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Fusion Fuel Cycle Design Concept

Hongsuk Chung [a*], Daeseo Koo [a], Haksu Jin [a], Myunghwa Shim [a], Kyu-Min Song [b], Duk Jin Kim [c], Min Ho Chang [d], Hyun-Goo Kang [d], Sei-Hun Yun [d], Seungyon Cho [d]
[a]*Korea Atomic Energy Research Institute, 1045 Daedeokdaero, Yuseong, Daejeon 305-353, Korea*
[b]*Korea Electric Power Research Institute, 65 Munjiro, Yuseong, Daejeon 305-380, Korea*
[c]*KOCEN, 5442-1 Sangdaewon, Seongnam, Gyeonggi 462-729, Korea*
[d]*National Fusion Research Institute, 113 Gwahakro, Yuseong, Daejeon 305-333, Korea*

[*]*Corresponding author: hschung1@kaeri.kr*

1. Introduction

A fusion fuel cycle plant is composed of various subsystems such as a fuel storage and delivery system (SDS), a tokamak exhaust processing system (TEP), and a hydrogen isotope separation system (ISS). The main purpose of the SDS is to store and supply the D-T gas needed for the DT plasma operation. The TEP recovers unspent D-T fuel yielding a product stream suitable for a transfer to the ISS, or for a transfer to the SDS. The ISS separates the hydrogen isotope mixtures into four cryogenic distillation columns [1]. In this paper we present the recent R&D progress on the nuclear fusion fuel cycle and the SDS design and operation concept.

2. SDS and Fuel Cycle Operation Procedures

In this section we present operating procedures for the SDS in a nuclear fusion fuel cycle.

2.1 SDS Functional Requirements

The SDS stores $D_2(T)$ gas in the $D_2(T)$ reservoir produced by the ISS. The SDS supplies $D_2(T)$ gas to the fuelling system (FS). The SDS stores $T_2(D)$ gas in the $T_2(D)$ reservoir produced by the ISS. The SDS supplies $T_2(D)$ gas to the FS. Other functions of the SDS are to perform pressure-volume-temperature-concentration (PVT-c) measurements and in-bed calorimetry, to collect the decayed helium-3, etc.

2.2 SDS Operating Procedures

The tritium is supplied from a tritium loading station to the PVT-c tank for the PVT-c measurement. The tritium is stored then in the SDS ZrCo beds. When the ISS requests T_2 loading, the tritium is supplied to the ISS from the SDS ZrCo beds. When the ISS gets the steady state hydrogen isotope concentration profile, the ISS is ready to supply $D_2(T)$ gas to the $D_2(T)$ reservoir in the SDS. At the same time, the ISS is ready to supply $T_2(D)$ gas to the $T_2(D)$ reservoir in the SDS. The $D_2(T)$ and $T_2(D)$ gases are sent to the FS. The FS supply the D-T fuel to the tokamak, then the fuel circulates through the TEP, the ISS, the SDS reservoirs, then the FS, and so on. Once a campaign is accomplished, the tritium in the ISS can be stored in the SDS ZrCo beds [2].

2.3 Characteristics of the fuel cycle

The following are advantageous characteristics of the fuel cycle [3].

- It can meet the fuelling requirement of constant D-T composition because the D-T streams from the ISS are maintained constant by the ISS D-T isotopic control system once the D-T concentration profile in the ISS cryogenic distillation columns is established.
- It can avoid the D-T composition during direct supply from the SDS beds due to the well-known isotope effect during the desorption process.
- It can eliminate complex operational needs for every pulse operation (burn time 450 s, pulse cycle time 1800 s) for rapid heating of the SDS beds to deliver $T_2(D)$ gas to the FS and rapid cooling from the $T_2(D)$ gas into the SDS beds from the ISS.

2.4 Qualitative Merits of the fuel cycle

Our fuel cycle has the following merits.

- Substantial reduction of the required number of the SDS beds
- Substantial reduction of the number of the temperature cyclic operation of the SDS beds dehydriding (delivery) and hydriding (recovery)
- Substantial reduction of the number of the valve operation for delivery and recovery operation during DT plasma campaign
- Substantial reduction of the disproportionation
- Substantial reduction of the failure risk on mechanical equipments such as valves, pumps, and electrical equipment (heater) in the SDS
- In-bed caloric measurement during major shutdown period

2.5 Cost Aspects of the fuel cycle

Our fuel cycle has the following operational characteristics and cost aspects.

- The frequency of ZrCo beds heating will be dramatically reduced compared to the delivery and recovery bed operation method. So the SDS pump header method will necessitate only for a short time use of SDS beds.

- The life time of ZrCo beds will be dramatically prolonged.
- The tritium delivery pump from the SDS ZrCo bed to the ISS will be exposed to high level tritium only for a short time. So the use of an ISP pump with a magnetic coupling drive or other tritium vacuum pumps would be feasible. The vacuum pump Model I or Model N in Fig. 1 will then be applicable.
- Substantial reduction of the SDS capital cost, and SDS operation cost

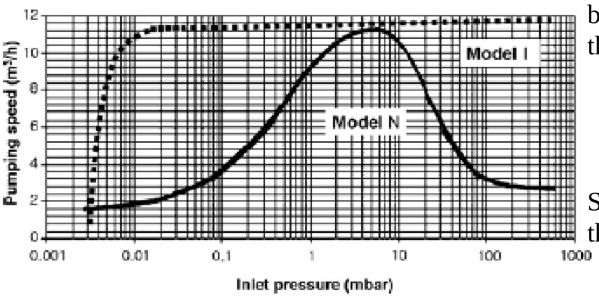

Fig. 1. Vacuum pumping speed characteristics [4]

3. SDS Beds and Fuel Cycle System

In this section we present fuel cycle aspects for the SDS beds and reservoirs.

3.1 Fuel Cycle Inventory

A fusion fuel cycle tritium inventory and the capacity of a bed result in the required number of beds.

3.2 Fuel Cycle and Reservoir Operation

An SDS pump header is composed of pumps and reservoirs. The pumps must be tritium compatible. We assume that metal bellows pumps are employed in the SDS pump header. If the quantity of tritium delivered is known during 450 seconds of burn time, the quantity of tritium for one shot will be obtained.

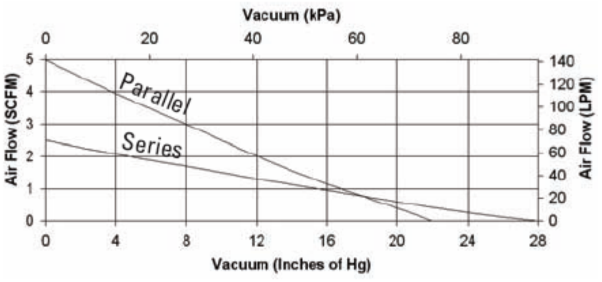

Fig. 2. Metal bellows pump MB-601 flows depicted at 60 Hz [5]

Considering the vacuum level for one shot, the average flow rate achievable will be obtained in a series pump (Fig. 2). Finally we would be able to obtain an optimum combination of pumps, reservoirs, and SDS beds to supply tritium to the FS.

4. Conclusions

We present the recent R&D progress on the nuclear fusion fuel cycle and the SDS design and operation concept. Especially we present the operating procedures for the SDS in a nuclear fusion fuel cycle. The fuel cycle considers not only the reservoir and the metal bellows pump characteristics but also the SDS ZrCo beds and the tritium vacuum pumps. The advantage of the fuel cycle is also presented.

Acknowledgement

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