Renewable and Sustainable Energy Reviews 30 (2014) 164–169

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Overview on fuel cells

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ARTICLE INFO

Article history:
Received 30 July 2012
Received in revised form
17 September 2013
Accepted 26 September 2013
Available online 20 October 2013

Keywords:
Entropy generation
Fuel cells
Irreversibility

ABSTRACT

Progress always requires energy. Up today, the energy needs have been provided by combustion of fossil fuels and this has increased the air pollution and the emission of greenhouse gasses. Consequently, the greenhouse emission problem could represents a concrete opportunity to promote the high-efficiency design of conventional plants, but also a new approach to energy systems and the consequent dissemination of advanced technologies. One of the most promising energy conversion technology is the fuel cell because it is an electrochemical device in which the chemical energy is directly converted into electrical energy, with low environmental impact. In this paper the losses of the fuel cells has been analysed.

Contents

1. Introduction

In the course of time, progress has always been associated with the growth of requirement for energy. Up today, the energy needs have been provided by combustion of fossil fuels and this has increased the air pollution and the emission of greenhouse gasses, such as CO_2, in particular in urban area. One of the main problem of the industrialized country is just the management of CO_2 emissions [1–5]. The Kyoto Protocol suggestion of the reduction of the CO_2 emissions can be attained by three primary actions:

1. renewable energy sources;
2. CO_2 sequestration whose estimated investment costs are very high and for this reason it is difficult to be carried out;
3. promotion of existing high efficiency technologies and the adoption of advanced low-CO_2 emission energy systems; indeed, CO_2 reduction is directly related to the thermodynamic efficiency of a plant and an energy policy to promote best existing technologies and their adoption could be developed.

Consequently, the CO_2 emission problem could represents a concrete opportunity to promote the high-efficiency design of conventional plants, the new approach to energy systems and the consequent dissemination of advanced technologies.

In this context, one of the most promising energy conversion technology is the fuel cell [6–19]. In this paper an overview on fuel cell and the thermodynamic approach to irreversibility in fuel cell will be developed. To do so in Section 2 and overview on fuel cell will be summarized, in Section 3 a general thermodynamic approach to fuel cell will be introduced, in Section 4 the irreversibility will be introduced and some numerical evaluation will be presented and in Section 5 some perspectives of fuel cells use will be suggested.

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1364-0321/$ - see front matter
http://dx.doi.org/10.1016/j.rser.2013.09.025

Table 1
Fuel cells classification.

Characteristics	Polymer electrolyte	Alkaline	Phosphoric acid	Molten carbonate	Solid oxide
Fuel cells					
Operating temperature [°C]	40–80	65–220	205	650	600–1000
Electrolyte	Hydrated polymeric ion exchange membrane	Mobilized or immobilized potassium hydroxide in asbestos matrix	Immobilized liquid phosphoric acid in SiC	Immobilized liquid molten carbonate in $LiAlO_2$	Perovskites (ceramics)
Electrodes	Carbon	Platinum	Carbon	Nickel and nickel oxide	Perovskite and perovskite/metal cermet
Catalyst	Platinum	Platinum	Platinum	Electrode material	Electrode material
Interconnect	Carmon or metal	Metal	Graphite	Stainless steel or nickel	Nickel, ceramic or steel
Charge carrier	H^+	OH^-	H^+	CO_3^+	O^-

Table 2
Come fuel cells reactions.

Fuel cell kind	Reaction at the anode	Reaction at the cathode
Polymer electrolyte and Phosphoric acid	$H_2 \rightarrow 2H^+ + 2e^-$	$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$
Alkaline	$H_2 + 2OH^- \rightarrow 2H_2O + 2e^-$	$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$
Molten carbonate	$H_2 + CO_3^{2-} \rightarrow H_2O + CO_2 + 2e$-	$O_2 + CO_2 + 4e^- \rightarrow 2\ CO_3^{2-}$
	$CO + CO_3^{2-} \rightarrow\ 2CO_2 + 2e$-	
Solid oxide	$H_2 + O^{2-} \rightarrow H_2O + 2e^-$	$O_2 + 4e^- \rightarrow 2O^{2-}$
	$CO + O^{2-} \rightarrow CO_2 + 2e^-$	
	$CH_4 + 4O^{2-} \rightarrow 2H_2O + CO_2 + 8e^-$	

2. The fuel cells

Fuel cell is an electrochemical device in which the chemical energy is directly converted into electrical energy [13,14].

In 1801, the British chemist Humphry Davy (1778–1829) developed his researches on electrolysis using the voltaic pile in order to split up common compounds discovering several new metals, as sodium, potassium and the alkali metals [20]. He laid the scientific foundations for the fuel cells, then designed in 1838 by the German-Swiss chemist Christian Friedrich Schönbein (1799–1868) [21]. In 1839, the Welsh chemical-physicist William Robert Grove (1811–1896) realized the first gas voltaic battery with which he proved that an electrochemical reaction between oxygen and hydrogen produce an electric current [22,23]. The British chemist Ludwig Mond (1839–1909) and Charles Langer used coal as fuel and introduced the term fuel cell obtaining 20 Am^{-2} at 0.73 V [23]. In 1932, the British engineering Francis Bacon modified the Langer's and Mond's cell realizing, in 1958, the first alkaline fuel cell, used later in Apollo spacecraft, and in 1959 he was able to obtain 5 kW system which was really used, with a power of 15 kW, in an agricultural tractor by Harry Karl Ihrig. At the end of the 1950s NASA developed fuel cells for space missions: Willard Thomas Grubb and Leonard Niedrach designed the first Polymer Electrolyte Membrane Fuel Cell, used by NASA in Gemini space programme, while a 1.5 kW Alkali Fuel Cell has been used in Apollo space missions, providing the astronauts both power and drinking water; later, a 12 kW AFC has been used in space shuttle. Since 1970, an interest for use of fuel cells in electric vehicle is growing up today, and since 2007 they are commercialized [24–26].

The core of the fuel cells is the unit cell, the component in which the device converts the chemical energy in electrical energy. It consists of an electrolyte in contact with an anode (negative electrode) and a cathode (positive electrode). The fuel cells are classified in relation to their electrolytes and fuels used as follows [24,25]:

1. PEMFC (proton exchange membrane or polymer electrolyte membrane fuel cell) uses a water-based, acidic polymer membrane as the electrolyte and platinum-catalysed electrodes. It uses pure hydrogen, but also reformed natural gas, removing carbon monoxide. Its operative temperature is below 100 °C;
2. HT-PEMFC (high temperature PEMFC) is a PEMFC obtained by changing the electrolyte from a water-based to a mineral acid-based system. It operates up to 200 °C;
3. DMFC (direct methanol fuel cell) uses a polymer membrane as the electrolyte and the platinum–ruthenium catalyst on its anode uses the hydrogen from liquid methanol directly;
4. MCFC (molten carbonate fuel cell) uses a molten carbonate salt suspended in a porous ceramic matrix as the electrolyte with coal-derived fuel gas, methane or natural gas, operating at temperatures of about 650 °C;
5. PAFC (phosphoric acid fuel cell) consists of an anode and a cathode made of a finely dispersed platinum;
6. catalyst on carbon and a silicon carbide structure that holds the phosphoric acid electrolyte. It operates up to 200 °C;
7. SOFC (solid oxide fuel cell) uses a solid ceramic electrolyte;
8. AFC (alkaline fuel cell) uses an alkaline electrolyte and is fuelled with pure hydrogen and oxygen.

Their properties are summarized in Table 1 while some fuel cells reactions are summarized in Table 2 [28–36]. Today, fuel cells can be applied in power systems as follows [26,27]:

1. in the rang 1 W–10 kW: cell phones, personal computer and personal electric equipments;
2. in the range 1–100 kW: power vehicles and public transportation;
3. 1–10 MW: power systems for energy.