Letter to the Editors on the feasibility of thermochemical and bacterial hydrogen production methods for nuclear systems

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Abstract

Multiple hydrogen production methods were investigated for implementation in a nuclear system that generates electricity, hydrogen, and biofuels. The Br-Ca-Fe (UT-3) and the Sulfur-Iodine (SI) hydrogen production cycles are two appealing thermochemical methods for commercially producing hydrogen using heat from a high temperature nuclear reactor. Bacterial hydrogen production methods were also investigated for their commercial feasibility. The UT-3 process was found to be the most favorable for our purposes out of the three hydrogen production methods investigated, and was chosen overall as the desired hydrogen production process for this project.

1. Introduction

The overall design problem being addressed with this study is the development of a nuclear reactor system which can produce at least 100 megawatts of electrical energy (MWe), hydrogen, and synthetic biofuels. The main motivation behind this design problem is the concern over climate change from human generated greenhouse emissions, and also the desire to reduce dependence on foreign sources of fossil fuels to ensure domestic energy security. Nuclear power provides an greenhouse emission-free source of base-load electricity which eliminates a portion of our greenhouse emissions from coal-fire power plants. However, oil, the fuel relied on most heavily for transportation today, is a substantial greenhouse emission source, and much of the oil consumed domestically is imported from various foreign sources. To ensure domestic energy security and lower greenhouse emissions, biofuels and hydrogen have been presented as domestic, green alternatives to conventional oil products. The production of hydrogen and biofuels is largely an energy intensive process, and thus requires an greenhouse emission free source of energy to produce carbon neutral products. Thus, nuclear heat can be used to produce hydrogen and biofuels domestically and with zero net greenhouse emissions.

2. Background

The objective for our sub-group was to develop a hydrogen production plant for use in the design project. The preliminary design decision was to determine what the purpose of the hydrogen production plant would be, either for mass producing hydrogen for sale in a future hydrogen economy, or providing enough hydrogen for mass production of biofuels at the nearby plant. The ultimate decision for the latter purpose for the hydrogen plant was made due to the uncertainty of a future hydrogen economy, resulting from distribution infrastructure issues that could render such an infrastructure economically and technically inviable [2]. Biofuels are already being used in small quantities in gasoline and diesel engines today, and can be used in greater concentration with modifications to current internal combustion engine designs [5]. From these economical and technical considerations, the choice was made to produce hydrogen solely for mass biofuel production, 0.1 kg per second at 4 bar pressure. The main challenges for the group were to determine the hydrogen production methods that could yield the quantity of hydrogen the biofuel group requested, and to address the material concerns from chemical, temperature, and pressure requirements, and emissions from each particular hydrogen production process of interest.

3. Results

The main design considerations used to compare hydrogen production methods were: the maximum of temperatures required for each process, the commercial viability of each approach, and material considerations that could jeopardize the reliability and longevity of the plant. Four major hydrogen production methods were investigated: water electrolysis, high-temperature steam electrolysis, thermochemical water splitting, and bacterial hydrogen production. Other hydrogen production methods using natural gases were quickly rejected due to the requirement for greenhouse gas emissions for the production of hydrogen, which compromises an overall design goal of a greenhouse emission-free nuclear system. Material concerns dominate the high temperature steam electrolysis and thermochemical water splitting due to relatively high temperatures (500-900 C) and corrosive reactants and products, whereas the concern over commercial viability dominates the water electrolysis and bacterial hydrogen production methods.

My contribution to the hydrogen production research process was investigating the Sulfur-Iodine (SI), Br-Ca-Fe (UT-3), and bacterial hydrogen production processes in detail to determine their feasibility for our purposes. Dark fermentation hydrogen production was determined to be the most commercial viable bacterial method; however, the rather large volume required for our desired hydrogen production rate coupled with the risk of system failure from biological contamination led to the rejection of this method for our purposes [3]. After investigating the two thermochemical processes mentioned, the UT-3 process was favored over SI since it occurs at a lower temperature, and has minor material concerns relative to the SI process [6]. The UT-3 reaction proceeds as follows at the various desired temperatures [4],

$$CaBr_2 + H_2O \rightarrow CaO + 2HBr \ (760\,C)$$

$$CaO + Br_2 \rightarrow CaBr_2 + \frac{1}{2}O_2 \ (571\,C)$$

$$Fe_3O_4 + 8HBr \rightarrow 3FeBr_2 + 4H_2O + Br_2 \ (220\,C)$$

$$3FeBr_2 + 4H_2O \rightarrow Fe_3O_4 + 6HBr + H_2 \ (560\,C)$$

The UT-3 process has been well demonstrated, and has been cited as both an economically and technically viable approach for commercial hydrogen production [1]. The UT-3 process can also be scaled specifically for our hydrogen production needs, 0.1 kg per second at 4 bar pressure. With these multiple advantages in favor of the UT-3 process, and with the favorability of UT-3 over processes researched by the other members of the group, UT-3 was chosen as the process for our hydrogen production plant.

4. Conclusion

After investigating the SI, UT-3, and bacterial hydrogen production processes, the UT-3 process was determined to be the most viable of the three for our purposes. Manageable material concerns and the proven commercial scalability of the UT-3 process were the major advantages that led to this result. In comparing UT-3 to other methods of hydrogen production investigated by other members of the group, it was determined that UT-3 is the most favorable of all the processes, and was chosen as the process for the hydrogen production plant. Next, the flow rates of reactants and heat required in multiple variations of UT-3 plant designs must be determined for our desired hydrogen output of 0.1 kg per second at 4 bar pressure. A storage system for hydrogen must also be developed to ensure some biofuel production capabilities even during hydrogen plant maintenance periods. Finally, material concerns should be addressed more rigorously to ensure the reliability and overall longevity of the hydrogen plant in accordance with the expected lifetimes of the biofuel fuel production plant and the nuclear reactor itself.

5. References

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