DEVELOPMENT OF TRITIUM FUEL PROCESSING SYSTEM USING ELECTROLYTIC REACTOR FOR ITER

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Abstract

The system composed of a palladium diffuser and an electrolytic reactor was proposed, and was developed for a Fuel Cleanup system of ITER. The performance of the system was studied in a stand-alone test in detail. A fuel simulation loop of ITER was constructed by connecting the developed Fuel Cleanup and Hydrogen Isotope Separation systems; and the function of each system in the loop was demonstrated. For the tritium recovery from the exhaust gas at He glow discharge cleaning of vacuum chamber of ITER, a cryogenic molecular sieve bed system was proposed and demonstrated.

1. INTRODUCTION

A fuel system of fusion reactor is composed of the following subsystems: a fueling system injecting deuterium and tritium; an exhausting system; a set of front-end permeators recovering pure hydrogen isotopes; a Fuel Cleanup System(FCU) extracting tritium from impurities; an Hydrogen Isotope Separation System(ISS); a storage system using metal beds. In addition, a Water Detritiation System(WDS) and a tritium recovery system from the gas produced at breeding blanket are important as tritium plant in fusion reactor. The research and development of above systems concerning tritium except for the fueling and exhausting systems have been carried at Tritium Process Laboratory(TPL) of Japan Atomic Energy Research Institute(JAERI) with ~10 g level of tritium since 1987. The FCU is a key subsystem of the fuel cycle; and a combination system of a palladium diffuser and an electrolytic reactor was proposed and designed for the FCU of ITER by Japan, which became a main ITER R&D task at the TPL[1] from 1993. After the basic performance of this type of the FCU was investigated in detail in a stand-alone test[1], its feasibility test in the total fuel system was planed and started, by constructing a fusion fuel simulation loop in the TPL[2]. Development of a system of cryogenic molecular sieve beds (CMSB) was also carried out as another ITER R&D task for the tritium recovery from the exhaust gas at the He glow discharge cleaning (GDC) of vacuum chamber[3].

This paper reports the results of the ITER R&D tasks mentioned above: the FCU using the electrolytic reactor; fusion fuel simulation loop; and the CMSB system. Other research activities related to ITER fuel system at the TPL are also described.

2. FUSION FUEL PROCESSING SYSTEM DEVELOPMENT FOR ITER

2.1 Development of electrolytic reactor

A FCU consisting of an electrolysis cell developed at the TPL was already demonstrated for its feasibility in Japan-US collaboration tests at Los Alamos National Laboraory[4]. As an advanced system based on this technology, a system consisting of the electrolytic reactor was proposed for ITER[2], and its prototype was developed. The proposed system has typical advantages: 1) It has virtually no tritium inventory, since no catalyst is used; 2) The system can process the plasma exhaust gas which contains a wide range of impurity composition. An electrolysis cell, a main part of the reactor, was made of sintered stabilized zirconia open-ended tube (50 cm x ϕ 3 cm). Figure 1 shows the basis of the electrolytic reactor. The potential difference is applied between the inner surface of the cell and the outer one. An impurity mixture, CH_4 and H_2O, is first fed to the outer surface of the cell, where methane is oxidized: $CH_4 \rightarrow CO_2 + 2H_2O$. The product stream then flows backward in the zirconia tube where the reduction of water proceeds: $H_2O \rightarrow 2H_2$. Figure 2 shows a typical data of this electrolytic reactor. The He gas containing 2% H_2O and 1% CH_4 were supplied to the electrolytic reactor. It was demonstrated that both methane and water were completely converted to CO_2 (1%) and H_2 (4%) at 2.0 V of electrolysis voltage.

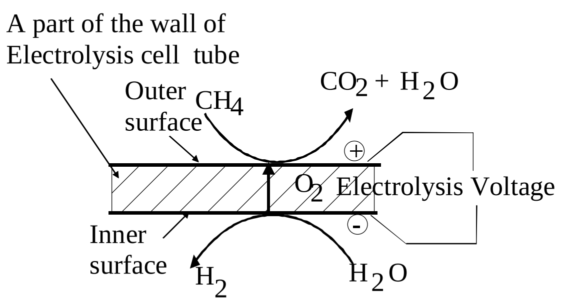

Figure 1 Basis of electrolytic reactor.

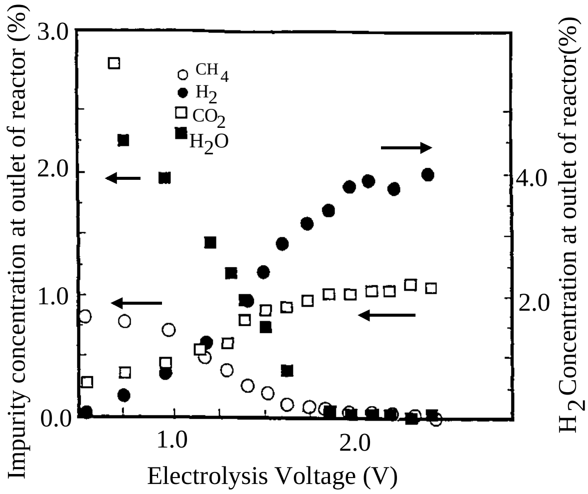

Figure 2 A typical processing data of methane and water vapor with an electrolytic Reactor.

2.2 Fusion fuel simulation loop test

2.2.1 Composition of the loop

Figure 3 shows a conceptual flow diagram of the fusion fuel simulation loop constructed at the TPL[2]. The ISS, a palladium diffuser, and a FCU are interlinked through a torus mockup tank. A hydrogen isotope stream (H-D-T mixture) is exhausted from the mockup tank. Impurities(He and Methane) are added to this stream, and are sent to the palladium diffuser, the front-end permeator. A pure hydrogen isotope stream (H-D-T mixture) is sent to the ISS, and an almost pure protium stream (H) is withdrawn from the ISS. The rest of hydrogen stream is returned to the mockup tank.

The FCU is composed of the electrolytic reactor and a palladium diffuser. The impurities (He and methane) and a small amount of hydrogen isotopes, which do not flow through the diffuser, are sent to the FCU. The methane is converted to CO_2 and H_2 in the electrolytic reactor, and only the hydrogen isotopes are recovered by the palladium diffuser. The ISS is composed of two cryogenic distillation columns[2], which has been applied in ITER. Four optical cells were installed to the top and bottom streams of each column[2]. These cells were interconnected with a laser Raman gas analysis system with optical fibers for rapid analysis and control system development. The detailed specifications of this system were reported in Reference 5.

2.2.2 Significant accomplishment in the fusion fuel simulation loop test

Major experimental conditions of the demonstration tests are summarized in Table 1. Total amount of tritium in the loop was 1 g. The flow rate was 10 mol/h (~1/8 of ITER). Helium and methane gases were intermittently added to the hydrogen stream at the flow rate of 0.1~0.3 mol/h. The temperatures of the palladium diffuser before FCU and that in FCU were set at 573 K and 673 K, respectively. The temperature of the electrolytic reactor was chosen to be 973 K. The amount of the methane decomposed in the reactor can be estimated from the composition of methane at the outlet of the electrolytic reactor. The efficiency for the decomposition of methane at the reactor was about 20% with the present conditions. Higher efficiency can be expected with a higher temperature. The efficiency greater than 97% was obtained at the stand alone test with 1073 K[1]. Higher temperature operation test in the loop will be performed in the feature. The measured performance of the front-end permeator was 99% as an average value of the permeation efficiency. This value is almost identical to that obtained with the same permeator in a previous experiment performed 10 years ago. No decrease of the permeation efficiency was observed for the diffuser in spite of the 10 years of operation.

2.2.3 Performance of the ISS in the loop test

The two columns of the ISS were stably operated for a week with the intermittent impurity addition. The protium stream essentially free from tritium was removed from the fuel simualtion loop by the ISS. The tritium atom fraction in the protium stream from the ISS could be decreased to $2.5x10^{-6}$. The initial tritium atom fraction was $1x10^{-2}$, so that the measured Detritiation factor(DF) was ~4000. The advantage of the laser Raman analysis system using the optical fiber is that an analysis result can be obtained with a short time interval, at a long distant place, with no sampling line. In the experiments, we could measure the composition of the product stream of the ISS with 2 min. interval. The feasibility of the laser Raman system using the optical fiber was thus demonstrated.

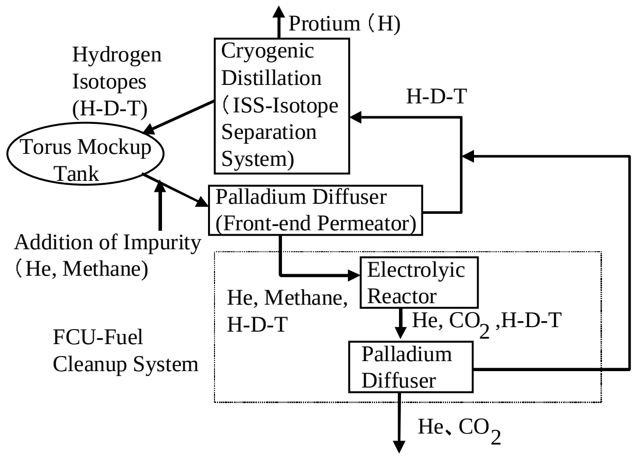

Figure 3 Configuration of fusion fuel simulation loop at TPL.

Table I CONDITIONS OF DEMONSTRATION TEST OF FUEL SIMULATION LOOP

Amount of tritium used : 1 g
Concentration of tritium : ~1%
Inventory of hydrogen isotopes within integrated system : 20 mol
Flow rate of integrated system : 10 mol/h
Flow rate of H_2 exhausted from the integrated system : 0.27 mol/h

2.3 Other R&D activities for ITER at TPL

To design the CMSB system, basic data for adsorption isotherm of hydrogen isotopes were measured. Simulation codes for the CMSB system have also been developed. A prototype CMSB system was made, and demonstration tests have been conducted to search optimum operating conditions of the CMSB system; and to verify the validity of the code with the test results.

The prototype system was composed of two CMSBs(285 mm in height). Molecular sieve 5A of ~2.5 kg (1.6 mm ϕ x 3.2 mm) was charged into an each bed. A helium stream of 140 mol/h containing 0.2~1.0% of H_2 was introduced to the system. This flow rate condition is almost identical to that for the present design of the gas produced by the He GDC operation of ITER. Figure 4 shows a typical test result of the prototype CMSB system[3]. The break through for H_2 was observed at 150 min. This result agreed with the calculated results. Some important information was also obtained for the necessary time for heating up and cooling down of the CMSB.

The Study of the ISS was carried out mainly for the simulations of the cryogenic distillation column[6]. The control system of the columns has been designed to supply useful information for ITER tritium plant. Some simulation codes of water distillation and chemical exchange columns were developed [6]. By using these codes, a WDS system applying the chemical exchange column have been proposed for ITER as a result of an ITER design task. The release behavior of tritium from the breeding blanket is still one of the important subjects to be studied[6]. The experiments for the tritium behavior in some promising materials of the blanket have been carried out from this viewpoint.

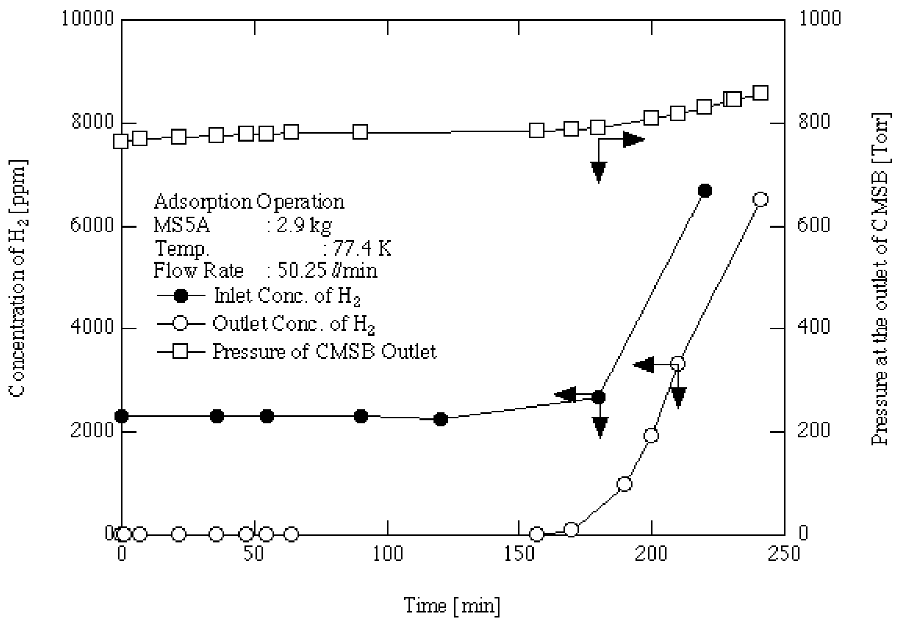

Figure 4 Breakthrough curve of H_2 of CMSB system.

3. CONCLUSION

Advanced fuel cleanup system consisting of the electrolytic reactor was developed, and its excellent performance was demonstrated in the stand-alone test. A fuel simulation loop of ITER was constructed, and the function of each subsystem such as FCU and ISS was confirmed. The laser Raman system analyzing process gas rapidly from the distant place using the optical fiber was also demonstrated, which enables the quick system control. A long-term operation test of the fuel loop is planned to optimize the system; to develop control and operation methods; and to verify the reliability of the system against tritium. In addition, the prototype CMSB system was developed for the He GDC gas processing system of ITER, and its demonstration tests were successfully carried.

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