RECENT ADVANCES OF WATER DETRITIATION TECHONOLOGIES

Jinguang Cai, Peilong Li, Xin Zhang, Bin Yu, Ning Zeng, Liuxin Yang, Chao Lv, Wenwen Yong, Fei Jiang, Junhong Luo, Jiangfeng Song, Yan Shi, Changan Chen, Jie Chen, Wenhua Luo

Institute of materials, China Academy of Engineering Physics, Jiangyou, Sichuan, China

Email: caijinguang@foxmail.com

1. MOTIVATION

Tritiated water is inevitably generated in fission nuclear power plants, future fusion reactors, spent fuel reprocessing, and nuclear accidents, significantly impacting system safety, personnel safety, and environmental security. Efficient and safe treatment technologies are urgently needed to address this challenge. This work focuses on the treatment of medium- and low-concentration tritiated water at an equivalent scale, utilizing a combination of water distillation pre-concentration, Combined Electrolysis Catalytic Exchange (CECE), and cryogenic distillation cascade processes to achieve efficient volume reduction, enrichment, and tritium recovery.

2. STATEGIES

To address the demand for processing large quantities of low-to-medium concentration tritiated water, our strategy is illustrated in Fig. 1. Specifically, we employ water distillation technology to treat large amount of low-concentration tritiated water, achieving effective volume reduction or pre-concentration. The resulting medium-concentration tritiated water from this enrichment process, along with other medium-concentration tritiated water sources, is then treated using combined electrolysis catalytic exchange (CECE) technology for further volume reduction and enrichment. The CECE process is coupled with cryogenic distillation to concentrate or recover the generated tritiated hydrogen gas. Ultimately, the system produces highly concentrated tritiated hydrogen gas or tritium gas.

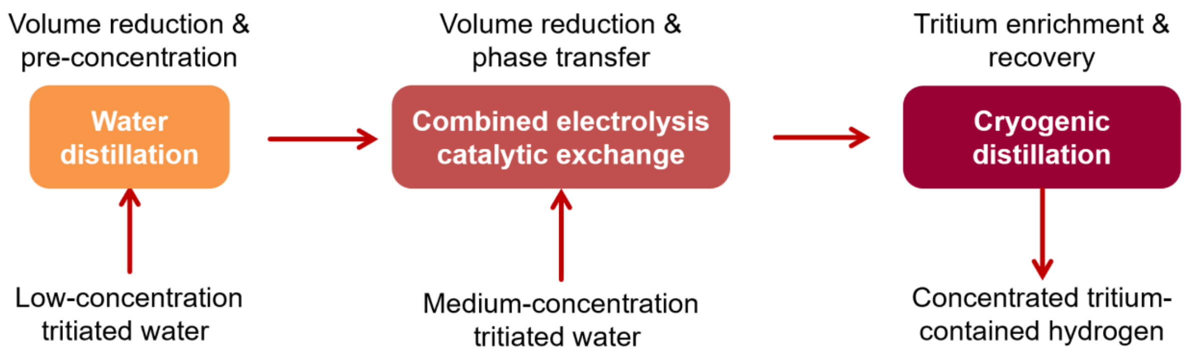

Fig. 1 Our strategy of water detritiation process for low- and medium-concentration tritiated water

3. PROGRESSES

In the R&D of water distillation technology, we conducted systematic screening of packing materials and optimized surface treatment processes. The newly developed advanced structured packings exhibit extremely low heights equivalent to a theoretical plate (HETP). The APW and APD packings boast HETPs as low as 4.4 cm and 8.5 cm, respectively, ranking among top-tier performance benchmarks with no significant scale-up effects, thereby substantially reducing material costs and operational expenses. Accelerated aging tests confirm no performance degradation under simulated operating conditions for over 30 years. Our self-developed high-performance liquid distributor achieves an average uniformity deviation of just 0.7%. Additionally, two configurations of self-heat recuperation technology—closed-cycle and open-cycled heat pumps—have been successfully integrated into water distillation systems, achieving over 70% energy savings. The closed-cycled heat pump system demonstrates a processing capacity of 75 kg/h, a deuterium-containing water decontamination factor >10, and 73% energy reduction. The open-cycled heat pump system handles 20 kg/h, achieves a 92.26% volume reduction, and delivers exceptional performance metrics: tritium-containing water decontamination factor of 26,826, separation factor of 302,206, and tritium extraction rate of 99.997%. Cumulative operation exceeds 8,000 hours.

In combined electrolysis-catalytic exchange (CECE) technology R&D, we designed and constructed the first PEM electrolyzer-based full-scale integrated CECE system. Through independent R&D, we accomplished full-process development including catalyst materials, membrane electrode assemblies, PEM electrolyzer sealing structure, bipolar/full-stack design, assembly, and leak detection. We independently produced PEM electrolyzers with 50 Nm^3/h hydrogen output, resolving challenges in low leakage rates and tritium compatibility. A groundbreaking "sandwich-type" structured packin—alternating hydrophilic humidification plates with hydrophobic catalytic plates—was innovatively proposed. This enables efficient water-gas generation and hydrogen catalytic exchange while overcoming scale-up effects and mass-production challenges, ensuring long-term material stability. The CECE system operates at 20–30 kg/h under standard conditions (maximum 50 kg/h), achieving: Deuterium-containing water decontamination factor >5,000 (HETP 25–35 cm); projected tritium-containing water decontamination factor $>10^7$; stable continuous operation exceeding 100 hours with cryogenic distillation systems.

4. FUTURE PLANS

We have completed the construction and operational assessment of full-scale systems integrating water distillation, CECE, and CD technologies. Next steps will involve: practical tritiated water treatment using the CECE system to validate tritium compatibility; implementation of intelligent control and automated operation for the process systems; further optimization of processing techniques, along with the production, cost, and performance of critical materials.