

## **Development Status of 20 Nm<sup>3</sup>/h class Hydrogen Production Unit at KIER**

**Dong Joo Seo<sup>1</sup> Kucktack Chue<sup>2</sup>, Sang Ho Park<sup>3</sup> and Wang Lai Yoon<sup>4</sup>**

<sup>1</sup>Korea Institute of Energy Research, Daejeon, Korea, djseo@kier.re.kr

<sup>2</sup>Korea Institute of Energy Research, Daejeon, Korea, ktchue@kier.re.kr

<sup>3</sup>Korea Institute of Energy Research, Daejeon, Korea, psh@kier.re.kr

<sup>4</sup>Korea Institute of Energy Research, Daejeon, Korea, wlyoon@kier.re.kr

**ABSTRACT:** The hydrogen production unit with a capacity of 20 Nm<sup>3</sup>/h has been developed in KIER. The natural gas reformer and pressure swing adsorption (PSA) system have been built and successfully produced 20 Nm<sup>3</sup>/hr of high-purity (99.99%) hydrogen. A commercially available nickel-alumina based catalyst was employed for steam reforming. The reforming efficiency of developed reforming system which consists of steam reformer and low temperature shift converter showed 74.7% as a LHV basis. The reforming efficiency is defined as the ratio of enthalpy of produced hydrogen over total enthalpy of supplied fuel and electricity. The hydrogen rich syn-gas from LTS is compressed and supplied to PSA for purification. The purity of product hydrogen from PSA system was 99.9996%.

**Keywords:** hydrogen production, natural gas, steam reforming, pressure swing adsorption

### **NOMENCLATURE**

LHV: Lower Heating Value  
PSA: Pressure Swing Adsorption  
LTS: Low Temperature Shift Reactor  
PEMFC: Polymer electrolyte Membrane Fuel Cell

### **1. INTRODUCTION**

Currently, steam reforming of natural gas is the most economical method to produce hydrogen in chemical industry. In the early demonstration phase of utilizing hydrogen as an energy carrier, the on-site hydrogen production system with 20 ~ 100 Nm<sup>3</sup>/h of pure hydrogen delivery may be an intermediate pathway to set-up infrastructure for the hydrogen vehicles and stationary fuel cell system. The main issues for the developing of a small-scale steam

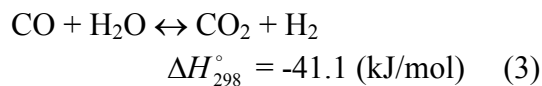
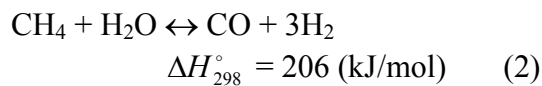
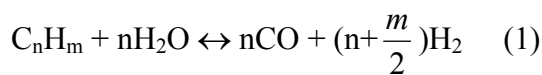
reformer are the effective heat supply into catalytic beds in which the endothermic reaction occurs[1].

This paper describes work to develop a hydrogen production unit using natural gas as a feedstock. A natural gas steam reforming and pressure swing adsorption system was designed and fabricated. The reforming efficiency and hydrogen purity of developed system was investigated at the production rate of 20 Nm<sup>3</sup>/h.

### **2. DESCRIPTION OF HYDROGEN PRODUCTION UNIT**

#### **2.1 Natural Gas Reforming Section**

The natural gas (NG) steam reforming system consists of a desulfurizer, catalytic steam methane reformer (SMR), low temperature shift reactor (LTS) and auxiliary components (including steam generator, heat exchanger and burner). An adsorptive desulfurizer operated at ambient temperature was used. The main reactions occur in SMR can be written by the following equations[2-3]. From Eq. (1), (2) and (3), the steam reforming of methane is highly endothermic reaction.



The energy required for endothermic heat of reforming reaction and vaporization of water are mainly supplied by the combustion heat of the fuel gas (NG or anode-off gas). To improve the thermal efficiency of SMR, the heat recovery design was adopted. The heat contained in reformat which comes out of the catalytic beds was also recovered by feed stream using internal heat exchanger. These features of design reduce the fuel consumption into burner and the heat duty of external heat exchangers, such as feed pre-heater and steam generator. The schematic diagram of hydrogen production unit is shown in **Figure 1**.

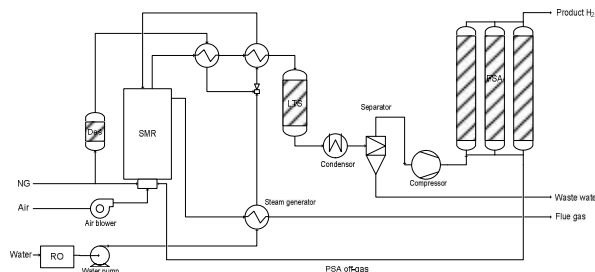


**Figure 1:** Schematic diagram of hydrogen production unit

## 2.2 Hydrogen Purification Section

The pressure swing adsorption (PSA) system was used to purify the reformed gas up to 99.999% of hydrogen. A conventional 3-beds type PSA system was designed and fabricated. The specification of PSA system is shown in **Table I**. The reforming system was operated at the pressure of 0.04 MPa. The reformed gas compressor was installed between reforming and PSA system to increase the pressure of PSA feed up to 0.99 MPa.

**Table I:** Specification of designed PSA system

| Dimension of adsorption bed |                         |
|-----------------------------|-------------------------|
| Bed diameter                | 20 cm                   |
| Bed Height                  | 160 cm                  |
| Operating condition         |                         |
| Adsorption pressure         | 0.99 MPa                |
| Temperature                 | Max. 40 °C              |
| Feed flow rate              | 40 Nm <sup>3</sup> /h   |
| Product gas                 |                         |
| Purity                      | > 99.99%                |
| Product flow rate           | > 20 Nm <sup>3</sup> /h |

## 3. PERFORMANCE OF HYDROGEN PRODUCTION UNIT

The natural gas reforming and PSA system has been fabricated and successfully produced 20.1 Nm<sup>3</sup>/h of high-purity hydrogen. **Table II** shows the typical results of the hydrogen production unit. The reforming efficiency of the natural gas reforming system is defined as the ratio of enthalpy of produced hydrogen over total enthalpy of supplied fuel and electricity. The total supplied fuel means the natural gas supplied for reforming and burning. The purity of product hydrogen from PSA system was 99.9996%. The hydrogen recovery ratio was 62.6% at this operating condition. The critical impurity of product hydrogen for the application of polymer electrolyte membrane fuel cell (PEMFC) is carbon monoxide. The carbon monoxide concentration in the product hydrogen was

1.3 ppmv. It is known that the upper-limit of carbon monoxide for PEMFC is 1 ppmv. The hydrogen recovery ratio is dependent upon product purity and pressure difference between adsorption and regeneration step of PSA system. Further investigation is required to increase hydrogen recovery more than 70% by adjusting operation parameter of PSA system, such as pressure of adsorption step and cyclic time.

**Table II:** Typical performance of hydrogen production unit

|                                                             |                 |          |
|-------------------------------------------------------------|-----------------|----------|
| Hydrogen production rate at LTS outlet (Nm <sup>3</sup> /h) |                 | 32.1     |
| S/C ratio                                                   |                 | 3.0      |
| Reforming temperature (°C)                                  |                 | 715.2    |
| Composition of reformed gas (vol. %, dry basis)             | H <sub>2</sub>  | 77.9     |
|                                                             | CO <sub>2</sub> | 19.1     |
|                                                             | CH <sub>4</sub> | 2.5      |
|                                                             | CO              | 0.5      |
| Methane conversion (%)                                      |                 | 88.8     |
| Reforming efficiency* (% LHV basis)                         |                 | 74.7     |
| Hydrogen production rate at PSA outlet (Nm <sup>3</sup> /h) |                 | 20.1     |
| Composition of purified gas (vol. %, dry basis)             | H <sub>2</sub>  | 99.9996% |
|                                                             | CO <sub>2</sub> | N.D      |
|                                                             | CH <sub>4</sub> | 2.3 ppmv |
|                                                             | CO              | 1.3 ppmv |
| Hydrogen recovery ratio (%)                                 |                 | 62.6     |

$$* \eta = \frac{\Delta H_{H_2-LHV} \cdot n_{H_2}}{\Delta H_{NG-LHV} (n_{NG-ref} + n_{NG-burn}) + Q_{Electric-heater}}$$

## 5. CONCLUSION

Kier developed a hydrogen production unit for the small scale on-site production of hydrogen. The hydrogen production unit consists of natural gas reforming and pressure swing adsorption system. The developed natural gas reforming system showed reforming efficiencies above 74.7 % (LHV basis) and could produce hydrogen at

a rate of 32.1 Nm<sup>3</sup>/h. The pressure swing adsorption system was integrated with reforming system to separate impurities from product hydrogen. The integrated reforming and purification system can produce high purity hydrogen (99.9996%) at a rate of 20.1 Nm<sup>3</sup>/h.

## ACKNOWLEDGEMENT

This research was performed for the Hydrogen Energy R&D Center, one of the 21<sup>st</sup> Century Frontier R&D Program, funded by the Ministry of Science and Technology of Korea.

## REFERENCES

- [1] Y. S. Seo, D. J. Seo, Y. T. Seo and W. L. Yoon 2006. Journal of Power Sources. Vol 161. pp 1208-1216.
- [2] J. Xu and G. F. Froment 1989. AIChE J. Vol. 35. pp 88-96.
- [3] J. Xu and G. F. Froment. 1989. AIChE J. Vol 35. pp 97-103.