Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, November 2-3, 2006

Concept of Low pressure water cracking for hydrogen production in the conventional Light water reactor

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1. Introduction

The global warnings associated with the global warming due to the flue gas from fossil fuel and with the unstable market of the fossil fuel have been expanding. As a solution, it has been widely accepted that hydrogen can be a good candidate for the future energy source. Hydrogen can be produced by splitting water, an abundant material in the earth, and no pollutants are produced during its combustion. Furthermore, it can produce electricity directly in the fuel cell. Therefore, transport industry is preparing the vehicles for the hydrogen fuel. The future society based on the hydrogen energy naturally needs the power station for the mass production of the hydrogen and distribution and storage systems.

Now the cheapest hydrogen production is the reforming of natural gas (2.3 C/kW), followed by the partially reduction of heavy oil (3 C/kW) and gasification of coal (3.9 C/kW). Then the Carbon Dioxide neutral production follows by bio mass gasification with 5 C/kW. The production of hydrogen by electrolysis using wind energy (15-20 C/kW) or photovoltaic energy (200 C/kW) seems in the moment still very expensive, so that there is still a big work to do, to get an acceptable market price. Therefore, it is most pertinent to the matter in hand that nuclear industry decided to develop the most efficient reliable solution to supply hydrogen in future. For this purpose, the hydrogen price needs to be less than 2.4C/KW which is very hard to achieve. By giving such a mission to the next generation nuclear reactors which are supposed to be improved in safety, nuclear industry tried to satisfy both goals of safety and clean energy supply for the general publics. As one of solutions, water splitting in high temperature is now widely studied in the GEN-IV research committee: the very high temperature gas cooled reactor and the iodine-sulfur (IS) cycle. However, large number of technical issues has been generated associated with the materials for the high temperatures. These problems may be resolved through GEN-IV program in future. However, we need to pay cost a lot to establish such technology working in the high temperature.

At this moment, at least we need to think about the way to produce hydrogen with the conventional light water nuclear reactor. Of course water splitting through electrolysis is irrelevant due to its independency of the power production system. At this moment, a new idea for the mass production of hydrogen is to be proposed here. The present system excites steam using RF power so that hydrogen ion and oxygen ion are separated from steam but they cannot recombined to return to be water when we set the environment in a cold condition which means the ions has lower kinetic energy than the recombination energy. After then we can apply the conventional separation technology for the purification of the hydrogen to extract hydrogen in the plasma. One of strong candidate is the pressure swing adsorption system. Therefore, the present idea is very compatible to any Rankine cycle. But the reason why nuclear power plant is good for this is nuclear power plant never produce the global warming gas.

We can say several merits of the present idea:

- It does not need to develop high temperature p ower plant.
- It does not need complex chemical process su ch as I-S which needs to handle strong acid.
- The loose link between reactor core and hydro gen production system will not produce seriou s safety issues.
- Nuclear industry has strong background in the plasma technology, so that almost major part in the hydrogen production can be developed by nuclear experts.
- Korea may have the technical leadership in this area when we develop this present technology because the high temperature reactor and I-S process was invented by USA and Japan.

2. Methods

2.1 Steam-Splitting Kinematics

The hydrogen in this study is produced by direct dissociation, i.e., cracking, of water vapor at low pressure (< 100 Torr) using a microwave plasma discharge. It is not a chemical method, but a physical one, namely cracking water molecules by electrons from "water plasma" and has been tried only in this research. The bonding energy between hydrogen and oxygen, which are constituent elements of water, is 5.0 eV (~ 55,000 K). The water discharge plasma produced by 2.45 GHz microwave power below 100 Torr pressure is characterized by a higher electron temperature (> 5 eV) than that of other discharge methods, such as lower frequency RF discharges, DC discharges etc. It is impossible for water to be split by atmospheric pressure plasma since a high electron collision rate at above 100 Torr pressure causes a very strong decrease of electron temperature due to high radiation pumping (or radiative cooling), which is the photon loss from the excited atoms and molecules produced by collisions with high energy electrons. Namely, if there are too many atoms and molecules that collide with electrons, electrons will not be able to ionize them or dissociate molecules, but only excite the atoms and molecules. Therefore, to maintain a high dissociation rate for water the plasma should be produced in an environment with less than 100 Torr pressure and should not become a thermal one, in which electrons do not have enough energy to break up water. This environment can be provided by the conventional LWR with very ease.

2.2 RF Plasml

We have developed a simple microwave plasma source using the magnetron of a kitchen microwave oven and a rectangular TE_{01} waveguide. The magnetron used provided up to 1 kW power at a frequency of 2.45 GHz. The discharge tube was 10 mm in diameter and 300 mm long. Figure 1 shows the microwave plasma source based on the magnetron, waveguide, tuners, and discharge tube. The plasma density and temperature as measured by a Langmuir probe were $10^{12} \sim 10^{13}$ cm^{-3} and 6 ~ 7 eV at 1 Torr, respectively. The pressure in the device could be varied from 500 mTorr to 100 Torr and the flow rate of the vapor could be varied from 0.1 lpm to 26 lpm.

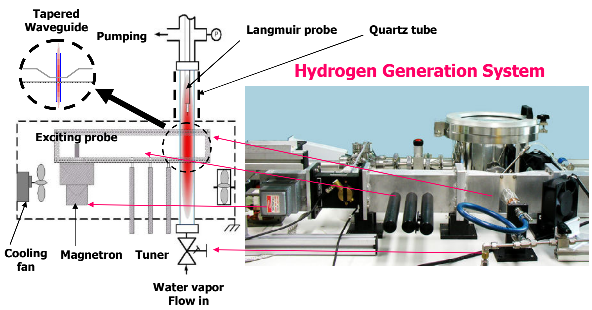
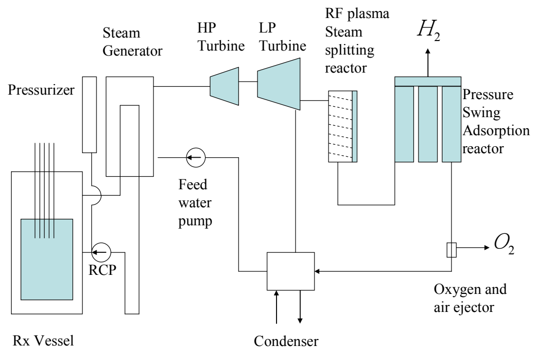


Fig. 1. A device to generate hydrogen using microwave plasmas. Water vapor evaporated by a heat gun flows into the discharge space, i.e., a quartz tube, in which the strong electric field due to the tapered waveguide is applied and the water molecule is dissociated by electrons from a water plasma.

2.3 Implementation to the PWR

The present method of water cracking is very compatible to the conventional light water reactor. At this moment the heat of steam in the condenser is released to the environment as a waste heat. However, if we utilize the steam to produce the hydrogen the efficiency of the current LWR will increase meaningfully. If we make up water to the BOP as much as the water split,



3. Conclusion

A safe and economic method to produce Hydrogen with the conventional PWR is proposed. The main idea is to freeze the hydrogen and oxygen ions not to recombine each other by maintain the environmental thermal energy lower than the recombination energy. Splitting steam is performed by RF plasma or others. The low pressure steam is extracted from the last stage of the low pressure turbine and cooled and ionized by the RF wave power. The produced hydrogen can be extracted by the pressure swing adsorption method which does not need any strong acid or high temperature environment. The present method has many merits of direct application to the conventional nuclear power plant so that we can save the budget and effort. Furthermore, low temperature operation eliminates almost all problems of material for high temperature which is extensively studied for the I-S process.

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