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Recovery of helium refrigerator performance for cryogenic hydrogen system at J-PARC MLF

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Abstract. At J-PARC's pulsed spallation neutron source, a cryogenic hydrogen system has been operated to provide liquid hydrogen (18K and 1.5 MPa) to the moderators since 2008. The pressure differences between No.1, No.2 heat exchangers (HXs) and an adsorber (ADS) in the helium refrigerator had begun to increase rapidly since the beginning of 2015, the refrigerator could not be operated continuously. The impurity in the refrigerator was measured by newly introduced quadrat mass spectrometer, but no significant impurities was observed. We suspected the oil contamination from the helium compressor, as it caused performance degradation of the cryogenic system in other facilities, such as RIKEN, CERN, etc. In the summer outage in 2016, we cleaned the HXs with Freon to remove the oil contamination, and replaced the activated charcoals of ADS and oil adsorber (OS-5). As a result, the performance of the helium refrigerator was recovered completely.

1. Introduction

In the Japan Proton Accelerator Research Complex (J-PARC), 1 MW pulsed spallation neutron source, called "Materials and Life science experimental facility, MLF", was constructed to promote cutting-edge materials researches [1]. A liquid hydrogen was selected as a cold neutron moderator from neutron irradiation point of view in a MW class source. A cryogenic hydrogen forced circulation system was applied to remove a nuclear high heat deposition (3.75 kW) [2] in the moderators. Furthermore, temperature increase in the moderator was designed to be less than 3 K in order to achieve the required neutronic performance.

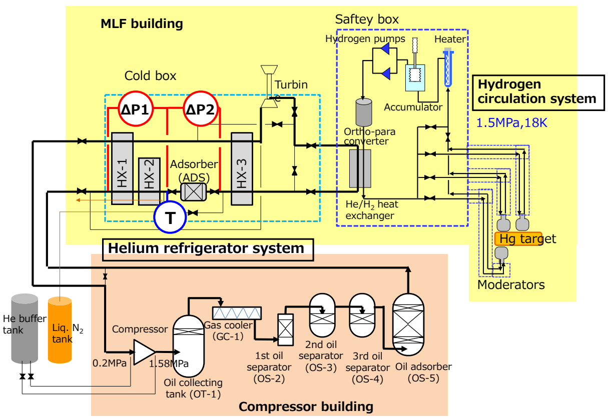

Fig.1 Overview of the cryogenic hydrogen system.

Figure 1 shows overview of the cryogenic hydrogen system, which consists of a hydrogen circulation system and a helium refrigerator system to produce the liquid hydrogen [3]. The refrigerator

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capacity was designed to be 6 kW in total. The helium flow rate of 280 g/s is used to provide the liquid hydrogen (18 K, 1.5 MPa and 180 g/s) to the moderators.

2. Performance degradation of the refrigerator

We have operated the cryogenic hydrogen system on good performance until December, 2014 with typical scheduled operation period of approximately 3 months. However, since January, 2015, the pressure differences at heat exchangers (HX-1 and HX-2) and the ADS increased gradually as shown in Fig. 2.

We suspected insufficient regeneration of activated charcoal of oil adsorver (OS-5) because about 100 ppm of nitrogen concentration in helium gas, which was sampled at closed ADS region, was detected after the operation from April to May, 2015 and the dew-point at heat exchangers (HX-1 and HX-2) was -45 °C at room temperature. The dew-point had been constant at about -80 °C under room temperature, and concentration of impurities, such as nitrogen, oxygen, methane and carbon oxide, which were measured by gas-chromatography, had been almost 0 ppm, respectively before January 2015.

In the 2015 summer shut-down period, therefore, we replaced the activated charcoal of OS-5 and regenerated it to remove the impurities by heated nitrogen gas (more than 100 ºC) and then the nitrogen was removed by vacuum and filling helium gas. We restarted the refrigerator operation in October. However, the pressure difference increased again as shown in Fig. 2, and what was worse, after 21 days operation, the outlet temperature heat exchanger HX-2 began to increase from 78.5 K to 81 K, resulting in hydrogen temperature rise. Finally, we were forced to stop the operation, which meant interruption of scheduled beam user program.

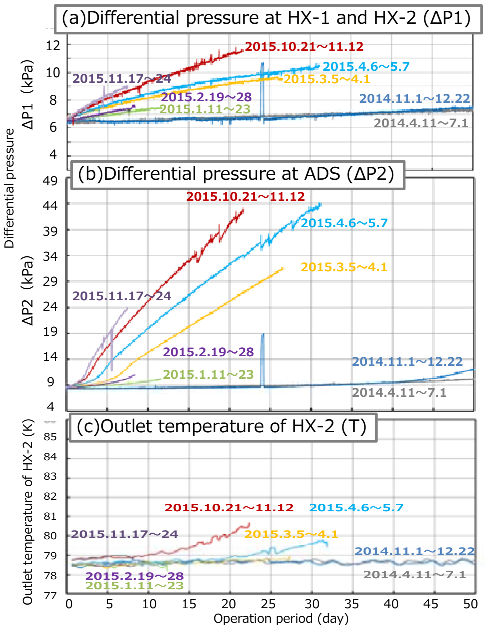

Fig.2 Trend of differential pressure at HX-1 - HX-2 (ΔP1) and ADS (ΔP2), and outlet temperature of HX-2 (T)

3. Investigation and countermeasure for the performance degradation

In December, in addition to regeneration of activated charcoal in OS-5, we regenerated activated charcoal in ADS and dried inside heat exchangers to remove the moisture. The dew points of OS-5 and ADS went down to -65 ºC and -80 ºC under heated condition, respectively, after one month. The heat exchangers were purged by nitrogen gas of 100 ºC for 10 days. A quadrupole mass spectro-analyzer (Q-mass) with a wide range (1-200) of mass/charge ratio was newly applied to analyze the impurities in the gas, which was sampled from OS-5, ADS and the heat exchangers. We also observed inner piping of the cold box by a fiber scope and ultraviolet light. The debris, etc. were not found in the inlet filter, inlet of heat exchanger, and surfaces of some valves. The surface of inlet filter and inside pipe glistened slightly by ultraviolet light. It might be due to small amount of oil contamination.

After the maintenance, a test operation was started in January 2016. However, the pressure difference at the heat exchangers and the ADS began to increase in the same or somewhat faster changing rate than the previous one.

We surveyed several examples of the refrigerator performance degradation. The similar trouble was reported at RIKEN [4] and CERN [5] etc. due to large amount of oil accumulation (several kilograms) in cold box from helium compressor. If the oil contamination caused the performance degradation, we predicted that a major repair work, taking several months, was required to remove the oil. On the other hand, Beam user program was already scheduled until end of June. In order to keep this schedule, we changed the operation cycle of cryogenic hydrogen system, such as 3 weeks operation (up to allowed maximum pressure difference) and 1 week shutdown, because we found that the pressure difference returned initial level for every restarting operation. We also reduced the helium flow by 25% to suppress oil exhaust from compressor to downstream.

4. Recovery measures and investigations at summer outage in 2016

In the 2016 summer maintenance period, we carried out cleaning of inside heat exchangers, replacement of ADS, and check of oil separators and exchange of the filters on the assumption that oil accumulation would cause the performance degradation.

4.1. Cleaning of inside heat exchangers

The heat exchangers (HX-1 and HX-2) with HX-3 were taken out from the cold box. They were transported to cleaning factory in Hyogo. The Freon, ASAHIKLIN AK-225G (c.a. 480 litters) was used to clean inside heat exchangers.

The cleaning procedure was as follows; filling Freon, circulating for 1 hour, circulating again with nitrogen gas bubbles for 1 hour, dipping overnight, circulating again, and then removing Freon. The extracted Freon (c.a. 350 ml) were analyzed to measure the oil content by NVR (Non-volatile residue) method. These were repeated three times. We found that total amount of accumulated oil was about 94 g inside heat exchangers. It seemed that the amount of measured oil was roughly equivalent to the predicted one from accumulation of oil contained in helium gas (10 ppb), which was design value.

4.2. ADS replacement

The ADS was replaced with a new one because most of the pressure difference was generated there. The ADS was removed from the cold box, and then new one with same design was installed at same position. The activated charcoal in new ADS was regenerated by heated nitrogen gas of 100 ºC in order to remove moisture.

We observed inside of inlet and outlet area of used-ADS by fiber scope and ultraviolet light. The surfaces of inlet and outlet area were relatively clean. There was little glistening oil that was illuminated by ultraviolet light. The used-ADS was dismantled each component, such as felt and activated charcoal. We found that the just surface (3 mm in thickness) of upper felt, where helium gas flowed into firstly, was yellowed, like oil color in the visual observation. We conducted to measure the amount of oil in the felt. The oil concentration in the felt and charcoal was analyzed by solvent extraction and infrared spectroscopy. The upper and lower felts were separated eight layers and each thickness of felt was 4 cm. The analyzed results are shown in Fig. 3. Total amount of accumulated oil was 48.0 g in ADS, however, total accumulated oil in ADS was also equivalent to the predicted one from accumulation of oil contained in helium gas.Almost oil (45.6 g) was trapped in upper felt and even more surprising, 17.7 g of oil was accumulated in the first layer of the upper felt. It seemed that upper felt played a role of filter of oil. In generally, the felt was used not for filter of oil but for holding the activated charcoal. We considered that even if small amount of oil accumulation, accumulated oil like film on the surface of felt might cause pressure difference during cooling down process.

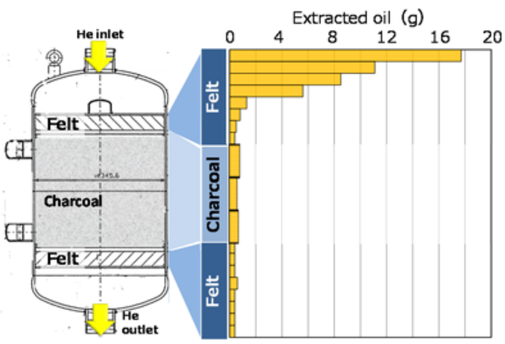

Fig.3 Result of oil analysis of used-ADS.

4.3. Check of oil separators and exchange of filters

We have three oil separators (OS-2, 3, 4) and one oil adsorber (OS-5) unit in order to separate the oil in helium gas after through screw compressor. In the summer outage, we confirmed that the OS-2, 3, 4, and 5 were normal situation without any clogging and breakage of filter. They were no problem from results of the check. Although not reaching the lifetime of each filter, these filters were exchange new ones in order to maximize the oil separation capability.

4.4. Recovery of the refrigerator performance after maintenance

After above measures at summer outage 2016, the refrigerator could be operated for over total fifty days (Nov. 1st to Dec. 20th 2016 and Jan. 12th to Mar. 8th 2017) without any problem. During the operation, the differential pressure at the heat exchangers (HX-1 and HX-2) and the ADS did not increase completely as shown in Fig. 4. The outlet temperature of heat exchanger HX-2 did not also increase.

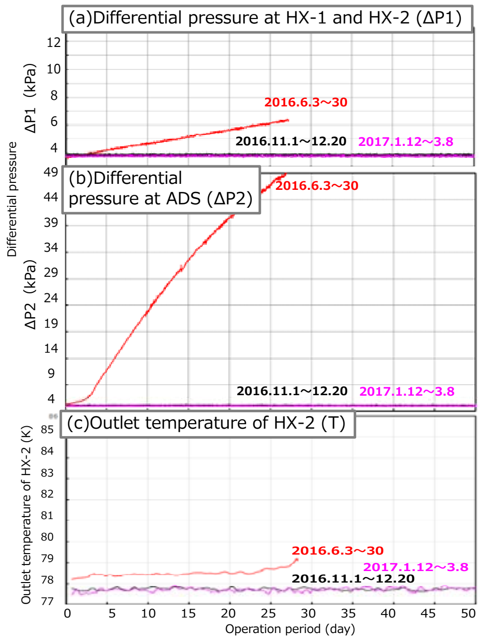

Fig.4 Trend of differential pressure at HX-1 - HX-2 (ΔP1) and ADS (ΔP2), and outlet temperature of HX-2 (T) after maintenance at summer outage.

5. Conclusion

Since Jan. 2015, we had performance degradation of the cryogenic hydrogen system, which is a critical function of the neutron moderator system at the pulsed spallation neutron source. The pressure difference rapidly increased between heat exchangers and ADS, resulting in hydrogen temperature increase.

The performance of helium refrigerator has been recovered by countermeasures, such as cleaning the heat exchangers with Freon and replacing ADS on the assumption that oil accumulation would cause the performance degradation. However, we have not yet identified the cause of degradation completely. We will carried out further investigation including any experiment to reveal the phenomena induced.

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