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An optimized process for tritium-containing waste water collection of High-Temperature Gas-cooled Reactor

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ABSTRACT

An optimized process for tritium-containing waste water collection of High-Temperature Gas-cooled Reactor (HTGR) was developed and experimentally verified using the 10 MW High-Temperature Gas-cooled Reactor-test module (HTR-10). Compared with the previous process, an auxiliary molecular sieve bed was added in helium purification regeneration system and new operation process was proposed to collect tritium-containing waste water. In this paper, the optimized process and verification experiment were presented in detail. In commissioning experiment of the improved HTR-10, a large quantity of high-dose tritium-containing waste water was successfully collected in the water separator of helium purification regeneration system, with the specific activity being 6.1×10^9 Bq/L. The verification experiment confirms that the optimized process is effective and reliable for the demonstration plant design of High Temperature Gas-cooled Reactor-Pebble bed module (HTR-PM) to avoid the large emission of detrimentally radioactive waste water to the environment.

1. Introduction

To avoid oxidation of graphite and corrosion of reactor structural components at high temperature condition, impurities in primary helium coolant of High-Temperature Gas-cooled Reactor (HTGR) must be controlled to pre-specified limited level (Yao et al., 2002; Olson et al., 1980; Chang and Wu, 2009; Sakaba et al., 2004, 2009). Helium purification system is usually set up to eliminate gaseous chemical impurities such as hydrogen, carbon monoxide, oxygen, carbon dioxide, water, nitrogen, methane, and to remove particulate solids and gaseous radionuclide fission products such as krypton and xenon etc. The normal sources of contaminants are those that are desorbed from reactor components, residual air and air in-leakage, fission products that migrate from the fuel, moisture from steam generator leakage, and contaminants from new helium supply. For the 10 MW High-Temperature Gas-cooled Reactor-test module (HTR-10), helium purification system mainly consists in sequence of cartridge filter for removing dustlike particles and three fixed-beds, that is, copper oxide bed for removing trace of oxygen and converting hydrogen (including trace of tritium) to water vapor (tritium to tritium water) and carbon monoxide to carbon dioxide, 5A molecular sieve adsorber for removing carbon dioxide and water vapor (including trace of tritium water) and cryogenic activated carbon adsorber for removing residual impurities such as methane and nitrogen as well as radioactive components of krypton and xenon (Yao et al., 2002). Five percent of loaded inventory in primary circuit of the HTR-10 per hour is drawn out, purified and finally returns back to reactor core or into helium storage tank. Helium purification system serves primary circuit, but is not relevant to reactor safety. However, it is important for reactor operation since it also serves to regulate pressure of primary circuit and mitigate consequences of some malfunctions. According to the operation experience of the HTR-10, the measured levels of various impurities in primary coolant helium basically meet operation requirement. However, there still exists an urgent problem in helium purification system that no tritium-containing waste water had been collected since the HTR-10 began operation. In addition, both issue of tritium-containing waste water collection and detailed collection process have rarely been mentioned in open literature.

At present, based on the technology and experience of the HTR-10, a demonstration plant of high-temperature gas-cooled reactor-pebble bed module (HTR-PM) (Zhang et al., 2009; Li et al., 2014) is currently under construction and will be finished by 2017 in Shidao Bay, Weihai, Shandong Province of China. With reactor total thermal power of HTR-PM increasing to 2×250 MW, more tritium-containing waste water will be

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produced, which must be collected to avoid the large emission of detrimentally radioactive waste water to the environment. To solve the tritium-containing waste water collection problem in the design of HTR-PM, an optimized process was developed and experimentally verified using the HTR-10. Compared with the previous process, an auxiliary molecular sieve bed was added in helium purification regeneration system and new operation process was proposed to collect tritium-containing waste water. In this paper, the optimized process for the tritium-containing waste water collection and the verification experiment using the HTR-10 were presented in detail.

2. Description of the optimized process for tritium-containing waste water collection of High-Temperature Gas-cooled Reactor

The sources of moisture in the helium are those that are desorbed from reactor components, moistures from hydrogen oxidation by the copper oxide bed of helium purification system, residual air and air in-leakage, steam generator leakage and new helium supply, all of which are mixed with tritium water. The schematic diagram of the optimized process for tritium-containing waste water collection of High-Temperature Gas-cooled Reactor is shown in Fig. 1. It mainly consists of two closed loop systems and two operation phases. One is for the regeneration of molecular sieve bed of helium purification system, while another for the regeneration of auxiliary molecular sieve bed of helium purification regeneration system. A bypass stream from primary circuit is introduced to helium purification system with operation pressure usually being several MPa. In copper oxide bed, hydrogen (including trace of tritium) within helium is oxidized to water (tritium to tritium water) at approximately 250 °C. Then helium enters the helium purification water cooler where the water-cooler heat exchanger reduces the helium temperature to approximately 40 °C, and further to about 10 °C by the cold water-cooler, then saturated water is separated in the helium purification water separator. The residual water is adsorbed in the following molecular sieve bed. Due to low moisture concentration at normal operation, there is no waste water that can be separated in the water separator of helium purification system except that there is a major water ingress into primary coolant. Consequently, almost all of tritium-containing waste water is mainly adsorbed by the molecular sieve bed of helium purification system. When one certain impurity gradually reaches its breakthrough point, the helium purification train has to be regenerated by helium purification regeneration system. So the key point for tritium-containing waste water collection is to design an effective helium purification regeneration system and regeneration operation process for capturing the tritium-containing waste water adsorbed in the molecular sieve bed.

During the regeneration operation of whole helium purification train, helium purification system is depressurized to approximately 0.6 MPa. In the first operation phase, the closed loop for the regeneration of molecular sieve bed can be formed by isolating molecular sieve bed from helium purification system and collecting it to helium purification regeneration system, which mainly consists in sequence of diaphragm compressor, electric heater, molecular sieve bed of helium purification system, water cooler, water separator and auxiliary molecular sieve bed. Filled with helium from helium purification system, the closed loop operates at pressure of about 0.5–0.7 MPa. Driven by the diaphragm compressor, helium is heated by the electric heater and flows through the molecular sieve bed to desorb water at regeneration temperature of approximately 250–300 °C. The gas leaving the molecular sieve bed enters the water cooler of helium purification regeneration system where the cold water-cooled heat exchanger reduces gas temperature to approximately 10 °C. The water separator removes condensed water from the gas, and the residual water is adsorbed in the auxiliary molecular sieve bed. After the molecular sieve bed is regenerated at regeneration temperature of approximately 250–300 °C for several hours, the regeneration of molecular sieve bed ends. By the closed loop system for the regeneration of molecular sieve bed and its operation process, the tritium-containing waste water adsorbed in molecular sieve bed can be desorbed thoroughly, with a little part condensed in the water separator of helium purification regeneration system and most of part adsorbed in the auxiliary molecular sieve bed. When the regeneration of molecular sieve bed is finished, the molecular sieve bed is isolated from helium purification regeneration system.

In the second operation phase, by using the closed loop for the regeneration of auxiliary molecular sieve bed, the tritium-containing waste water adsorbed in the auxiliary molecular sieve bed in the first operation phase can be transferred to water separator of helium purification regeneration system. The closed loop for

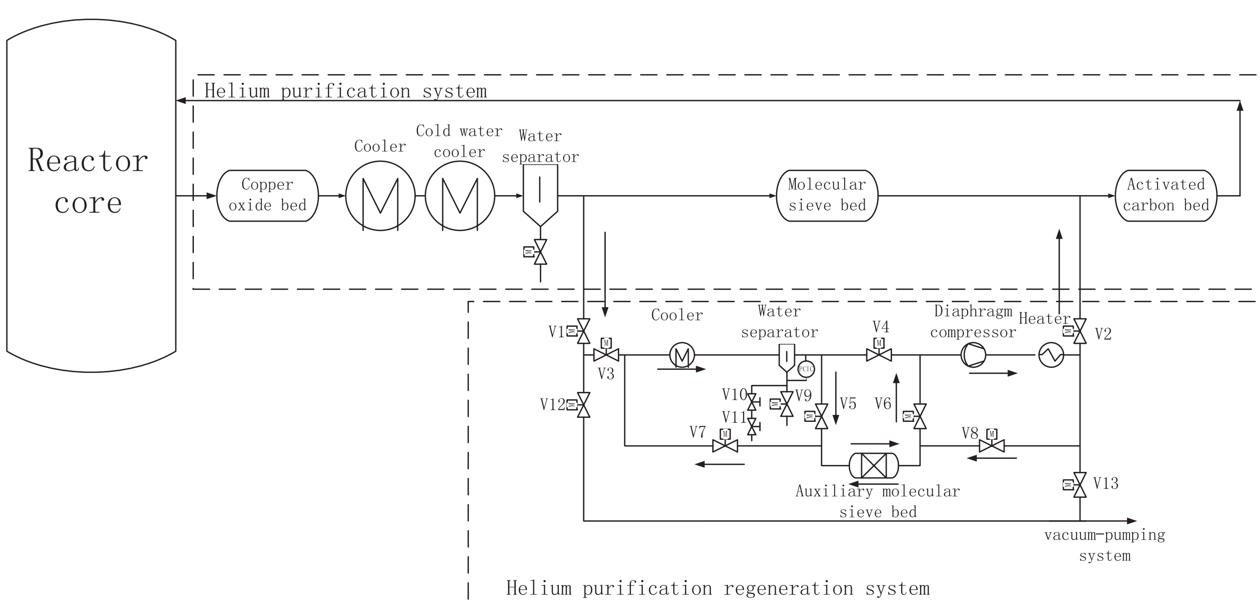

Fig. 1. Schematic diagram of the optimized process for tritium-containing waste water collection of High-Temperature Gas-cooled Reactor.