

Performance studies of Cryocooler based cryosorption pumps with indigenous activated carbons for fusion applications

Kasthuriangan S¹, Vivek G A^{1,2}, Ravi Verma¹, Upendra Behera¹, Swarup Udgata² and Ranjana Gangradey³

¹Centre for Cryogenic Technology, Indian Institute of Science, India

²I-Design Engineering Solutions Ltd, India

³Institute of Plasma Research, India

vivek.g.a07@gmail.com, ssu@rsbglobal.com, behera@ccf.iisc.ernet.in,
fantastini@gmail.com

Abstract. Cryosorption pumps are the only solution for pumping helium and hydrogen in fusion systems, due to their high pumping speeds and suitability in harsh environments. Their development requires the right Activated Carbons (ACs) and suitable adhesives to bind them to metallic panels with liquid helium (LHe) flow channels. However, their performance evaluation will require large quantities of LHe. Alternatively, these pumps can be built with small size panels adhered with ACs and cooled by a cryocooler. The paper describes the development of a cryopump using a commercial cryocooler (Sumitomo RDK415D), with 1.5W@4.2 K, integrated with small size AC panel mounted on 2nd stage, with the 1st stage acting as radiation shield. Under no load, the cryopump reaches the ultimate pressure of 2.1E-7 mbar. The pump is built using panels with different indigenously developed ACs such as granules, pellets, ACF-FK2 and activated carbon of knitted IPR cloth. We present the experimental results of pumping speeds for gases such as nitrogen, argon and helium using the procedures outlined by American Vacuum Society (AVS). These studies will enable to arrive at the right ACs and adhesives for the development of large scale cryosorption pumps with liquid helium flow.

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 [1].

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 that based on



cryosorption. Many investigators [2-7] have carried out experimental studies towards the development of cryopanel with increased pump efficiency for use with the next generation fusion devices. The above studies indicate that activated carbon is the right material for the development of cryosorption pumps.

Both adhesion and proper cooling of the ACs on the panel surface are critical aspects in the development of cryosorption pumps. Also, the poor thermal conductivity of the ACs degrades the performances of the panels used in the cryopump. Literature survey indicates that gases such as hydrogen and its isotopes can be pumped around 20 K, but helium cannot be pumped at this temperature. Only very few studies [4,6-7] are seen in the literature which demonstrate the pumping of helium around 4.5K. Hence, pumping speed studies of cryopanel built with specific indigenous ACs for pumping different gases inclusive of hydrogen and helium are needed. This study will enable to benchmark the performances of different AC panels against the standard commercial panel.

Towards this goal, the cryocooler based cryosorption pump has been developed. This uses a commercial cryocooler (Sumitomo model RDK415D), with the cooling power of ~ 1.5 W at 4.2 K. The small size AC panels are mounted on the second stage and cooled by the cryocooler, thus forming the cryocooler based cryosorption pump. The pump is built using panels with different indigenously developed ACs such as granules, pellets, ACF-FK2 and activated carbon of knitted IPR cloth. In this work, we present the results of pumping speed measurements using the American Vacuum Society (AVS) procedure for gases such as nitrogen, argon, hydrogen and helium. These results will be useful to arrive at the right ACs and adhesives to develop the large scale cryopump with liquid helium flow.

2. Adsorption characterization of indigenous Activated Carbons:

In our efforts towards building the cryosorption pumps for fusion applications, the development of different types of indigenous activated carbons has become possible, by the efforts of our industrial collaborators. Some of them are, (i) activated carbon granules, (ii) activated carbon pellets, (iii) activated carbon spheres ACS3, (iii) activated carbon fibre - flake knitted type ACF-FK2 (iv) activated carbon fibre - non-woven type ACF-NW3, (v) activated carbon cloth etc. Figure 1 shows some of the samples of activated carbons.

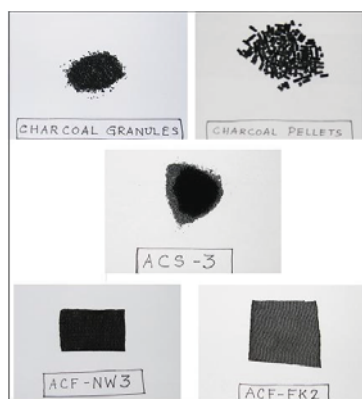
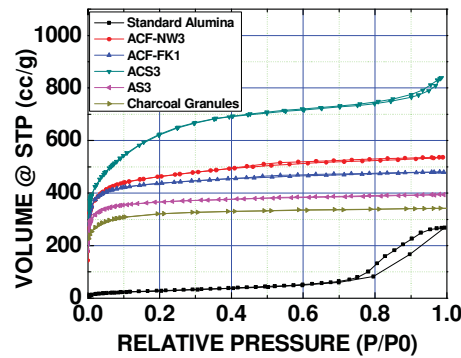


Figure 1. Samples of different types of indigenously developed activated carbons

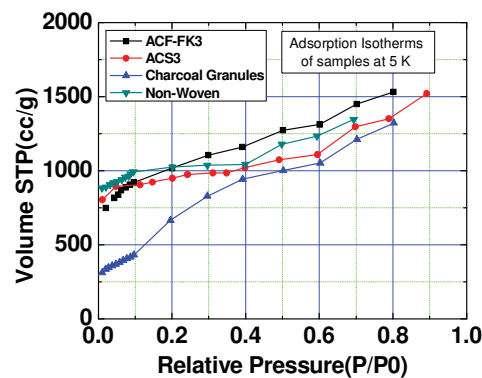
The adsorption characteristics of different types of activated carbons for gases such as hydrogen and helium are essential for the selection of the right adsorbents used in cryosorption pumps. The temperature range between 4.5K and 20K is suggested for the cryosorption of fusion exhaust components. However, this experimental data at cryogenic temperatures are scarce in the open literature, especially below 77K.

Hence a dedicated experimental facility to study of adsorption characteristics of different types of activated carbons was established by integrating a commercial micropore analyser (Quantachrome model ASIQ) operating at 77 K along with a two stage GM cryocooler (Janis, model SRDK415D) to

lower the sample temperature down to 4.5 K. Using this facility, small samples of different types of activated carbons could be studied to obtain the adsorption isotherms in the temperature range from 4.5 K to 77 K. These results can be further analyzed to obtain adsorption surface areas and pore size distributions etc., using suitable models. More details of this experimental facility are available in reference [8]. The typical adsorption isotherms for nitrogen as adsorbate at 77K and helium as adsorbate at 4.5 K on different activated carbons are shown in Figures 2 and 3 respectively.



Figures 2: Adsorption isotherms at 77K for different activated carbon samples with nitrogen gas as adsorbate



Figures 3: Adsorption isotherms at 5K for different activated carbon samples with helium gas as adsorbate

The surface areas of different activated carbons for adsorption are shown in Table 1.

TABLE 1 Surface areas of different activated carbons at 77 K and 4.5 K

| Sample | Surface Area at 77K with N ₂ (m ² /g) | Surface Area at 4.5K with He (m ² /g) | Surface Area at 5K with He (m ² /g) | Surface Area at 8K with He (m ² /g) | Surface Area at 10K with He (m ² /g) |
|---------------|---|--|--|--|---|
| Flake Knitted | 2230 | 2930 | 2697 | 2582 | 2015 |
| Gloubles | 2038 | 2700 | 2639 | 1963 | 1552 |
| Non Woven | 1773 | 1951 | 1924 | 1589 | 1335 |
| Granules | 1368 | 1801 | 1797 | 1188 | 1069 |

The above experimental results indicate that compared to the activated carbon granules, ACS3, ACF-FK2 and ACF-NW3 have better performances of adsorption. Hence, these can be used in the development of cryopanel. However, their adherence characteristics onto the panel and long term performances are still to be evaluated.

3. Design and development of cryocooler based cryosorption pumps:

The design of our indigenously developed cryosorption pump was selected to be similar to that of a commercial cryocooler based cryosorption pump. This will enable the interchangeability and the performances of different indigenous AC panels can be compared with respect to the commercial panel performance studied in our cryosorption pumps. The schematic of the commercial cryosorption panel is in figure 4. The photograph of the carbon coated cryopanel of the commercial cryosorption pump (Model Varian Ebara SP8, USA) is shown in figure 5. It is seen that the cryopanel is adhered with the activated carbons using suitable glue. The original cryopump uses a standard GM cryocooler for cooling the panels mounted on the second stage. The cooling power of the first stage is used to cool the radiation shield surrounding the above cryopanel. The values for the pumping speeds for gases such as nitrogen and argon specified by the manufacturer are in the range of 800 to 1000 l/s at the ultimate vacuum level of 10^{-9} mbar. We have used only the carbon coated panels in our experimental system (and not the other components of the commercial cryopump) for pumping speed measurements. Since the commercial panel is taken as a standard, the cryopanel of identical dimensions were fabricated and used for the indigenous AC panels in our pumping speed measurements.

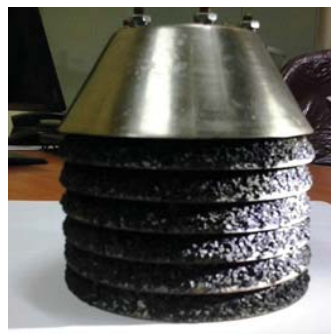
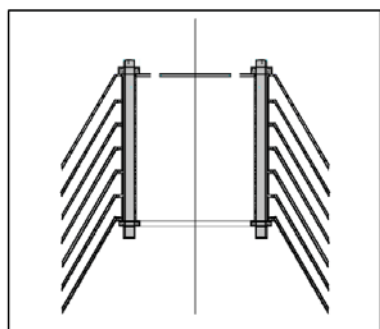


Figure 4. The schematic of the Cryopanel Figure 5. The cryopanel used in a commercial pump

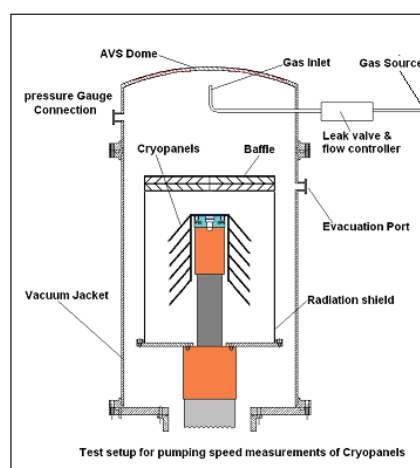


Figure 6. Schematic of the cryocooler based cryosorption pump with AVS procedure for pumping speed measurements



Figure 7. Photograph of the cryosorption pump with integrated with AVS procedure

The schematic of the developed cryosorption pump based on cryocooler is shown in Figure 6. It can be seen that the cryopanel is mounted on the second stage cold head and is surrounded by a radiation shield connected to the first stage of the cold head.

4. Experimental procedure for pumping speed measurements:

The photograph of the cryocooler based cryosorption pump integrated with AVS procedure [9] for pumping speed measurements is shown in figure 7. In the following, the experimental procedure for the measurement of pumping speed is described. Initially the vacuum chamber is evacuated by using a rotary pump to about 1.0×10^{-1} mbar. Subsequently, by using turbomolecular pumping system, the chamber pressure is reduced to $\sim 1 \times 10^{-3}$ mbar. Pfeiffer Vacuum gauge (Model PKR251, compact full range gauge) is used to measure the pressures of the system. On reaching the above chamber pressure, the two stage GM Cryocooler is operated to enable the cool down of the cold heads.

Under steady state conditions, the system reaches the no-load temperatures of $\sim 3\text{K}$ in the second stage and $\sim 30\text{K}$ in the first stage. The cryopanel mounted on second stage gets cooled and during mounting Indium can be used to improve thermal contact between the cold head and the cryopanel. Temperatures of the first stage and second stage of GM Cryocooler are measured by silicon diodes (SI-410). It is observed that although the second stage reaches a temperature of $\sim 4\text{K}$, the outer most cryopanel reaches a temperature of the order of 20K .

When the system reaches steady state conditions, the gas to be pumped is entered into the vacuum chamber through the pre calibrated leak valve (Oerlikon model 1123) and the pressure is monitored using the Pfeiffer vacuum gauge. The pumping speed can be obtained using the following formula.

$$Sp = Q / P \quad (1)$$

Here, Sp is the pumping speed, Q is the throughput of gas flow and P is the measured pressure.

5. Experimental results of pumping speed for different gases:

The pumping speeds have been measured at the lowest possible temperature of the cold head for different gases such as Argon, Nitrogen, Hydrogen and Helium. The typical temperature of the outermost cryopanel is in the range between 20K and 35K . We present below the results of experimental studies of pumping speeds for different gases using identical cryopanel adhered with different types of activated carbons.

The activated carbon studies are: (i) Granular Srilankan charcoal, (ii) activated carbon pellets, (iii) ACF- FK2, (iv) activated carbon of knitted IPR cloth. A commercial cryopanel with large size granular activated carbon (Varian cryosorption pump) has been used for benchmarking the experimental results. Figures 8 , 9 and 10 show the measured pumping speeds of nitrogen, argon and hydrogen on the cryopanel built with the above mentioned activated carbons.

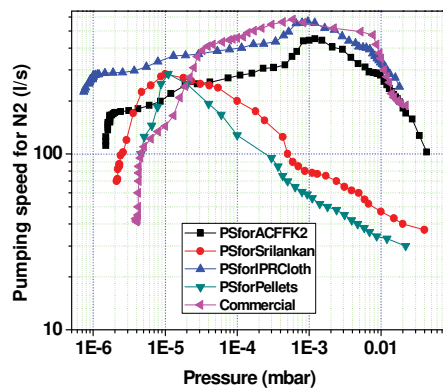


Figure 8. Pumping speed for N2 gas by different Activated carbon panels

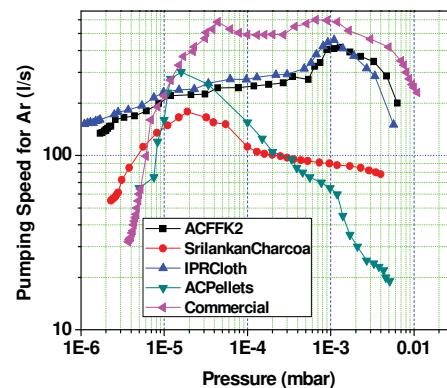


Figure 9. Pumping speed for Argon gas by different Activated carbon panels

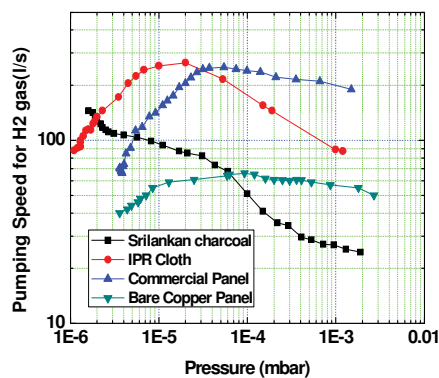


Figure 10. Pumping speed for H2 gas by different Activated carbon panels

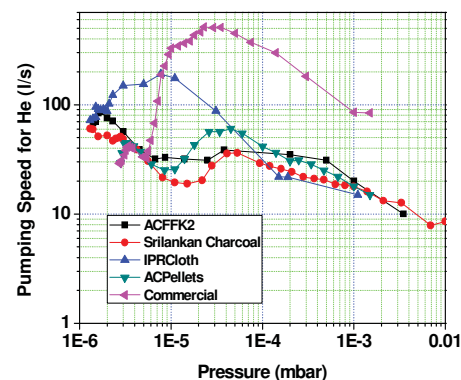


Figure 11. Pumping speed for Helium gas by different Activated carbon panels

It is observed that the measured pumping speeds for Srilankan charcoal and pellets are much lower compared to those of the IPR cloth and ACF-FK2 in all cases. This is quite understandable since the coating densities of srilankan charcoal and the pellets on the panels were much lower compared to that of the commercial panel. Hence, it is clear that the coating densities of activated carbons play an important role in deciding the performance of these pumps. The performance of the knitted IPR cloth is quite comparable to that of the commercial panel especially for the pumping of nitrogen gas. In fact, the pumping speeds are higher than that of the commercial panel, especially at lower pressures (i.e. 1E-6 mbar to 2E-5 mbar).

In the case of argon pumping, the performances of the knitted IPR cloth and ACF-FK2 are nearly identical, but lower than that of the commercial panel. Similar to the case of nitrogen pumping, the argon pumping speeds are higher than that of the commercial panel at lower pressures. Similar behaviour is also observed for hydrogen pumping and this can be seen in Figure 10.

The performances of cryopanel adhered with all different types of indigenous ACs are poorer when compared to that of the commercial cryopanel. The detailed analysis of the experimental data indicates that the temperatures of the outermost section of the indigenous AC coated cryopanel are in the range from 30 to 35 K.

On the other hand, for the commercial cryopanel, this value is ~ 20 K. The detailed examination of the cryopanel indicates that the copper sheets used in the fabrication of commercial cryopanel are thinner than those fabricated by us for making indigenous activated carbon cryopanel. The approximate thickness ratio of copper sheets of commercial panel to that of indigenous panel is 1 : 2.

The measured pumping speeds for indigenous carbon panels are lower than those of commercial panel due to two reasons. (a) Due to the increased wall thickness of the copper sheets used for making the panels, the temperatures of the outermost section is higher causing considerable reduction in the measured pumping speeds especially for hydrogen and helium. (b) The density of activated carbon filling on the indigenously developed cryopanel is lesser compared to that of the commercial panel.

In view of this, efforts are now being made (i) to fabricate cryopanel with thinner copper sheets and (ii) to increase the density of activated carbon coating by suitable methods, especially in the case of granular and pellet type activated carbons.

6. Conclusions:

In this work, we have presented the development of a cryosorption pump using a commercial cryocooler which has the refrigeration power of ~ 1.5 W at 4.2 K and integrating with small size AC panels mounted on its second stage. The cryosorption pump has been built by using panels with different indigenously developed ACs such as granules, pellets, ACF-FK2 and activated carbon of knitted IPR cloth. The pumping speeds for different gases such as nitrogen, argon, hydrogen and helium have been measured for using the AVS procedure.

The measured pumping speeds for indigenous carbon panels are somewhat lower than those of commercial panel. The possible reason could be the increased wall thickness of copper sheets used in making our cryopanel, which has perhaps led to increased temperatures of the outermost section of the cryopanel leading to the considerable reduction in the measured pumping speeds especially for hydrogen and helium. Also, the density of activated carbons filling on indigenously developed cryopanel is lesser compared to that of the commercial panel and this has led to the lower pumping speeds of the indigenous activated carbon panels.

Now efforts are underway to fabricate cryopanel with thinner copper sheets and to increase the density of activated carbon coating by suitable methods, especially in the case of granular and pellet type activated carbons.

7. Acknowledgement

The authors wish to acknowledge the financial support given by NFP, IPR, Ahmedabad, which has enabled the development of cryocooler based cryosorption pumps. They also acknowledge the valuable support given by I Design Engineering Solutions Pvt. Ltd., Pune and staff of CCT towards the fabrication of the cryosorption pumps and conducting the experiments.

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