An Evaluation on the Performance
of a Vacuum System for a Cold Neutron Source in HANARO

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1. Introduction

In HANARO, a Cold Neutron Source (CNS) project is being designed to enhance its utilization capacity. To realize the CNS, a vacuum system is required for the thermal insulation of the low-temperature thermo-siphon loop in a moderator cell. [1] The main performance of the vacuum system is to serve the normal operation vacuum pressure, which is 1×10^{-5} torr. There are many problems to be solved in the vacuum system design to reach the desired vacuum pressure with a reasonable evacuation time. The performance of the vacuum system mostly depends on the conductance of the vacuum chamber and the pipeline. Also, the pipeline length from the chamber to the vacuum pump is a very important factor. The design characteristics of the vacuum system are described herein and an evacuation time calculation for the basic design is presented.

2. Evacuation Time

2.1 System Concept

The main function of the vacuum system inside the vacuum containment is to act as a thermal insulation for the cold part of the in-pile assembly and to act as a safety barrier against the irruption of liquids and/or gases from the outside. The thermal insulation is of relevance to the performance of the in-pile assembly cooling. The vacuum level for the insulation shall be at least lower than 1×10^{-5} torr during a normal CNS operation. [2] A vacuum is achieved by means of two vacuum pumping sets. One of the pumping sets is in operation while another is on standby. The pumping set array is completed with a set of valves, fittings and pipelines known as a vacuum manifold. The vacuum pumps discharge into the reactor hall. The vacuum pumps and the manifold are placed within a box filled with nitrogen gas. The box can be divided into respectively three parts for considering an easy maintenance of the vacuum pumps. The nitrogen blanket is to isolate the vacuum system from the air.

2.2 System Component

The primary pump is a dry pump (oil-free and scroll-type). The displaced volume in the suction is about 4.16 l/s, while the ultimate pressure is about 1.2×10^{-2} torr.

And, the high vacuum pump is a turbo molecular pump with a volume displacement of 230 l/s, while the ultimate pressure is about 3.75×10^{-8} torr. [3] It is assumed that the final pressure of the vacuum system is below 1×10^{-6} torr. Although the processing pressure during a normal operation is defined as lower than 1×10^{-5} torr, it was conservatively enlarged to improve the pressure distribution within the vacuum containment. It is assumed that the DN 65 vacuum pipeline connects the vacuum pumping sets and valves manifold array to the vacuum containment. The diameter was adopted by considering the pipeline length and desired vacuum level. Although it is not the optimum diameter in view of the nearly 20 m of the length, it is not necessary to reach a vacuum within the vacuum containment in a short time.

2.3 Flow Type Determination

It is required to define the vacuum volume to be evacuated from the vacuum containment and pipelines to evaluate the pumping velocity of the IPA. Its volume may be calculated in 100 liters. Since it is possible that it will be modified due to dimensional changes in the upcoming detailed design for the IPA, the volume was over estimated in nearly double. The length of the pipelines is about 20 m, while their diameter is assumed as DN 65 (Inner diameter: 0.0669 m). The volume of the pipeline may be estimated in 70 liters. So, it is assumed that the total vacuum volume is about 170 liters. The Reynolds number was calculated to determine the type of flow in the initial conditions (P=1 bar, T=20°C). Reynolds number is calculated as 687 by using equation 1. Since it is lower than 1200, the flow is viscous at an atmospheric pressure. Limit pressure for each flow rate can be determined for every flow rate by means of the inner diameter of the pipeline expressed in cm. As results of the limit pressure, the limit of the viscous flow is higher than or equal to 0.075 and that of the transition flow is from 0.022 to 0.075, and that of the molecular flow is lower than or equal to 0.022

$$\mathrm{Re} = \frac{D \, v \, \rho}{\mu} \qquad (1)$$

2.4 System Performance

The pipeline is viewed as a long cylindrical tube to calculate its conductance at different flow rates. The

conductance calculated by using equation 2 is modified with a correction factor in view that the gas to be evacuated is helium and the equations used consider air. The conductance for a viscous flow rate is presented as equation 2. The conductance for a molecular and a transition flow rate is respectively presented as equations 3 and 4. The system suction velocity is calculated by combining the system conductance with the pump velocity. It can be expressed by equations 5 or 6. In the case of the system velocity in the transition, the average pumping velocity (190l/s) is adopted according to the operating curve of the turbo molecular pump. Evacuation time for each flow rate of the vacuum containment was calculated respectively by equations 5 and 6. It takes a total within 15 minutes to reach the required vacuum of 1×10^{-6} torr from 760 torr.

▪Viscous flow rate: $\quad C = \dfrac{182\,D^4\,\bar{P}}{L}$ (2)

▪Transition type flow rate: $\quad C = \dfrac{12.17\,D^3\,j}{L}$ (3)

▪Molecular flow rate: $\quad C = \dfrac{12.17 D^3}{L}$ (4)

$$t = \frac{2.3V}{S}\log\frac{(P_i - P_b)}{(P_o - P_b)} \quad (5)$$

$$t = \frac{V}{S_{ef}}\ln\frac{101325}{P_f} + \frac{V}{S_{eh}}\left(\frac{P_f}{P_m} - 1\right) + \frac{V}{S_{eh}}\ln\frac{P_m}{P_{op}} \quad (6)$$

The result calculated by equation 5 is shown in Fig. 1. According to a pressure drop from atmosphere to 1 Pa the pumping velocity is linearly increased by a full power operating of the vacuum pump. After then, it reaches 10^{-4} Pa by a nearly pumping exhaustion. This property shows a very similar trend with that of the typical high vacuum system, which was designed around 10^{-4} Pa. [4]

This result did not consider the out-gassing rate due to the surface roughness of the vacuum containment and the pipeline. If considering the above conditions, it would be expected that the evacuation time of the vacuum system may be increased in several times. But, in the case of a super high vacuum system designed to lower than or equal to 10^{-5} Pa, it was reported that the pumping velocity is almost governed by the vacuum properties of the materials [4]. So, it is not necessary to consider the out-gassing rate for the vacuum system designed around 10^{-4} Pa. The vacuum level for a CNS in HANARO will be considerably lower than or equal to 10^{-3} Pa during a normal operation.

On the other hand, there is a plan to make a test system for verifying the cryogenic performance of the In-Pile-Assembly. In the upcoming test, it will also measure the pumping velocity of the vacuum system connected to the test IPA. To achieve the design goal of the vacuum system, it is necessary to compare the calculation with the test results.
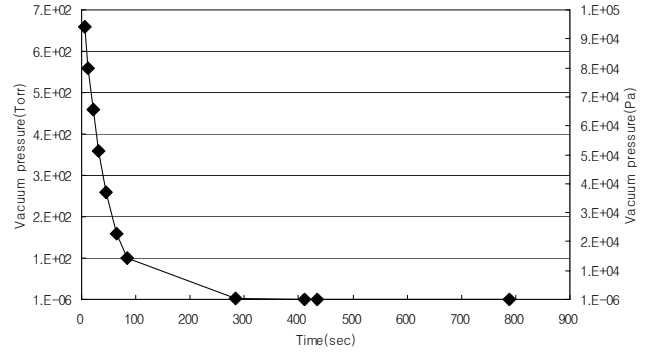

Fig. 1. Pumping time calculated by Eq. 5

3. Conclusion

The vacuum system for the CNS should be designed through the means of two vacuum pumping sets. One of the pumping sets is in operation while another is on standby. It is required to continuously maintain the processing vacuum pressure in the vacuum containment. Although it is not required for reaching the vacuum level in a short time, it is necessary to evaluate the pumping velocity of the vacuum system. According to the results, it takes a pumping time within 15 minutes to reach the required vacuum pressure, which was assumed to be 10^{-4} Pa. The pumping velocity up to 1 Pa is linearly increased by a full power operating of the vacuum pump. After then, it reaches 10^{-4} Pa by a nearly exhaustion capacity of the pump. In general, it is not necessary to consider the out-gassing rate for the vacuum system designed around 10^{-4} Pa. The vacuum level for the CNS insulation will be considerably lower than or equal to 10^{-3} Pa during a normal operation. Therefore, it would be not expected that the out-gassing rate will be affected on the pumping velocity.

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