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HYDROGEN PRODUCTION AND NUCLAR ENEGRY

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This topic is concerned with the hydrogen production connected to nuclear energy. This work describes some methods of hydrogen production that are the most perspective. These methods will be connected with generation IV. of the nuclear reactors. There will be described the chemical reactions in the methods of production and assumed cooperation with nuclear power plant.

Keywords : hydrogen, production, nuclear, reactor

Introduction

Hydrogen is the third most widespread element on the Earth. At standard conditions, hydrogen is colorless, odorless, non-toxic and highly combustible diatomic gas. It was discovered, described and for the first time synthetically produced by Henry Cavendish in 1766.

Hydrogen is very promising fuel for future because the products of its combustion are only energy and water. Greenhouse gasses aren't produced. Hydrogen can be used for direct combustion or for energy production by fuel cells. If the hydrogen could be used as energy carrier, it must be able to produce it in sufficient amount.

This topic deals with methods of hydrogen production. These methods have high requirements for the heat and electrical energy. One of the promising energy resources for hydrogen production is nuclear power plant. It can produce enough quantity of clean heat and electric energy. Problem of the recent nuclear power plants (GENERATION III and lower) is a low outlet temperature. There is a chance for GENERATION IV nuclear reactors that will be designed for high temperatures.

Review of the methods and applicable reactors

Electrolysis

Electrolysis is the best known method of hydrogen production. The water is decomposed to water and oxygen by using electricity and heat in case of high temperature electrolysis (HTE). A basic device for electrolysis is an electrolyzer. Low temperature electrolysis (LTE) works on temperatures about 100°C and it needs only electricity and water input in comparison with high temperature electrolysis (THE) which needs temperatures between 800 and 1000°C. Current nuclear reactors could be used for LTE, as source of electricity, but the output temperature is low for the HTE.

Electrolyzer is a basic device for electrolysis; it consists of two electrodes (cathode with catalyst on the surface and anode). Between the electrodes is a porous diaphragm which inhibits commixture of the hydrogen and oxygen because the mixture is highly unstable. Hydrogen is produced on the side where is the cathode and oxygen on the side of anode. In case of the LTE is space of electrolyzer filled by liquid electrolyte – KOH solution. There exist many configuration of electrolyzer (plate, tubular…).

In case of HTE is temperature very high for using liquid electrolyte. For the HTE configuration of the electrolyzer is used solid electrolyte – polymer electrolyte membrane. Process of high temperature electrolysis is reverse to process in solid fuel cell. Because of the high working temperature, there are very strict requirements to the materials of equipment.

Research program for hydrogen production in comparison with solid electrolysis cells was started in the 1980s. A lot of power sources were analyzed for example nuclear solar and geothermal. For the calculations with nuclear reactor was chosen Very High Temperature Reactor (VHTR) with thermal power about 600MW.

Thermochemical decomposition of water

Thermal decomposition of water proceeds on a temperature of 4310K and pressure 0,1MPa. The temperature is very high for actual chemical engineering equipment. A part of the heat must be substituted by energy in other form. This energy can be put in chemical reactions form. The boundary for thermochemical decomposition of water decreases because of chemical reactions.

Sulfur – Iodine (S-I) process

The research of this process began in the 1960s by the General Atomics Company. It is one of the most perspective methods of mass hydrogen production.

S-I process is based on chemical reactions of sulfuric acid and hydrogen iodine. The maximal necessary temperature of 1123.15K is used for decomposition of SO_3 reactant in sulfuric acid decomposition. Corresponding to temperature delivered from the HTGR, the range of coolant temperature could be 673-1223K. The coolant of HTGR is helium.

S-I process chemical reactions

$$SO_2(g) + I_2(l) + 2H_2O(l) \rightarrow H_2SO_4(aq) + 2HI(aq) \qquad \Delta H=-98kJ \qquad (2.1)$$

$$H_2SO_4(aq) \rightarrow SO_2(g) + H_2O(g) + \tfrac{1}{2} O_2(g) \qquad \Delta H=329kJ \qquad (2.2)$$

$$2HI(aq) \rightarrow H_2(g) + I_2(g) \qquad \Delta H=119kJ \qquad (2.3)$$

$$H_2O(l) \rightarrow H_2(g) + \tfrac{1}{2} O_2(g) \qquad \Delta H=286kJ \qquad (2.4)$$

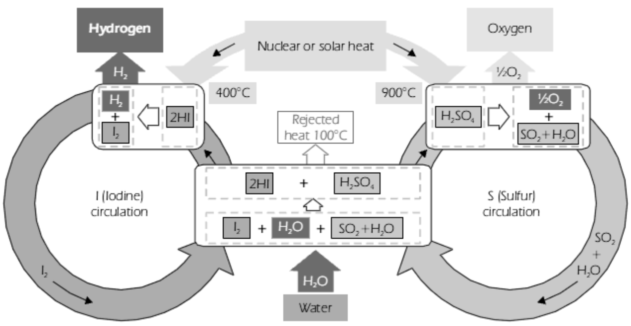
Reaction 2.1 – Bunsen reaction has two sub-steps, low temperature step and exothermic step. Reactions are spontaneous. Products of the reactions are liquid acids (H_2SO_4; HI) and the reaction temperature is 373K. Two phases of the solution (H_2SO_4; HI) are separated because of affluence of iodium.

Thermochemical decomposition (Reaction 2.2) has two steps too. Both steps are highly endothermic.

$$H_2SO_4(aq) \rightarrow SO_3(g) + H_2O\ (g) \qquad \Delta H=363kJ\ (673,15K) \qquad (2.5)$$

$$SO_3(g) \rightarrow SO_2(g) + \tfrac{1}{2} O_2(g) \qquad \Delta H=97kJ\ (1123,15K) \qquad (2.6)$$

Process works cyclic, the substances are recycled. It is necessary to complement only water and a small amount of reactants. Chemical substances in thermochemical processes are very aggressive. The construction materials of a plant must be very chemical and heat resistant. There are a lot of researches interested in the materials for chemical reactors, pipelines and heat exchangers for



Picture 1 – Sulfur Iodine proces [2]

mass production of the hydrogen.

Hybrid cycles – Hydrogen Sulfur cycle (HyS)

Hybrid sulfur cycle is one of the most simple thermochemical cycles. It is based on simultaneous use of the chemical process and electrolysis for hydrogen production. This method is known as Westinghouse process or Ispra Mark 11 process.

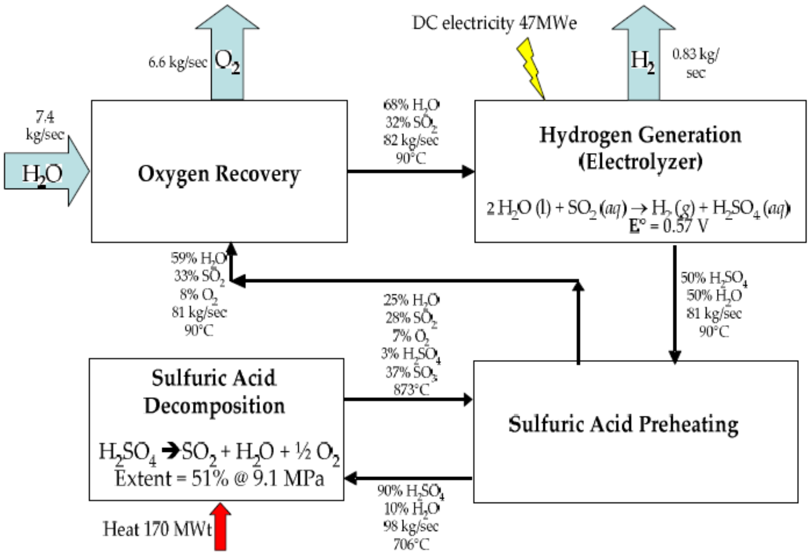
HyS cycles are based on two chemical reactions. The first step is thermochemical. This step is used in all of the sulfur cycles, it is a decomposition of sulfuric acid to water, sulfur oxide and oxygen. Step temperature is higher than 800°C.

$$H_2SO_4(aq) \rightarrow H_2O(g) + SO_2\,(g) + \tfrac{1}{2}\,O_2(g) \qquad (T>800°C) \qquad (2.1)$$

The reaction needs catalyser and heat input. Heat and electricity resource for the Westinghouse process will be HTGR. Next step is SO2 – depolarized electrolysis of water. It needs temperatures between 80 and 120°C and electricity input.

$$SO_2(aq) + 2H_2O(l) \rightarrow H_2SO_4(aq) + H_2(g) \qquad (T=80\text{-}120°C,\ el.\ ) \qquad (2.2)$$

This method looks very simple but there is one question. *Why is the thermochemical part used? We could use only water electrolysis and we don´t need chemical cycles which need highly resistant device and high temperatures.* The answer is hidden in lower requirements for electricity in 2nd step SO2 – depoliarized electrolysis. Voltage for standard electrolysis of the water is 1,229V at 25°C. SO_2 – depolarized electrolysis needs only 0,158V at 100°C in laboratory conditions. In industrial production is the voltage 1,8-2V for water electrolysis and for SO_2 – depolarized electrolysis is expected max. 0,6V.



Picture 2 – Hybrid Sulfur cycle [2]

Research of HyS

The first design of HyS cycle was developed for NASA. Heat resource was HTGR and the operation temperature was 1010°C. It was designed for use in the space program. In 2005 it was presented a study concerned with plant for production electricity and hydrogen. There was designed 450-900MW HTGR, output temperature on primary circuit 700-900°C. There were presented two designs for electricity production, 1st with Brayton cycle and second with Rankin cycle. Rankin cycle design had higher efficiency but it is more expensive because of higher pressures and problems with sealing of helium. The heat is served to chemical reactor where is the hydrogen produced. The conditions in the chemical reactor are 900°C and 10MPa.

Nuclear reactors applicable for hydrogen production

Main purpose of the nuclear reactor in hydrogen production process is heat supply. IV. Generation nuclear reactors will have output temperatures between 600 – 1000°C. Commercial use of IV.GEN reactors is planned approximately for the year 2030. Most of them are fast reactors.

GFR – Gas Cooled Fast Reactor

Core is cooled by gas; in most researches is implemented helium. Helium is heated form 450 to 850°C. Brayton cycle is used for electricity production. GFR will use reprocessed fuel from thermal nuclear reactors. One of possible fuels is UPuC covered by SiC.
Technological base for GFR are (were) this gas cooled research reactors: Dragon Project (Great Britain; closed), AVR,THTR (Deutschland; closed), Peach Bottom, Fort Train (USA; closed), HTTR (Japan, 30MWt), HTR-10 (China; 10MWt), PBMR (JAR, in design process).

LFR – Lead cooled Fast Reactor

Core of LFR will be cooled by natural convection of melt lead. LFR will be fast reactor and it could use closed fuel cycle. This project has three parts. First is the battery system (power between 50-150MWe), modular system (300-400MWe) and large monolithic reactors (1200MWe). Very interesting is battery system which is designed for use in developing countries. The reactor will be encased, the fuel will be metal alloy and the user shall have no access to the reactor. Technology of LFR´s is based on the technology of Russians submarines class Alpha.

MSR-Molten Salt Reactor

MSR´s will use uran-plutonium of thorium cycle. Fuel will be melt in fluoride salt. The fuel will be filled in the operation. Main advantage of the salts is very high heat capacity and low pressure of the steams. The reactor vessel can be more subtle. Operational temperatures will be between 450 and 800°C. The temperatures could be higher but it is limited by the construction materials. There are other reactors that are designed for hydrogen production: SFR – Sodium cooled fast reactor, SWCR – Supercritical Water Cooled Reactor, VHTR – Very High Temperature Reactor and PB-AHTR – Pebble Bed – Advanced High Temperature Reactor. All of mentioned reactors are scheduled to IV. GENERATION. They are in the research and first prototypes could be in operation in the next 20 years.

Conclusion

Hydrogen is very promising supply of energy. Production in connection with nuclear power plant could be very useful. The capacity of power plant will be fully used. It will produce electricity that can be used for the hydrogen production or could be sold. Other product of the power plant used for the hydrogen production is heat. This production will be clean because there is no exhalations form the power plant and the production of the hydrogen is closed. It means that the chemicals in the process are recycled.

Literature

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