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Modelling of hydrogen production from hydrogen sulfide in geothermal power plants

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ABSTRACT

Geothermal power plants emit high amount of hydrogen sulfide (H_2S). The presence of H_2S in the air, water, soils and vegetation is one of the main environmental concerns for geothermal fields. There is an increasing interest in developing suitable methods and technologies to produce hydrogen from H_2S as promising alternative solution for energy requirements. In the present study, the AMIS technology is the invention of a proprietary technology (AMIS® - acronym for "Abatement of Mercury and Hydrogen Sulfide" in Italian language) for the abatement of hydrogen sulphide and mercury emission, is primarily employed to produce hydrogen from H_2S. A proton exchange membrane (PEM) electrolyzer operates at 150 °C with gaseous H_2S sulfur dimer in the anode compartment and hydrogen gas in the cathode compartment. Thermodynamic calculations of electrolysis process are made and parametric studies are undertaken by changing several parameters of the process. Also, energy and exergy efficiencies of the process are calculated as % 27.8 and % 57.1 at 150 °C inlet temperature of H_2S, respectively.

Introduction

One of the most important enviromental issues related to the geothermal operating fluids to generate electricity is non-condensable gases emission. Vent stacks in geothermal plants emit carbon dioxide (CO_2) and methane (CH_4) gases which consequently raise serious concerns in terms of greenhouse gases. The amount of these emissions are quite small compared to carbon and fossil fuel plants, which indicates that the contribution of these sources is practically negligible. Geothermal power plants also emit higher amount of hydrogen sulfide (H_2S) due to the employment of H_2S as a main constituent of the geothermal fluids. The presence of H_2S in the air, water, soils and vegetation is one of the main enviromental concerns [1].

Hydrogen sulfide is a colorless water-soluble gas, smelling as rotten eggs and is known for this putrid gas. Its origin may be natural (about 90% of the total H_2S in the atmosphere given by EPA, [2]) as gas species produced by anaerobic bacterial reduction of sulfur-containing animals and vegetable proteins and as gas released from volcanoes and geothermal areas. The artificial origin of hydrogen sulfide derives from the production process of coking coal, cellulose, fertilizers, dyes and pigments, refinement of crude petroleum, tanning of hides and waste water treatment.

Background concentrations of H_2S in unpolluted ambient air have been estimated to be between 0.14 and 0.4 $\mu g/m^3$ [2],

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whilst the typical concentration in urban area is about one order of magnitude higher (1.0–3.0 μg/m^3 [3]). The high air levels of H_2S are measured near waste-water treatment plants, oil refineries, and land-fills (from a few units to a few tens of mg/m^3 [4], as well as in volcanic and geothermal areas, where H_2S is likely formed by water-rock interaction, which is accelerated by the high heat gradient induced by the presence of a cooling magma body. In these situations, the H_2S is released in the atmosphere by hot vents and hot springs.

H_2S is normally in gas phase and can be absorbed in lungs through inhalation. Health effects include respiratory, ocular, neurological, and metabolic effects and the death after single exposures to concentrations higher than 700 mg/m^3 [4]. A summary of these effects is presented in Table 1.

Due to resources depletion and non-sustainable resources, fossil fuels are not capable of compensating the growing energy needs. In addition, the easily extractable fossil fuels are facing an increase in their prices. It is worth mentioning that greenhouse gases (mainly CO_2) have been accumulated in the atmosphere by burning fossil fuels. Therefore, clean and sustainable energy has become much more important and researches have been intensified to make it more affordable and productive.

High efficient, environmentally benign, more feasible and societal are among the main advantages of clean energy systems. In order to achieve afore-mentioned goals, the following criteria should be met by a clean energy system: (i) zero or ignorable undesirable environmental or societal influence; (ii) ignorable or zero natural source exhaustion; (iii) capability to provide the current and forthcoming population's energy needs; (iv) trustworthy, cheap and effective fashion; (v) air, land, and water safety; (vi) insignificant or zero net Greenhouse Gas (GHG) emissions; and (vii) ignorable burden to prospect generations [5].

It can be seen that hydrogen has number of advantages such as higher energy exchange efficiency, possessing no emission while it is produced from water and employed energy is renewable based. Furthermore, it has capability to be stored in various ways and inherently is an ample energy carrier and easy to be transferred with least loss [6]. An amount of 120.7 MJ (LHV) energy can be obtained from 1 kg hydrogen which is equal to 2.1 kg natural gas, 2.8 kg gasoline and 3.1 kg fuel oil as illustrated in Fig. 1.

Considering these advantages, the current research is mainly dealing with hydrogen energy systems in order to produce hydrogen in a more affordable, reliable and efficient way with minimum environmental impacts. Determining the most suitable hydrogen generation method depends on various number of system characteristics, such as feasibility, technical aspects, resource accessibility, geographic position, climate features, affordability and reliability play an important role to detect the most beneficial hydrogen generation technique.

Electrolysis technology is considered as an effective and practical method to produce hydrogen via electrochemical reactions. Different electrolyzer types for hydrogen production include alkaline electrolyzer (AEL), polymer electrolyte membrane electrolyzer (PEMEL), and high temperature electrolzyer (HTEL). Alkaline electrolysis is more accepted technology in industrial technology and large scale units as a prevalent technology. Employing cheap materials, high durability due to the employment of robust cell separators, and more corrosion resistivity of stainless steel in 30% KOH can be considered as the main advantages of this technology. At the same time, there are specific drawbacks for alkaline systems including difficulty in handling of sodium or potassium hydroxide electrolyte, hard to reach high-pressure hydrogen production in case the storage tank size puts known limitations and limited operating temperature for the systems (80 °C) in order to support moderate current density. In contrast, recent acid PEMEL systems owe specific technical advantages compared to alkaline systems, especially once integrated with renewable energies. In comparison to alkaline systems, PEM systems show better efficiency and higher production rates. Through applying a static vapor feed configuration, PEM systems can also be further simplified which in turn, leads to further decrease in operation costs and equipment footprint. Response time in start-up and shutdown of PEM systems are almost ignorable and larger loads can be handled by this technology without problem. Up to 350 bar high-pressure operational condition can be achieved. This is

Table 1 – Human health effects resulting from exposure to H_2S [4].

Exposure (mg/m^3)	Effect/Observation
0.011	Odor threshold
2.8	Bronchial constriction in asthmatic individuals
5.0	Increased eye complaints
7.0–14.0	Increased blood lactate concentration, decreased oxygen uptake
5.0–29.0	Eye irritation
>140	Oldfactory paralysis
>560	Respiratory distress
≥700	Death

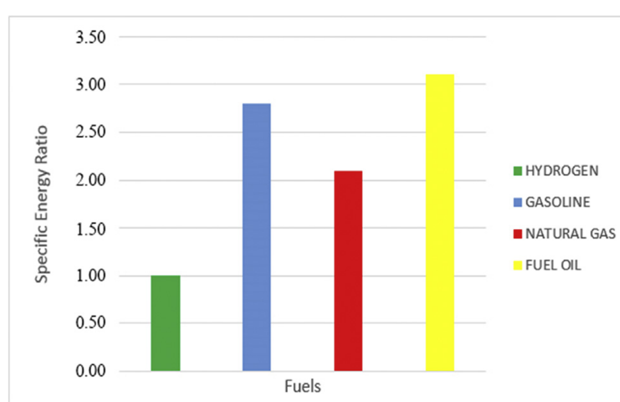

Fig. 1 – Quantities required to obtain energy from fossil fuels that can be obtained from one kilogram of hydrogen (data from Ref. [7]).

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