

Available online at www.sciencedirect.com

SciVerse ScienceDirect

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

Energy and exergetic evaluations of Bunsen section of the sulfur–iodine thermochemical hydrogen production plant

Saeed Dehghani, Hoseyn Sayyaadi*

Faculty of Mechanical Engineering-Energy Division, K.N. Toosi University of Technology, P.O. Box: 19395-1999, No. 15-19, Pardis Str., Mollasadra Ave., Vanak Sq., Tehran 1999 143344, Iran

ARTICLE INFO

Article history:

Received 26 January 2013

Received in revised form

22 April 2013

Accepted 6 May 2013

Available online 10 June 2013

Keywords:

Bunsen reaction

Energy and exergy analysis

Efficiency

Sulfur–iodine cycle

Thermochemical hydrogen production

ABSTRACT

Hydrogen is the main product of sulfur–iodine (S–I) thermochemical cycle which is generated from water as a feed. In this cycle, water is splitted into hydrogen and oxygen through several chemical processes. The required heat energy for supplying thermal process demands of the cycle can be provided from nuclear energy or concentrated solar energy sources. This cycle consists of three main sections, in which water reacts with recyclable intermediate compounds of sulfur and iodine as follows: (I) Bunsen reaction section, (II) sulfuric acid decomposition and (III) hydrogen iodide decomposition. Bunsen reactor produces two main acidic solutions for facilitating water decomposition in other sections. In this paper, the Bunsen reactor was evaluated through a comprehensive energy and exergy analyses. Performance of the Bunsen reactor was analyzed by applying diverse parametric studies on aspects of energy and exergy as a function of the reaction variable and reference-environment temperatures. At a constant reaction temperature of 125 °C, the exergetic efficiency varied from approximately 97%–98.5% when the reference-environment temperature increased from –25 °C to 55 °C while these values for reference-environment temperature of 25 °C were in the range of 97.3%–97.5% in the reaction temperature range of 115 °C–135 °C.

Copyright © 2013, Hydrogen Energy Publications, LLC. Published by Elsevier Ltd. All rights reserved.

1. Introduction

Nowadays, depletion of fossil fuels' limited resources and increasing the quantity demanded of energy carriers on the one hand and global warming issues due to greenhouse gas emissions on the other hand have encouraged researchers to investigate new sources of energy. Among new energy carriers, hydrogen is the most promising one which can be applied in extensive applications such as transportation systems and so on.

Hydrogen as an energy carrier not only provides diversity in energy carries but also brings some environmental and economic benefits. Utilization of hydrogen as a new energy carrier has its own opportunities and challenges. Great technological progress has resulted from change in energy carrier. From this standpoint, hydrogen becomes one of the most important energy carrier alternatives [1].

There are various methods for hydrogen generation, as addressed in [2]. Selection of the suitable process is recommended to be performed based on the five following criteria:

* Corresponding author. Tel.: +98 21 8406 3212; fax: +98 21 8867 4748.

E-mail addresses: sayyaadi@kntu.ac.ir, hoseynsayyaadi@gmail.com (H. Sayyaadi).

Nomenclature		ΔG	Change in Gibbs function for a reaction, kJ
\dot{E}	Energy, kW	<i>Greek letter</i>	
\dot{E}_x	Exergy rate, kW	Δ	Finite change in quantity
\bar{e}_x^{ch}	Specific molar chemical exergy, kJ/mol	η_{ex}	Exergy efficiency
\bar{g}	Specific molar Gibbs free energy, kJ/mol	<i>Subscripts</i>	
\bar{g}_f°	Specific molar Gibbs free energy of formation, kJ/mol	0	Reference state
\dot{H}	Total enthalpy rate, kW	des	Destruction
\bar{h}	Specific molar enthalpy, kJ/mol	f	Formation
\bar{h}°	Specific molar enthalpy, kJ/mol	in	Inlets
\bar{h}_f°	Specific molar enthalpy of formation, kJ/mol	out	Outlets
M	Molar mass, kg/kmol	P	Product
\dot{m}	Mass flow rate, kg/s	R	Reactant
\dot{n}	Molar rate per cycle, mol/s.molH ₂	rxn	Reaction
\dot{Q}	Heat rate, kW	sys	System
R	Gas constant, J/mol.K	Mix	Mixture
\bar{s}	Specific entropy, kJ/mol.K	<i>Superscripts</i>	
\bar{s}°	Specific entropy at reference state, kJ/mol.K	·	Quantity per unit time
\bar{s}_f°	Specific entropy of formation, kJ/mol.K	-	Quantity per unit mole
T_{rxn}	Reaction temperature, K	°	Standard reference-state
T_0	Reference-environment temperature, K	<i>Acronyms</i>	
G	Gibbs function, kJ	CEA	Commissioner to Atomic Energy
P	Pressure, bar	GA	General Atomics
T	Temperature, °C	HYTHEC	Hydrogen by Thermochemical Cycles
V	Velocity, m/s	JAERI	Japan Atomic Energy Research Institute
Y	Molar ratio	I-NERI	The International Nuclear Energy Research Initiative
Z	Elevation, m		

(1) Within the temperature range, ΔG of each reaction should be very small, approaching zero. This is the most important criterion. (2) It should have minimal step reactions. (3) Each step reaction should have fast rates of reaction on the one hand and similar rates to other reaction steps in the process. (4) Chemical by-products should not be formed in reactions. Moreover, minimal energy and cost should be consumed for separation of the reaction. (5) Intermediate products should be handled easily [2].

Thermochemical processes are one of the technologies for producing hydrogen from water, which have attracted researcher's attention [3]. The sulfur–iodine (S–I) and copper–chlorine water splitting cycles are the most promising thermochemical methods for producing hydrogen. These two cycles were compared from the aspects of heat grade and quantity, thermal efficiency, engineering challenges and cost of hydrogen production cost by Wang et al. [4]. The sulfur–iodine water-splitting cycle is also known as the ISPR Mark 16 and was developed by General Atomics. It was originally developed in the United States to split water by high-temperature heat from nuclear power plants [5].

French CEA has started an integrated program since 2002 in order to produce hydrogen using the high temperature heat available from the fifth generation of nuclear reactors [6]. Also, they proposed a new flowchart for sulfur-iodine cycle within the collaborative framework of International Nuclear Energy Research Initiative Project (I-NERI) with the United States Department of Energy (DOE) at General Atomics [7]. Lybros

et al. [7] considered effects of operational parameters including possible decrease of excessive amounts of iodine and water, reaction temperature and phase separation on the Bunsen reaction. Based on their analysis, a countercurrent reactor was developed for the Bunsen reaction.

In 1981, the GA studied working principles of the countercurrent heat exchanger reactor [8]. JAERI [9] continued the study in 2003 and an alternative flowsheet utilizing a countercurrent multiphase reactor was developed by CEA in 2009 [7].

The European project named “HYTHEC” (Hydrogen by Thermochemical Cycles) conducted a research for developing flow-sheeting, industrial scaling-up, safety and cost modeling and developing fundamental concept and efficiency analysis of the S–I cycle thermochemical hydrogen production cycle. Moreover, they investigated application of the solar energy for providing heat demands of the S–I cycle [10].

In the range of various primary energy sources, nuclear energy is a promising energy source for larger scale thermochemical production of hydrogen by water splitting cycles. Especially, the sulfur–iodine thermochemical cycles seem to be the best option for being integrated to the fifth generation nuclear reactors called Very High Temperature Reactor (VHTR). One advantage of the sulfur–iodine cycle is well-developed knowledge and flowsheets for the sulfuric acid concentration and the decomposition section as the sulfuric acid process is widely utilized in chemical and petrochemical plants. Moreover, the required heat in the sulfuric acid section matches with the generated heat of the VHTR [11].

Download English Version:

<https://daneshyari.com/en/article/7722245>

Download Persian Version:

<https://daneshyari.com/article/7722245>

[Daneshyari.com](https://daneshyari.com)