Advanced Atomic Energy Research Section

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1. Introduction

Main objective of our research division is to realize advanced energy systems for the sustainable development under global environmental constraints. We have shown a Zero-emission energy scenario based on fusion energy with biomass-based recycling system where biomass waste is converted into liquid fuel or hydrogen. And further we now propose an innovative Negative emission scenario to isolate CO_2 in the atmosphere by a carbonization process. Our research section focuses on development of hydrogen isotopes fuel circulation system, breeding blankets, fusion material R&D, feasibility study for fusion-biomass hybrid power system, conversion of biomass waste, and fusion neutron generation/measurement. The following are main research achievements in the fiscal year of 2023.

- Accomplishment of the highest efficiency for fusion fuel extraction from lead lithium eutectic alloy using the droplet system in the fusion study field.
- Electrochemical purification of nitrogen in liquid lithium using chloride molten salt.
- Elucidation of corrosion behavior on reduced activation steel F82H.
- Development of the water-cooling system for the cathode in the glow discharge type of fusion neutron source.

2. Fusion fuel (hydrogen isotope) recovery system development from liquid lead lithium droplets

Lead lithium eutectic alloy (Pb-17at%Li, Pb-Li) is a promising liquid material for the efficient fuel (hydrogen isotope) breeding on a fusion reactor. Effective recovery of the bred fuel is a key issue of liquid blanket fusion reactor.

We developed the vacuum sieve tray method, fusion fuel recovery from liquid Pb-Li droplets falling in vacuum. This fiscal year, on a collaboration work with National Institute for Fusion Science (NIFS), the continuous fuel recovery campaign was performed. We obtained fuel extraction efficiencies between 0.6 and 0.7 (Fig. 1). The long blue line shows proof-of-principle results performed in our division in 2013 [1]. Red circles show the results performed at NIFS this year. The two results are almost identical, showing the consistency of this method. This is the highest efficiency record in the fusion field.

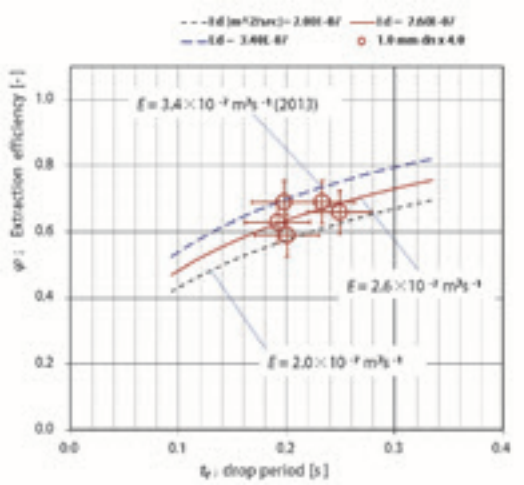

Fig.1 Obtained extraction efficiencies as a function of the droplet falling period. Blue long dash line shows a proof-of-principle result obtained in 2013 [1]. Red circles are results in 2023. Both are almost identical, showing the consistency of this recovery method.

3. Electrochemical purification of nitrogen impurities in liquid lithium using chloride molten salts

Fusion-relevant neutron sources, such as Advanced Fusion Neutron Source (A-FNS), are necessary for neutron irradiation experiments for the fusion material development. Liquid lithium is the flowing target of A-FNS, and easily absorbs nitrogen impurities which may cause corrosion of the structure material. Therefore, nitrogen extraction technology is essential for the A-FNS development.

We adapted an electrochemical method using chloride molten salt to extract nitrogen. In this ex-

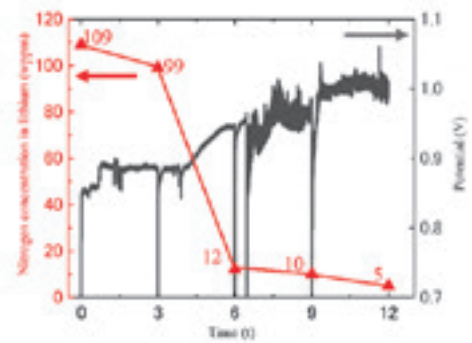

Fig.2 Temporal change of N concentration in liquid Li and the required potential for 2mA current.

periment, an electrochemical cell filled with chloride molten salt (LiCl 58.5 mol% – KCl 41.5 mol%) was prepared, and Li supported by a stainless-steel tube was placed in the chloride molten salt as the counter electrode. The working electrode was coil-shaped nickel wire. The temporal change of nitrogen concentration in liquid lithium was monitored at a constant current of 2mA (Fig. 2). This purification system sufficiently extracted nitrogen impurities.

4. Corrosion of reduced activation steel F82H steel by solid breeder material (LTZO) pebble

JA-DEMO plans to adapt lithium zirconate titanate ($Li_{2+x}TiO_{3+x}$+Li_2ZrO_3; LTZO) pebbles as the solid blanket breeder material, and reduced activation ferritic/martensitic (RAFM) steel F82H as the blanket structure material. The corrosion characteristics of F82H by LTZO pebbles are crucial because corrosion on F82H may degrade the strength of the structure. We experimentally investigated the formation of the corrosion layer on F82H to find the activation energy, which is required to predict corrosion behavior.

The corrosion on F82H by the LTZO pebbles was induced at 693, 833, and 993 K under sweep gas (Ar + 0.1% H_2) flow. The temperature dependence of the diffusion coefficient is shown in Fig.3. ① is plotted based on the corrosion layer formed up to 380 hours, while ② is based on the corrosion layer formed up to 190 hours. The activation energies in the cases of ① and ② are calculated to be 1.67 eV and 0.94 eV, respectively. The red line in Fig.3 is the result of a similar study that investigated corrosion between Li_2TiO_3+excess Li_2O and EUROFER (another type of RAFM steel) [2]. The difference between ① and ② will be due to the "breakaway behavior" which is also reported by the work [2]. The activation energies in the present study are higher than that of the prior study on EUROFER. This may be due to the difference in the contact area between the solid breeder specimen and the structural material, and the supply rate of the Li_2O vapor. Therefore, it is expected that the mechanism of corrosion and diffusion of Li and O that contribute to corrosion is not significantly different among the different types of solid breeder materials and structural materials.

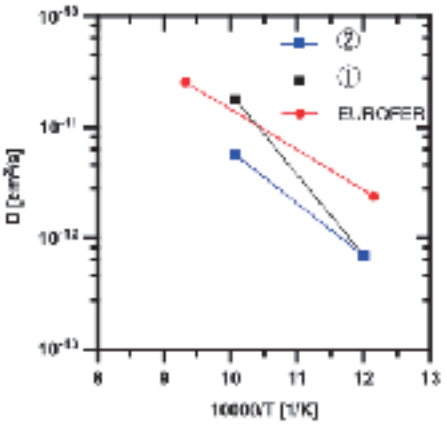

Fig.3 Temperature dependence on the diffusion coefficient of the corrosion layer on F82H or EUROFER.

5. Upgrading of the glow discharge type fusion neutron source by cathode cooling

The fusion neutron source of glow discharge type emits neutrons by inducing nuclear fusion reactions between deuterium and/or tritium. Fusion reactions in this device mainly occur on electrodes, especially on a cathode. This neutron source is expected to be used not only for fusion research but also for industrial applications and medical applications.

The device generates ions by applying an electric input (several tens of kilovolts and several tens of milliamperes) to induce a glow discharge. Although a neutron production rate (NPR) has a positive correlation with a current, an NPR tends to stagnate at a high current operational regime. This stagnation of NPR is caused by the decrease of deuterium concentration on a cathode due to deuterium desorption.

We constructed the water-cooling feedthrough system to solve the issue caused by deuterium desorption. The present study aims to evaluate the cathode cooling effect on NPR. The diamond-like carbon (DLC)-coated cathode was employed in the neutron production experiment. Fig.4 shows that the cathode cooling prevents the stagnation of NPR in the high current regime (> 30 mA) and enhance the NPR. This effect means the cooling system surpasses deuterium concentration on the cathode. At 50 kV and 60 mA (the maximum electric input of this experiment), the NPR in the case using the water-cooling system achieved more than twice as high as the NPR in the case without the water-cooling system. The water-cooling system is expected to expand applications of fusion neutron sources.

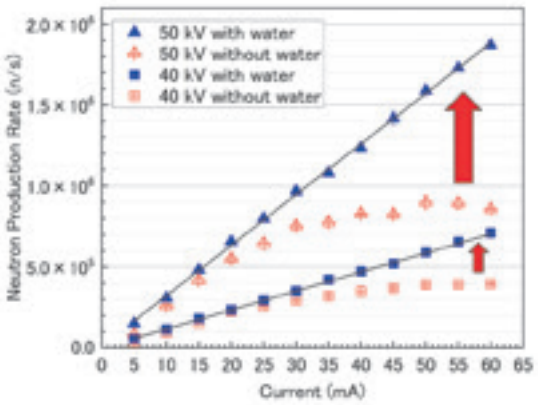

Fig.4 Comparison of NPRs between the cases with/without the water-cooling system.

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