Studies of cryocooler based cryosorption pump with activated carbon panels operating at 11K

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Abstract. Cryosorption pump is the only solution for pumping helium and hydrogen in fusion reactors. It is chosen because it offers highest pumping speed as well as the only suitable pump for the harsh environments in a tokamak. Towards the development of such cryosorption pumps, the optimal choice of the right activated carbon panels is essential. In order to characterize the performance of the panels with indigenously developed activated carbon, a cryocooler based cryosorption pump with scaled down sizes of panels is experimented. The results are compared with the commercial cryopanel used in a CTI cryosorption (model: Cryotorr 7) pump. The cryopanel is mounted on the cold head of the second stage GM cryocooler which cools the cryopanel down to 11K with first stage reaching about ~50K. With no heat load, cryopump gives the ultimate vacuum of 2.1E-7 mbar. The pumping speed of different gases such as nitrogen, argon, hydrogen, helium are tested both on indigenous and commercial cryopanel. These studies serve as a bench mark towards the development of better cryopanels to be cooled by liquid helium for use with tokamak.

1. Introduction

Cryopumps belong to the class of entrapment or capture vacuum pumps and they retain the gas molecules by sorption and / or by condensation on its internal surfaces. Thus the performance of cryopump is governed by the interplay of these two pumping mechanisms. The equilibrium pressure of adsorbed gas particles is significantly lower than the corresponding saturation pressure for cryo-condensation. This is due to the fact that the dispersion forces between the gas molecules and the surface are greater than between the gas molecules themselves in the condensed state. The adsorption takes place at the porous surfaces. Hence, porous materials are of great importance towards this technology.

Commercially available cryo-pumps are intended for industrial application and operate in the temperature range of 20-25K, since they do not require the pumping of lighter gas molecules like hydrogen, deuterium and helium etc. However, for fusion devices which involve extremely high temperatures and magnetic fields, the only possible pump that can be used is the cryosorption pumps to pump these gases. Many investigators [1-3] have carried out experimental studies towards the development of cryopanels with increased pump efficiency for use with the next generation tokamak fusion devices. These studies also indicate that activated carbon is the right material for these applications.
Both adhesion and proper cooling of the charcoal at panel surface are critical aspects in the development of cryopanels. Also, the poor thermal conductivity of the charcoal degrades the performances of the panels used in the cryopump. Literature survey indicates that gases such as hydrogen, helium and their isotopes can be pumped around 20 K, but helium cannot be pumped at this temperature. Very few literatures are available which demonstrate the pumping of helium at ~ 4.5 K. Hence, there is a need for studies of measurements of pumping speeds of cryosorption panels (with the specific activated charcoal with a suitable binder) for different gases inclusive of Helium in the temperature range from 4.5 K to 10 K. Such a study will also enable to benchmark the performances against a standard commercial panel.

Towards the above goal, the present work has been undertaken using a commercially available two stage GM cryocooler based cryopump (Cryotorr 7) reaching the lowest temperature of 11 K. Various indigenous activated carbon panels are mounted on the cold head and tested with gases such as nitrogen, argon, hydrogen and helium. These experimental results are discussed in this work.

2. Experimental Setup

Figure 1 shows the schematic of the cryopump and the experimental setup. This is based on the commercially available CTI cryopump of Model Cryotorr 7. The housing of a cryopump is made of stainless steel with an ‘O’ ring sealed high vacuum flange of 300 mm diameter. The top flange has provisions to connect the pressure gauges and also for gas into the system. The two stage GM Cryocooler is driven by a 3 kW helium compressor along with a rotary valve. The system reaches no-load temperatures of ~ 11 K in the second stage and ~ 50K in the first stage. Temperatures of the first stage and second stage of GM Cryocooler are measured by silicon diodes (SI-410). The cryopanel is mounted on second stage cold head of the GM cryocooler. Indium is used to improve thermal conductivity. Heat switch is mounted in between cold head and cryopanels, which helps to heat the sample without affecting the performance of cryocooler.

![Schematic of the cryocooler with activated carbon cryopanels and actual experimental setup.](image)

Pfeiffer Vacuum gauges are used to measure the pressures of the system. Aalborg mass flow controller GFC 17 (0-50 ml/min) is used to control the mass flow during the gas inlet for measurement. Test gas mixing facility is used to mix the gas in different percentages. All the gases used for measuring pumping speeds have ~ 99.999% purity. Rotary vane pump is used to create initial vacuum of the system.
3. Experimental Results

The experimental results of cool-down behaviour of the GM Cryocooler, ultimate pressures obtained under no load conditions and also the pumping speeds for different gases are presented below.

3.1 Cool-down Behavior

Figure 2 plots the cool-down characteristic of two stage GM cryocooler, with Cryopanel mounted on the second stage cold head. The cryocooler reaches the no load temperature of ~ 11 K and hence the cryopanel mounted on the second stage can only reach the lowest temperature of this value. The typical cool down time is of the order of 200 minutes.

![Cool down curve of two-stage GM cryocooler](image1)

![Ultimate pressures reached with no gas load on the panels](image2)

3.2 Ultimate pressures reached on no gas load

Rotary vane pump is used initially to develop the base pressure levels of ~ 2.2E-2 mbar. Figure 2 shows the pressure versus temperature wherein the ultimate pressure of ~ 2.2 E-07 at ~11 K has been achieved for both imported and indigenous charcoal panels. This indicates that without gas load both the panels perform similar.

3.3 Pumping Speed studies of different gases on different types of charcoal panels

Experiments have been conducted for different gases such as Nitrogen, Argon, Hydrogen and Helium as adsorbate. The imported charcoal panel (original panel used in the Cryotorr 7 Cryopump) has been used as benchmark for comparison of indigenous activated carbon panels. The imported activated carbon consists of granules of sizes ~ 2 to 3 mm. On the other hand, three types of indigenous activated carbons have been studied namely granules with sizes ranging from 0.5mm to 1 mm. The prepared panels had approximately the same physical surface areas as that of the imported charcoal panel.

3.4 Pumping Speeds for Nitrogen and Argon

Figure 4(a) shows the pumping speed versus pressure of different cryopanel for nitrogen gas (of purity 99.999%). The pumping speed in general decreases with increasing pressure for all the cryopanels. However, the commercial cryopanel with the largest granular size has the highest pumping speed.
The indigenous cryopanel with largest granular size activated carbon has slightly lesser pumping speed compared to the commercial one. The activated carbon panels having medium and smaller granular sizes have still lesser pumping speeds. These results can be understood as follows. Assuming that the physical areas of the panels to be the same and the adhesive closes almost the same number of pores in each panel, the granules of activated carbon of larger size has increased internal surface area. Hence, this leads to increased pumping speeds for the panels with larger activated carbon granules. It is also observed that when the experiments are repeated with the same cryopanel, the pumping speeds improve with each run.

This is due the better cleanup of the pores with the subsequent runs. Figure 4(b) shows the pumping speed versus pressure for different cryopanels for argon gas (of purity 99.999%). Here again, the pumping speed decreases with increasing pressure. Also, the commercial cryopanel shows the highest pumping speed. The cryopanel with indigenous activated carbon with larger granular size has pumping speeds similar to the commercial one. The panels with medium and smaller granules have slightly lesser pumping speeds.

3.4 Pumping Speeds for hydrogen and helium

Figure 5(a) plots the pumping speed versus pressure for indigenous and imported activated carbon cryopanels with the adsorbate of Hydrogen (3%) in nitrogen. Since the temperature of the panel rises rapidly, due to the increased thermal conductivity of hydrogen, experiments could not be conducted with pure hydrogen and so the above gas mixture has been chosen. Even in this case, it is observed that the imported cryopanel performs better compared to the indigenous one. Also, the pumping speeds for Hydrogen are found to be relatively lower compared to those of Nitrogen and Argon.

When the experiment was conducted using helium gas (99.999%), there was sudden increase in temperature when helium was introduced in the system and the temperature kept on increasing due to which the pressure of the system also increased. Similar to the case of hydrogen, helium – nitrogen gas mixture was chosen as adsorbate in the subsequent experiments. The experimental results for small granular charcoal panels with helium gas mixtures in nitrogen as adsorbate are shown in Figure 5(b). The results indicate the extremely low pumping speeds of this system, that too in the limited pressure range.
Fig. 5. Pumping speeds for (a) hydrogen (3%) in nitrogen gas mixture and (b) helium (0.5% and 1%) in nitrogen gas mixtures as adsorbate.

It is seen from the above table that the system performance is better for the imported cryopanel with larger granular activated carbon for all gases. With hydrogen as adsorbate, the pumping speeds are lower compared to those for nitrogen and argon. In the case of helium, the pumping speeds are extremely low. The above results clearly indicate that for pumping helium gas we need to have cryopanels operating at temperatures much lower than 11 K.

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Table 1. Comparison of pumping speeds for different gases for different cryopanels at 3.0E-5 mbar.

| Panel                  | \(N_2\) | \(Ar\) | \(H_2\) | \(He\) |
|------------------------|---------|--------|---------|--------|
| Without charcoal panel | 192     | 127    | 50      | 0.2    |
| Cryostar 7 charcoal panel | 1450   | 1135   | 250.2   | 0.15   |
| small charcoal granule panel | 600   | 825    | 100.8   | 0.14   |
| Medium charcoal granule panel | 575   | 720    | 155.3   | 0.23   |
| Large charcoal granule panel | 1370 | 1129   | 215.3   | 0.22   |

3.4 Effect of Degassing on Cryopanels
Figure 7 indicates that degassing of the cryopanels are very much needed to improve the performance of cryopump. The pumping speed of cryopump increased after it degassed upto 350K. This degassing temperature of the panels is limited upto 350K due to the presence of the adhesive. Heat switch is mounted in between GM cryocooler cold head and cryopanels to heat up the panels without affecting the performance of Cryocooler.
Fig 6. Pumping speeds of indigenous charcoal panel with nitrogen with and without degassing the sample

4. Conclusion
Towards the development of cryosorption pumps and to benchmark the performances of indigenous activated carbon based cryopanels, pumping speed measurements have been made using a CTI Cryosorption pump (model Cryotorr 7). The indigenously fabricated panels are mounted at the second stage cold head of the GM Cryocooler which reaches 11 K on its second stage cold head. The experimental studies show that the performance of the indigenous activated carbon panels is better compared to the original panel for all gases. For hydrogen, the pumping speed is much lower compared to nitrogen and Argon. For pumping helium, the studies clearly indicate the need for having temperatures much lower than 11 K. Hence attempts are now in progress to develop an experimental setup based on a Cryocooler which reaches 4.2 K.

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