U.P.B. Sci. Bull., Series …, Vol. …, No. …, 2009 ISSN 1454-23xx

OPPORTUNITY OF HYDROGEN PRODUCTION IN A NUCLEAR CYCLE

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The development of Generation-IV nuclear reactors is mainly focused on providing noticeable advancements in safety, proliferation resistance and economics.

Hydrogen represents the energy carrier of the future. Hydrogen production involves only water based methods, among them the Sulphure- Iodine (S-I) thermochemical cycle which involves use of high temperature.

The Very High Temperature Reactor (VHTR) represents one of the candidates to deliver these high temperatures. The heat provided by the nuclear installation is used in a Hydrogen Production Plant (HPP) for hydrogen production. This system is completely separated from the nuclear part of the installation

The paper analyzes the VHTR main reactor parameters in order to determine the feasibility of hydrogen production and to provide key information on the results obtained by using S-I cycle.

Keywords: *Renewable energy, Nuclear Energy, Hydrogen production, VHTR.*

1. Introduction

Nuclear generated electricity will play a significant role in the world for the next century. Decreasing supplies of fossil fuels, along with the urge to decrease greenhouse gas emissions (Kyoto protocol established severe limitations in such gases), led to increasing research in the development of alternative energy sources and carrier.

As stated in different reviews [1], the International Generation-IV Initiative, a joint venture of different countries, established in 2000, aims to increase the research and development necessary for the development of a new generation of nuclear power plants. The activities are coordinated by an international "consortium", namely the Generation-IV International Forum (GIF). The Generation-IV equipments comprise both the nuclear powered reactors and their associated fuel-cycle facilities. The research in this direction is intended to deliver significant improves for reactors compared with current advanced light water reactors (the so-called Generation-III systems) in respect of economics,

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safety, environmental performance, and proliferation resistance. The Generation-IV power plants are expected to be commercially exploited by the end of 2030.

GIF members have identified six nuclear reactor systems that tend to meet the Generation-IV goals:

a. very high-temperature gas-cooled reactor(VHTR);
b. gas-cooled fast reactor(GFR);
c. sodium-cooled fast reactor(SFR);
d. lead-cooled fast reactor(LFR);
e. molten salt reactor(MSR);and
f. super-critical water-cooled reactor(SCWR).

The hydrogen represents an attractive energy carrier intended to be for the support of the increasing energy along with the opportunity of reducing greenhouse gases' emissions [2]. Nowadays most of the hydrogen is produced mainly from hydrocarbons. Despite this the raw material for a hydrogen production should be represented by carbon-free materials considering the increasing concentrations of greenhouse gases in the atmosphere. The water has a major advantage over hydrocarbons: the hydrogen produced from water turns back to water after its energy is extracted. If one can consider obtaining the hydrogen from water it should take into consideration the high temperature needed to split the water molecules into hydrogen and oxygen. There are a few power systems that can supply such temperature. One of them is the very high temperature reactor (VHTR) that can supply energy to electrochemical and thermochemical water-splitting processes (namely for the S–I cycle). Some other countries are urging to develop systems similar to the ones that the GIF group is developing. Among them there is South Korea [3] with a bold plan. They are conducting some focused research on developing the NHDD (Nuclear Hydrogen Development and Demonstration) reactor to compete to GIF's Gen IV reactors.

The S–I process is to be the technology to be coupled to a VHTR for obtaining hydrogen.

2. The Neutronic primary characteristics of the VHTR

In order to determine the primary characteristics of the VHTR concept and to provide the necessarily information for the second part of the Hydrogen production cycle, are calculated with WIMSD code, K-infinite versus burn-up.

WIMSD is a deterministic code for standard lattice neutron physics analysis, which performs a wide variety of calculations [4], such as neutron flux distribution and values of k- infinite and k-effective, solving the transport equations. By solving the transport equations, the code calculates:

- Reactivity
  - Reactivity coefficients
  - Flux and power distribution
  - Variations of inventory with irradiation
  - Poison burn-up
  - Actinide fission product inventory
  - Reaction rates and reaction rates ratio.

The simplified flowchart of WIMS calculations is the following:

- Input of geometry and composition of materials and calculate the basic pin cell in 69 groups
- Input of the detailed geometry and composition of the cell and calculate the fluxes, the cross sections and the k- infinite
- Buckling treatment and leakage correction
- Burn-up calculations.

Using the WIMSD code capabilities in this chapter it is presented simulations for the VHTR. The main input data are presented in table 1 [5].

Table 1

VHTR main input data

Fuel characteristic	**Unit**	**Value**
Fuel composition	Atoms/barn cm	U-235 9.24802E-03 U-238 3.67543E-02 C 7.87630E-01 O 7.82039E-02 Si 8.81594E-02 B-10 8.98535E-07 B-11 3.65101E-06
Fuel density UO_2	g/cm^3	10,62
Power density	MW/m^3	6,6
Fuel temperature	K	1373

Using the WIMSD code and the VHTR characteristics the k-infinite variation is presented in figure 1.

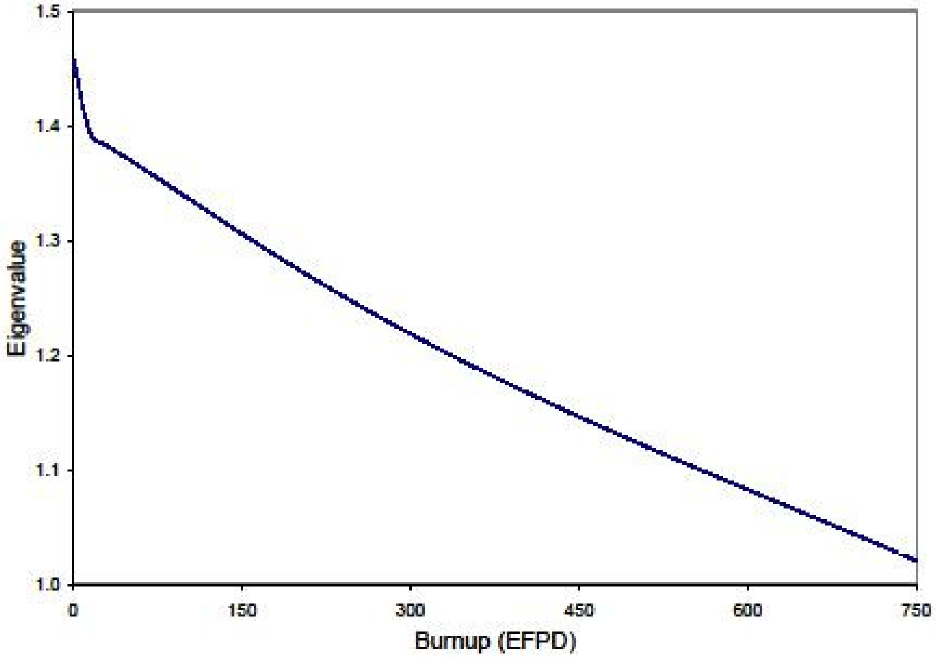

Fig.1. K-infinite for the VHTR in EFPD (Burn up in Effective Full Power Days)

From figure 1 one can observe that the k-infinite at BOL is 1.4673, and at EOL is 1.015. The critical burn up obtained is 66.67 GWd/tHM, and the discharge burn up is 100GWd/tHM.

From our results we determined that the optimal fuel temperature is 1373K.

All these characteristics will be used as input data for the second part of the paper.

3. The S-I technology

The S-I process, which will be discussed later on, utilizes an endothermic chemical reaction and sulfur and iodine cycles thus only requiring heat from a VHTR.

It can be said that research conducted in the area of hydrogen production with the help of an nuclear reactor is quite recent. Although the S-I cycle was first used by General Atomic in the 1970-1980 [6], the energy prices made these researches to reach their end prematurely. In the late 90s same company reached the conclusion that this thermochemical cycle has the highest efficiency among others a great opportunity for future improvement. The technology has been studied and developed by different countries as Korea, Japan, USA and others.

4. The S-I process

The S–I thermochemical process involves three steps as described in equations (1)-(3) and presented in Figure 1).

$$H_2SO_4\text{->}1/2O_2+SO_2+H_2O \qquad (1)$$

$$I_2+SO_2+2H_2\,O\text{->}2HI+H_2SO_4 \qquad (2)$$

$$2HI\text{->}H_2+I_2 \qquad (3)$$

The sulfuric acid decomposition step is made at high temperature requirements (over 800^0C) which can be satisfied by a VHTR reactor. This step is one of the key transformations in the S–I cycle. The decomposition of the sulfuric acid takes place in two steps. First the sulfuric acid is decomposed into H_2O and SO_3 and then the SO_3 is decomposed into SO_2 and O_2.

This step is followed by a so called Bunsen [7] transformation. With the help of water in this part, two kinds of acids are produced: H_2SO_4 and HI. Also this reaction is exothermal (about 120^0C). The Bunsen reaction products are separated and sent to decomposition. In this moment the conversion of O_2 and H_2 takes place at a high temperature (see equations 1 and 3).

The last section and the most important is represented by a hydrogen iodide concentration and decomposition part

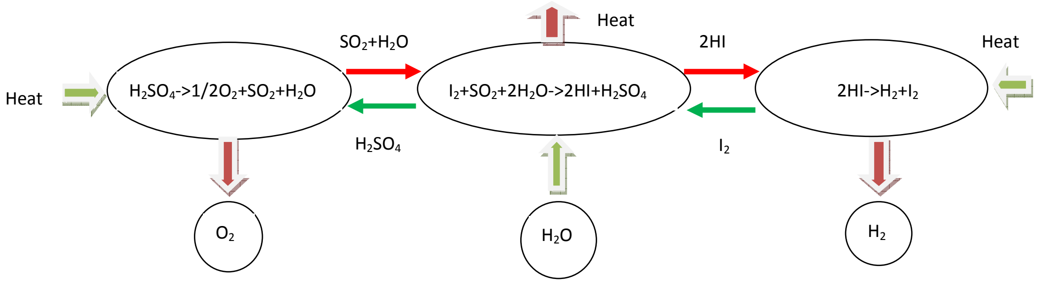

Fig. 1. The S-I cycle

5. Modeling prerequisites

The Sulphur Iodine (SI) cycle, involves three separate stages, as shown in Section 3. Starting from the cycle explained in the previous chapter a three step design has been made. Each of the reactions that take place in a certain area are represented by the equations of the S-I cycle as presented in Section 3. It has been considered that between each step of the process some mass exchange take place. The inlet parameters and the outlet parameters are represented by the species involved in the process. The volumetric approach has been considered which supposes that the reactions are taking place into the entire volume. The model sketch is presented in figure 2.

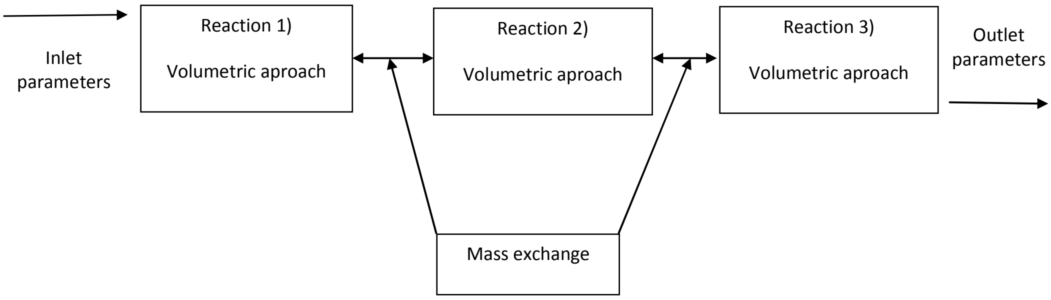

Fig. 2. The model description

6. Conclusions

The paper presents the combined use of two dedicated software used for the evaluation of the hydrogen produced with the help of a new, very high temperature reactor. First part of the paper described the results obtained withy WIMSD, computational software which can precisely predict different nuclear related parameters. The K inf was computed and determined the optimal working temperature for the VHTR. For this temperature the expected parameters [5] were obtained and presented.

The second part of the paper describes the technology used for obtaining hydrogen with the help of a VHTR nuclear reactor. The high temperature that this reactor can provide makes it the best suitable for obtaining hydrogen with great system efficiency. The S-I technology has been presented, the S-I process has been described and also the model prerequisites were taken into consideration. The model description along with it's limitations were used to create similar working conditions for the reactors used to obtain hydrogen using sulfuric acid cracked at a very high temperature. In order to take place, the reaction needs a temperature of 850^0C. The results obtained will be presented in a different paper.

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