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Tritium evacuation performance of a large oil-free reciprocating pump

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Abstract

A large oil-free reciprocating pump, with carbon polyimide composite piston rings and dynamic metal bellows seal, has been developed for tritium services at the Tritium Process Laboratory of the Japan Atomic Energy Research Institute. The design pumping speed is 54 $m^3 h^{-1}$ for hydrogen gas at 5 Torr suction pressure and 875 Torr discharge pressure. Tritium evacuation performances were measured at 400–675 Torr discharge pressure at the Tritium Systems Test Assembly (TSTA) of the Los Alamos National Laboratory under the US–Japan collaboration programme on fusion fuel technology. The pumping speed for tritium was greater than 120 $m^3 h^{-1}$ at 4 Torr suction pressure and 500 Torr discharge pressure. The ultimate pressure with tritium was 0.8 Torr at 500 Torr discharge pressure. Performance data for tritium were slightly better than those for H_2, D_2, He and N_2. The discharge pressure did not affect the evacuation performance. In order to check the long-term effect with tritium on pump, semicontinuous tritium pumping operations were performed for a total of 350 hours within 3 months. However, no performance changes were found. After stand-alone tests, the pump was successfully demonstrated as a DT fuel vacuum and transfer pump during a TSTA loop run.

1. Introduction

In fusion reactors, large dry vacuum and transfer pumps are required for various applications, such as backing and roughing for torus evacuation, gas transfer and processing in the fuel cycle and facility vacuum for safety systems. There are some commercial mechanical oil-free pumps which have been used successfully in facilities operating with gases containing tritium [1–4]. In particular, oil-free scroll-type pumps have been tested for use in various sybsystems of the fusion fuel cycle as large roughing pumps [5] because of their larger evacuation capacity. Through these tests, however, it was pointed out that the scroll-type pump had low pumping speeds for hydrogen gases at high discharge pressures [6,7]. Also, larger pumps still have some uncertainties for long-term operation and maintenance with tritium.

From the above point of view, mechanical oil-free reciprocating-type pumps have been developed for various tritium services at the Tritium Process Laboratory (TPL) of the Japan Atomic Energy Research Institute (JAERI) in collaboration with Toyo Engineering Co. The main advantage of reciprocating-type pumps is

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expected to be constant evacuation performance for all gas species over a wide range of discharge pressures. A small oil-free reciprocating pump (10 $m^3 h^{-1}$ for H_2 at 5 Torr suction pressure and 760 Torr discharge pressure) [4] has been used as a roughing pump for low level tritium at the TPL facility for 6 years, requiring no maintenance.

A large oil-free reciprocating pump (54 $m^3 h^{-1}$ for hydrogen gas at 5 Torr suction pressure and 875 Torr discharge pressure) was developed for high tritium level fusion fuel processing. Initial evacuation performances were measured with H_2, D_2, He and N_2 at the TPL [8]. In order to test the function with a large amount of tritium, the pump was shipped and installed in the Tritium Systems Test Assembly (TSTA) loop at the Los Alamos National Laboratory (LANL) under the US–Japan collaboration programme on fusion fuel technology. At the TSTA, tritium evacuation performances were measured at 400–675 Torr discharge pressure. Long-term tritium pumping operations were performed semicontinuously for 3 months to evaluate the initial effect of tritium exposure. After the initial stand-alone tritium evacuation tests at the TSTA, the pump was connected into the TSTA loop, which is a simulated fusion fuel processing loop, and was used to pump DT gas during a loop run.

This paper describes the results of the above tritium tests and discusses the tritium pumping performance and further R&D applications for this pump.

2. Experimental details

2.1. Pump specification

The pump has four-stage compression vertical cylinders and a single acting piston utilizing carbon polyimide composite piston rings. Each stage in the cylinder has 16 special check valves. In order to eliminate flow fluctuation caused by the reciprocating action, buffer tanks are utilized at the suction and discharge. The volume of each buffer tank is about 27 standard litres. A cooling water flow of 5 l min^{-1} is required to cool the cylinder head.

The design pumping speed is 54 $m^3 h^{-1}$ for hydrogen gas at 5 Torr suction pressure and 875 Torr discharge pressure. The section of the pump contacting the process gases with tritium is completely isolated from the crankcase oil by dynamic metal bellows. The dynamic metal bellows are covered with leak-tight cases. Metal gaskets are used at all connections; no elastomer seals are used. This pump has secondary containment and safety interlocks for bellows break, etc. Additional detailed specifications and drawings are given in Ref. [8].

2.2. Configuration of evacuation performance test

For the tritium test, the pump was installed in the TSTA. The dynamic bellows and the pump secondary containment were connected to other glove-boxes in series and controlled at negative pressure and low tritium concentrations by purging with N_2.

After the installation, the evacuation performance test was carried out with N_2, He, D_2, H_2, HDT mixture and T_2 using the closed piping loop of the TSTA. Fig. 1 shows the test configuration. The total loop volume including the pump was 148.9 standard litres, as determined by the PVT (pressure–volume–temperature) method. The volume of the reciprocating pump including buffer tanks is 138 standard litres, though the actual gas inventory was about 30 standard litres during the pumping operation (at about 5 Torr suction pressure and 760 Torr discharge pressure). This configuration is almost the same as for the previous test in the TPL [8]. After purging of the test loop several times, gases were supplied directly from gas cylinders, except for tritium mixtures. Typical HDT mixtures were supplied by uranium beds at the TSTA and the H:D:T ratio was determined to be 16:75:9 by mass analysis. Tritium gas was supplied from a gas vessel after ^{3}He purification using a ZrCo bed. The tritium concentration of the purified gas was more than 84%, with about 8% H and D (H:D:T ratio 8:8:84). During the tests, loop flow

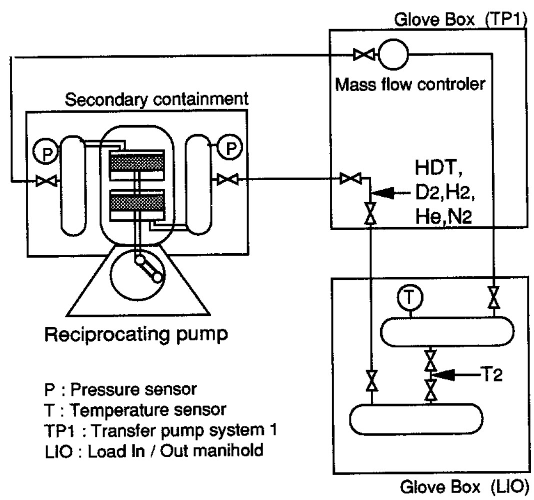

Fig. 1. Configuration of tritium evacuation performance tests at the TSTA.

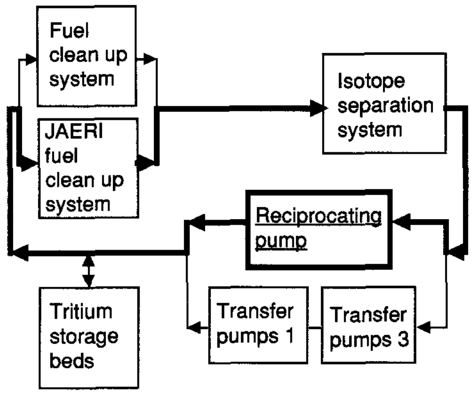

Fig. 2. Configuration of demonstration test in the TSTA loop.

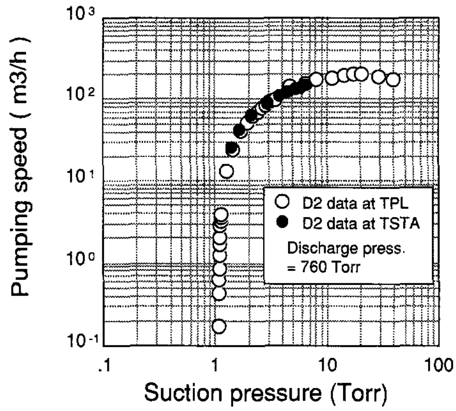

Fig. 3. Comparison of D_2 pumping speeds between the previous test at the TPL and this test at the TSTA as a function of suction pressure.

rates, suction pressures and gas temperatures were measured at discharge pressures of 500, 760 and 875 Torr. Pumping speeds were calculated from the above data.

After the above evacuation performance test, semicontinuous tritium pumping tests were performed in order to check the long-term effect with tritium on pump. The semicontinuous tritium tests were performed with about 1 g of tritium, isolated from the TSTA loop. The pump was turned on every morning and kept running for several hours and then turned off. This cycle operation with tritium was continued for 3 months, monitoring the ultimate pressures. After 3 months of semicontinuous operation, the evacuation performance was investigated again with He and H_2 using the method of the previous test. The actual gas composition was also measured by mass analysis after the semicontinuous operation.

2.3. Demonstration test with TSTA loop

The reciprocating pump was used as a DT fuel vacuum and transfer pump during a TSTA loop run. Normally, several metal bellows pumps are used for TSTA loop gas circulation. The configuration of this demonstration test is shown in Fig. 2. The reciprocating pump evacuation capacity is much larger than those of metal bellows pumps. Therefore the loop flow rate was controlled by a mass flow controller (1–30 standard litres per minute (slpm)) at the suction side of the pump.

3. Results and discussion

3.1. Tritium evacuation performance

Fig. 3 shows the comparison of D_2 pumping speeds between the previous test at the TPL and the test at the TSTA as a function of suction pressure. It is seen that the D_2 evacuation function data were quite consistent even though the test loop was different. Results for N_2, He and H_2 were also consistent. Therefore the tritium data in this test could be compared directly with the previous test at the TPL [8].

The pumping speeds of tritium gas are shown in Fig. 4 compared with N_2, He, D_2 and H_2, all measured at the TSTA. The tritium pumping speed was about $120\ m^3\ h^{-1}$ at 4 Torr suction pressure and 500 Torr discharge pressure. The tritium evacuation was slightly better than those of D_2, He and N_2. These data are better than the design values. As with the other gases, the pumping speed of tritium gas decreased at lower than 3 Torr suction pressure. The reason for this is that the check valves at the first stage of this reciprocating pump cannot open owing to the low gas pressure. The ultimate pressure of tritium evacuation is 0.8 Torr at 500 Torr discharge pressure.

As described in Ref. [8], the evacuation performances of this pump for N_2, He, D_2 and H_2 did not decrease markedly at discharge pressures from 500 to 875 Torr; however, the pumping speeds of the scroll pump were clearly reduced, especially for hydrogen gases [6,7]. For example, Fig. 5 shows the D_2 pumping speed as a function of discharge pressure. Unfortunately, tritium evacuation tests at more than 500 Torr (T = 84%) or 675 Torr (T = 9%) discharge pressure were not conducted, because a large amount of tritium was required. However, tritium evacuation functions were measured at 400 or 675 Torr discharge pressure and were almost constant at 400, 500 and 675 Torr discharge pressures. Therefore this tendency can be extrapolated to more

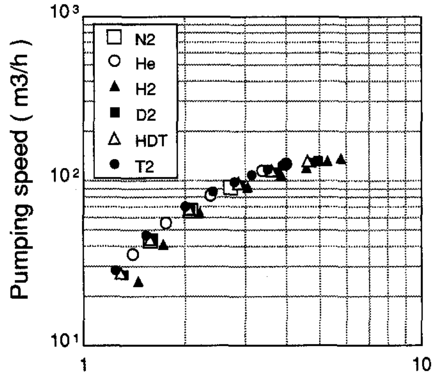

Fig. 4. Pumping speeds of tritium gas (T_2 and HDT mixture) in comparison with those of N_2, He, D_2 and H_2 at 500 Torr discharge pressure.

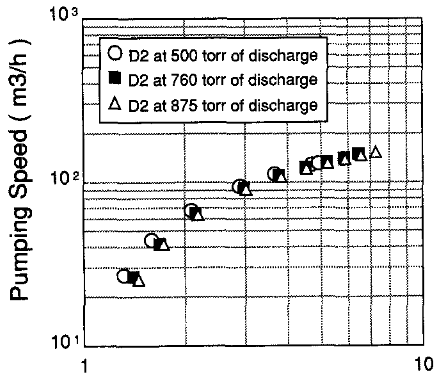

Fig. 5. Comparison of D_2 pumping speeds at 500, 760 and 875 Torr discharge pressures.

than 500 Torr discharge pressure, the same as for the other gases.

The tritium concentration in the secondary containment was watched continuously. There was no detectable increase in tritium concentration during the test.

3.2. Long-term operation

In order to investigate the long-term effect with tritium on pump, the pump was operated with a gram level of tritium (initial H:D:T ratio 8:8:84) for 3 months semicontinuously in a closed line. The total accumulated operation time was 350 h. During the semicontinuous operation ultimate pressure was 0.6 Torr at 150 Torr

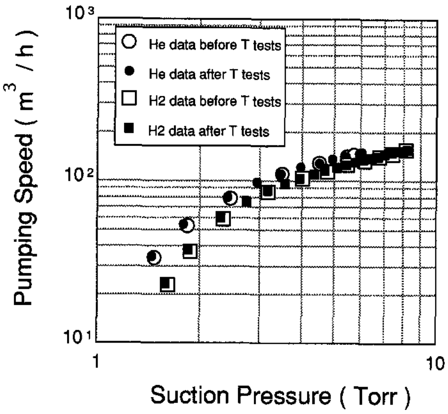

Fig. 6. Comparison of He and H_2 pumping speeds at 760 Torr discharge pressure before and after semicontinuous tritium pumping operations for 3 months.

discharge pressure and was almost completely stable for 3 months. Fig. 6 shows a comparison of the He and H_2 pumping speeds before and after the 3 months of tritium operation at 760 Torr discharge pressure. Almost no change in evacuation performance was detected after the above tritium operation. No tritium leaks were found during the long-term operation.

A total of about 6.8 g of tritium were used for the tritium evacuation tests, while 1.3 g of tritium were used for the long-term operation. At the end of these tritium tests, a total of about 6.1 g of tritium were recovered directly. The recovered gas H:D:T composition after long-term operation was measured to be about 2:1:7 by mass analysis, which includes small amounts of tritiated methane and water vapour. The recovered gas volume was consistent with the initial supply. In later tests, more than 0.1 g of tritium was recovered by purging and evacuation with He and H_2. However, not all the tritium was recovered from the pump. From the gas volume and H:D:T compositions recovered after the above tritium test, it is suspected that some of the tritium exchanged with protium contained in the pump materials, such as the cylinder steel and the carbon polyimide composite rings. There is also a possibility of diffusion through the metal of the cylinders; however, this would be difficult, because the cylinders were continuously cooled to lower than 323 K by chilled water.

3.3. Demonstration of DT fuel transfer in the TSTA loop

A TSTA loop run was performed in December 1993 mainly to investigate the isotope separation system

(ISS) functions. Initially, loop flow was achieved by a set of metal bellows pumps. During the above run, the reciprocating pump was used for loop flow circulation instead of the above metal bellows pumps. Unfortunately, the operation period of the pump was only about 1 h owing to a tritium leak in the discharge-side piping connection to the loop. However, it was successfully demonstrated that the reciprocating pump could evacuate and transfer a realistic DT fuel mixture. The loop flow rate was adjusted to 0.5–4 slpm for the preparation of the ISS experiment and the pumping capacity was sufficient when the discharge pressure went to 1200 Torr. No operational difficulties and no tritium leaks were found with the reciprocating pump.

3.4. Future R&D items

The oil-free reciprocating pump demonstrated performances higher than design values during tritium evacuation tests. Furthermore, improvement items were also found from the above tritium test, concerning ultimate pressure, tritium inventory and safer tritium handling.

As described above, the pumping speed and ultimate pressure of this reciprocating pump are suspected to be limited by the small opening of the check valves at low pressure. Therefore the pumping performances at low pressure could be improved if alternative check valves, e.g. solenoid types, were available to provide better opening at low pressure.

In order to reduce the tritium inventory, a smaller buffer tank would be effective. To better understand the residual tritium inventory, further investigation is required on the isotope exchange in the pump materials.

No difficulties were found concerning safe tritium handling through the above pumping tests. However, the possibility of vibration from the reciprocating action could have caused the leak in the piping connection. Powder from the carbon polyimide rings may be generated and become a source of residual tritium contamination in further long-term operations. Therefore the vibration and the amount of piston ring material should be kept to a minimum.

4. Conclusions

A large oil-free reciprocating pump was developed at TPL/JAERI and its tritium evacuation performance was investigated wtih H_2, D_2, He and N_2 at TSTA/LANL under the US–Japan collaboration programme on fusion fuel technology. The pumping speed of tritium was more than 120 $m^3 h^{-1}$ at 4 Torr suction pressure and 500 Torr discharge pressure. The ultimate pressure with tritium was 0.8 Torr at 500 Torr discharge pressure. The evacuation performance with tritium was slightly better than with H_2, D_2, He and N_2. Although the evacuation function of a scroll pump decreases drastically at higher than 500 Torr discharge pressure, the pumping speed of this reciprocating pump was maintained even at discharge pressures up to 875 Torr. The evacuation performances of the pump were not degraded after long periods of semicontinuous operation with gram levels of tritium for 3 months. Finally, this reciprocating pump was used in the TSTA loop and was successfully demonstrated to evacuate and transfer realistic DT fuel mixtures.

Through the above tritium tests, further R&D items were also found, such as ultimate pressure improvement using alternative solenoid valves, tritium inventory minimization with smaller buffer tanks, and reduced vibration of reciprocating action to minimize external leak possibilities.

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