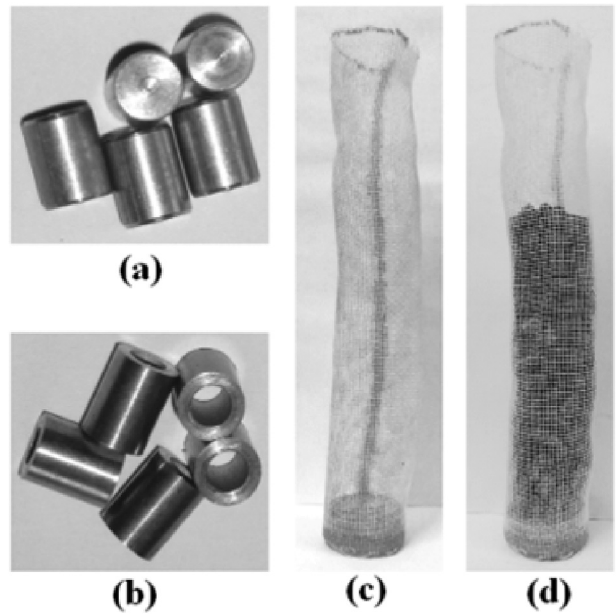

Fig. 1 – (a) Solid packing materials, (b) Hollow packing materials, (c) Cylindrical cage of non-conducting polypropylene net to hold the packing materials, and (d) Packed bed electrodes randomly packed by SS 316 solid cylindrical packing materials.

tube and sheets, consisted of two compartments (inner diameter and height of each compartment were 8 cm and 28 cm, respectively) which were connected by a narrow rectangular conduit (size: 15 cm × 4.5 cm × 4 cm). The distance between two electrodes was fixed at 5.5 cm throughout the experiment. Voltage applied to and current passing through the cell were measured by a pair of multimeters (Mastech – MS8240D) connected in parallel and series to the cell, respectively. A computer data logger system was used to collect and record the data at intervals of 0.5 s. Temperature and manometer readings were recorded at intervals of 1 h, for a period of 6 h. Three litres of electrolyte solutions required for each experiment were prepared using double distilled water (pH = 7). Experiments were carried out at ambient temperature of about (33 ± 4)°C. The gases produced were collected separately in two storage tanks (S_1 and S_2) by downward

Table 1 – Specifications of packed-bed electrodes and packing materials of electrodes.

Hollow packing		Solid packing	
Length, cm	0.8	Length, cm	0.8
Outer diameter, cm	0.6	Diameter, cm	0.6
Inner diameter, cm	0.354	Surface area, cm^2	2.07
Surface area, cm^2	2.76		
Electrode I		Electrode II	
Height, cm	13.3	Height, cm	14.2
Diameter, cm	3.3	Diameter, cm	3.2
Void (Hollow packing), %	76.85	Void (Hollow packing), %	77.30
Void (Solid packing), %	57.18	Void (Solid packing), %	57.63