Reconstruction and operation of the helium purification system in the cryogenic system for EAST Tokamak

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Abstract. EAST (Experimental Advanced Superconducting Tokamak) cryogenic system has participated in the physical experimental campaigns over 15 years since the first cool-down experiment in 2006. Some fault of the heat exchanger blocking due to the purification of gas helium has occurred several times during the cryogenic system’s operation since 2017, which caused the system warmed up to deal with the malfunction. Therefore, the helium gas purification system including the oil-removal system after the oil-injected screw compressors, the adsorbers inside the cold-box and two sets of external purifiers as well as the control system has been redesigned and reconstructed from 2019 to 2020, and put into operation in the 18th cool-down experiment of EAST cryogenic system at the beginning of 2021. The process flow of new helium purification system and the equipment parameters together with the reconstruction process will be presented in detail in this paper. Meanwhile, the commissioning operation results will be illustrated to show the purification performance good and the reconstruction successful.

1. Introduction

The Experimental Advanced Superconducting Tokamak (EAST) device has a cryogenic system, which consists of a compressor station, 2kW@4.5K helium refrigerator and the cryogenic distribution system, to provide the supercritical helium (SHe) forced flow cooling for the superconducting magnets and other cold components including the PF Coils, TF Coils, Cases, thermal shields (THS), buslines, high temperature superconductive current leads (HTS CL), built-in Cryopumps, neutral beam injection (NBI) cryopumps and so on [1][2]. It has been put into operation for 18 cool-down experiment campaigns since the first cool-down in 2006 and the total operation time has already been over 2000 days. The EAST cryogenic system was designed and built by the Institute of Plasma Physics, Chinese Academy of Sciences, and has completed its upgrade including HTSCL cooling, warm compressors and turbines.[3][4] The total performance and the reliability have been improved after the gradual upgrade. However, some fault of the heat exchanger blocking due to the impurity of gas helium has occurred several times during the operation since 2017, which caused the system warmed up to deal with the malfunction. The impurity in gas helium will be frozen on the surface of heat exchanger, degrade heat exchange performance and damage to the turbines [5]. The helium purification system in EAST cryogenic system consists of the oil-removal system, the cryogenic adsorbers in cold box and two sets of external purifiers. The purifiers were produced by Russia in the 1950s, which had big flow resistance and poor automation. The oil-removal system was designed and manufactured at home [6].
but the performance of oil gas separating degraded and oil separators have had the bad seals through over ten years. Meanwhile, the 80K/20K adsorbers in cold box have been operated over 38000 h in total, which already exceeded their design operation life. The aging equipment and the degrading performance are the root cause of the heat exchanger blocking fault. In order to guarantee the long-term reliability and stability, the EAST helium purification system has been upgraded and reconstructed.

2. Process flow of EAST cryogenic system with its purification system
The cooling of EAST superconducting magnets has a high helium gas purity requirement of 99.999\% or higher. During the stable operation period of EAST cryogenic system, the helium gas purity must meet: H2O <5 ppmV; N2 <3 ppmV; CxHy <1 ppmV; Oil<10 ppbW [5]. Therefore, a helium purification system must be installed in the cryogenic system. Figure 1 is a simplified process flow of EAST cryogenic system, which also shows the location of the helium purification system. The oil-removal system was installed at the outlet of the compressors, mainly used to remove the oil and water impurity in helium gas after compressors. The external two purifiers were installed after the oil-removal system and before the cold-box, mainly used to remove the air impurity in helium gas. The original two Russian purifiers have processing flowrate of 50g/s each, and switch one to another in use. Before the helium refrigerator start-up, the helium gas in storage tanks should be purified. Only once purity arrives above 99.999\% can it enter into the refrigerator. The cryogenic adsorbers were installed inside the cold box, which include two groups of 80K adsorbers for removing nitrogen and oxygen and one 20K adsorbers for removing neon and hydrogen. One group of 80K adsorbers are used in the cooling of magnets, another ones are used in the thermal shield of the Tokamak.

![Figure 1. Simplified process flow of helium purification system in EAST helium refrigerator.](image)

3. Reconstruction of EAST helium purification system

3.1. External purifiers reconstruction
Two old purifiers were replaced, and the main technical parameters of two new ones are shown as table 1. During the reconstruction, the process flow of new external purifiers system was designed as figure 2, and the amount of adsorbent as well as the heat power and the resistance was calculated. As figure 3 shows, the main components include the aluminium plate-fin heat exchangers, adsorption separators, LN2 dewars, heat exchanger cold box, related piping and valves bracket. The processing capacity of each purifier increase to 1700 Nm\(^3\)/h. Two purifiers can be spare for each other. All of the purification process can be executed automatically and switched to another online.
Table 1. Main technical parameters of new purifiers

| Item                                      | Unit | Specification        |
|-------------------------------------------|------|----------------------|
| Treated gas                               | /    | Helium gas           |
| Impurity gas                              | /    | Air                  |
| Processing capacity                       | Nm³/h| 1700                 |
| System pressure drop                      | Bar  | ≤1.5                 |
| Source helium gas purity                  | %    | ≥98                  |
| Helium gas purity after purified          | %    | ≥99.999              |
| Working pressure                          | Bar  | 20                   |
| Activation method                         | /    | N2 blowing & evacuation |
| Control method                            | /    | Automatic            |

Figure 2. Process flow of new purifiers.

As figure 2 shows, the helium gas entering into purifier firstly goes through the heat exchanger to be cool-downed to about 90K. The minor oil from oil-removal system was frozen by the heat exchanger. Then the helium gas enters into the coil heat exchanger which immersed in LN2 bath and is cooled
down to 78K. Whereafter, the impurity of N2 and O2 will be removed by the charcoal in adsorbers inside the LN2 dewar. Each purifier has three adsorbers in serial with 360kg active carbon inside one adsorber. When the length of adsorption bed arrives at 3/4, one purifier should be switched to another in order to ensure the continuous purification.

Figure 3. New purifiers.

3.2. Oil-removal system reconstruction

Figure 4 shows the process flow of two new oil-removal systems. One consists of imported water cooler and two levels of oil separators from MYCOM company, one home-made active carbon with molecule sieve mixed adsorber and one dust filter, and another home-made one consists of one water cooler, four oil separators, one active carbon adsorber, one molecule sieve dryer and one dust filter. The two oil-removal systems can be spare for each other to ensure the long-term operation. The N2 heating blowing equipment has been increased for two oil-removal systems. The seal structure of the oil separators has been improved to lower helium leakage. The oil return system was also improved.

Figure 4. Process flow of oil-removal system after reconstruction.
Table 2 is the filter elements specification of oil separator in home-made oil-removal system. The oil impurity after MYCOM compressors is about 100ppm(W). Adopting the mature filter elements, the oil impurity will reach below 0.05ppm(W) after three levels of oil separators. The active carbon of 3mm diameters was used to adsorb the residual oil, and the molecule sieve was used to adsorb micro water impurity in helium gas. Table 3 and table 4 show the design calculation results of the adsorber and the dryer.

Figure 5 is the real picture of the two new parallel oil-removal systems. A set of auxiliary system was designed and built to evacuate the system and heat the adsorbent, which can be used to pre-processing and online regeneration.

### Table 2. The filter elements specification of oil separators

| First separator | Second separator | Third separator | Total pressure drop | Separator diameter |
|-----------------|------------------|-----------------|--------------------|-------------------|
| 3-SLXA 600/240  | 3-CLXD 600/240   | 3-CLXE 600/240  | <0.3bar            | 0.8m              |

### Table 3. Active carbon adsorber calculation

| Active carbon mass (T) | Volume (m³) | Height/Diameter | Resistance (Pa) |
|------------------------|-------------|-----------------|-----------------|
| 2.31                   | 4.2         | 2.18            | 393             |

### Table 4. Molecule sieve dryer calculation

| Molecule sieve mass (T) | Volume (m³) | Height/Diameter | Resistance (Pa) |
|-------------------------|-------------|-----------------|-----------------|
| 3.64                    | 5.2         | 2.7             | 486             |

**Figure 5.** Imported oil-removal system (left) and domestic oil-removal system (right).

### 3.3. Cryogenic adsorbers reconstruction

Figure 6 is the new process flow of the cryogenic adsorbers after reconstruction. There are two groups of 80K adsorbers A2210 and A2212, A2310 and A2312, and one 20K adsorber A2250. Two adsorbers in each group were installed in parallel for the continuous adsorption.

During the reconstruction period, the cold box was opened and the five cryogenic adsorbers were replaced. Replacing new acid pickling active carbon of 3mm diameters, after baking and dedusting then put into the adsorption container can decrease the charcoal dust greatly. Meanwhile, improving the filter unit in adsorbers by adopting the sintering or winding filter element can promote the filtering effect and avoid the charcoal powder entering into the downstream. The original single-deck 400 mesh filter net were replaced to double-deck ones, which can block the charcoal powder efficiently. These adsorbers were tested by 80K cold shock, and then pressurized and helium leakage detected, which can avoid the helium leakage problem in cryogenic temperature. In addition, the seal structure were improved and some broken valves and instruments were replaced too. The valve installation location were also improved to increase the anti-vibrating ability of piping. Figure 7 is the adsorbers reconstruction process.
3.4. **Control system reconstruction**

The purification control system was reconstructed and integrated based on EAST cryogenic control system DeltaV DCS [4]. The new structure of control system is shown as figure 8. Two new purifiers adopt two sets of Siemens S7-1200 PLC for acquisition and control, and adopt S7-1500 CPU as main controller to control the public process. The local PLCs communicates with DCS through PROFI BUS DP protocol to realize the remote control, local/remote switch, safety interlock and fault monitoring. The oil-removal system is located in the compressor station, which has a long distance with DCS. So the Siemens ET200SP distributed I/O was used to acquire data and communicated with DCS through MODBUS protocol for the centralized supervision. The cryogenic adsorbers used the DCS cards directly for acquisition and configured the supervisory interface and programs of the adsorbers in DCS to realize the adsorption mode and regeneration mode.
4. Commissioning and Operation of helium purification system

The helium purification system in EAST cryogenic system has two common operational modes. One is gas purification mode that helium gas with impurity compressed by compressors from the suction inlet enters into the purifier and then the purified helium gas returns to the gas storage tanks. The second mode is system purification mode, which is purification of the refrigerator together with the Tokamak cooling components. The helium gas compressed by the compressors enters into the purifier and after that goes into the refrigerator to purge the whole system until the purity meets the requirement to cool-down. With the cool-down process, the system supplies helium gas through purifier until the cool-down flow rate is not enough. The two operational modes of the purifiers both need the oil-removal system. Before the commissioning, all of the piping were pressurized, evacuated and leakage detected. And all of the seal leakage rate was lower than 10^{-7} \text{pa} \cdot \text{m}^3/\text{s}.

The purifier firstly operated in gas purification mode with the home-made oil-removal system, then operated in the system purification mode. The 1700Nm^3/h processing capacity of each purifier was tested. In the nominal flow rate, the pressure drop of the purifier was 1.4bar (inlet 19.7bar, outlet 18.3bar); and the temperature difference of the main heat exchanger was 3.7K (inlet 290.4K, outlet 286.7K). The outlet purity after the purifiers was 0.076ppm of N2 and 0.022ppm of H2O, which was higher than the purity of 99.999%. Each purifier was not saturated over 80h of total operation time. Each purifier was not saturated over 80h of total operation time.

The purifiers were started with the remote automatic mode in default. Each purifier has three automatic modes of precooling, purifying and activating, which was selected and activated by the operators during the commissioning. The design total pressure drop of the oil-removal system is less than 40kPa. The commissioning result was 2kPa. The imported and home-made oil removal system were switched without any influence during the system running. When the helium gas goes through the refrigerator, one 80K adsorber was operated in adsorption mode with the normal pressure drop of 0.08bar. When the pressure drop increased to 0.2bar, another precooled 80K adsorber will be put into operation in parallel and the used one get out to regeneration mode. Through the operation of depressurizing, warm-up, evacuation, pressurizing and pre-cooling, then the regenerated adsorber was ready to run in the next adsorption mode. There are several purity detection interfaces in EAST cryogenic system, which use the Linde multi-component detector to analyse the impurity in helium gas. Figure 9 are the long term system purity curves after the purifiers withdraw. The vertical coordinates from left to right are the required upper limit values of Oil, CxHy, N2 and H2O in sequence. We can find that the real-time purity was much lower than the requirement. The oil impurity sometimes fluctuated with the maximum value of 5.88 ppb.
5. Conclusion
The reconstruction of EAST helium purification system has been completed and put into operation in cool-down experiment at the beginning of 2021. The new purifiers, oil-removal systems and 80K adsorbers all have the spare and can be switched to each other when the refrigerator is running. And their design parameters and the system purity were tested that they can meet the requirement. The commissioning and long-term operation have proven the reconstruction successful and effective. New helium purification system can guarantee the impurity within the requirement over three months‘ continuous operation. However, for over five months‘ continuous operation, two oil-removal system could be switched to another during the operation. The N2 heating blowing system is essential when replacing the active carbon and molecule sieve, so some problem such as internal leakage of valves must be solved in subsequent work.

6. References
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