Pumping speed offered by activated carbon at liquid helium temperatures by sorbents adhered to indigenously developed hydroformed cryopanel

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Abstract. Towards the aim of developing a pump with large pumping speed of the order of 1 L/(s-cm^2) or above for gases like hydrogen and helium through physical adsorption, development of activated carbon based sorbents like granules, spheres, flocked fibres, knitted and non -knitted cloth was carried out. To investigate the pumping speed offered, a test facility SSCF (Small Scale Cryopump Facility) which can take samples of hydroformed cryopanel (a technology developed in India) of size ~500 mm x 100 mm was set up as per international standards comprising a dome mounted with gauges, calibrated leak valve, gas analyser, sorbent adhered to cryopanel etc. The cryopanel was shielded by chevron baffles. Pumping speed measurements were carried out for gases like hydrogen, helium and argon at a constant panel temperature in the pressure range of 1x10^{-7} to 1x10^{-4} mbar, and pumping speed was found to be in the range of 2000 L/s for a pressure range 1x10^{-6} to1x10^{-4} mbar, and 4000 L/s for pressure range 1x10^{-7}mbar and below for a pumping surface area of ~1000 cm^2 thus giving an average pumping speed of about 2 L/(s-cm^2). Using the Monte Carlo codes SSCF was modelled and simulation studies performed. Parameters like sticking coefficient, capture coefficients affecting the pumping speed were studied. This paper describes the experimental setup of SSCF, experimental results and its correlation with Monte-Carlo simulation.

1. Introduction

Pumping a fusion reactor grade machine incorporates challenges like requirement of very large pumping speeds(~300 to 400 m^3/sec for example in ITER) to pump enormous gas load and producing ultra- high vacuum(UHV) in large volume of vacuum vessel(800-900 m^3). Considering the challenges, the concept of developing cryopump was undertaken at Institute for Plasma Research, India. By international classification, a cryopump is defined as a vacuum pump which captures the gas by surfaces cooled to temperatures < 120 K [1]. The experience of working with cryo condensation pumps exists in tokamaks like DIIID, JET, which have pulsed operation and mainly hydrogen as exhaust gas to be pumped. Helium pumping is difficult with cryo condensation pumps and requires very low temperatures (2 to 3 K) [2]. To pump Helium and hydrogen isotopes the concept of cryosurface coated with porous adsorbent cooled down to liquid Helium temperature works better [3].

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Sorbents to be coated on cryosurface have to go through characterisation process with respect to various properties related to working in UHV environment and fusion machine. A study in detail to obtain performance data of porous sorbent materials with respect to adsorption of hydrogen and helium for selecting the sorbents was carried out. Various facilities were established like OGMS (Out Gassing Measurement System), FADS (Facility for ADsorption Studies), DGMS (DeGassing Measurement System) [4,5,6,7].

To investigate the pumping speed offered by a cryosurface coated with sorbent a test facility SSCF (Small Scale Cryopump Facility) which can take samples of hydroformed cryopanel (a technology developed in India [9]) of size ~500 mm x 100 mm was set up. The SSCF is set up as per American Vacuum Society (AVS) Standard [8]. Pumping speed measurements were carried out for gases like hydrogen, helium and argon at a constant panel temperature in the pressure range of 1x 10^{-7} mbar to 1x 10^{-4} mbar.
To predict the theoretical pumping speed a monte-carlo simulation was done using MOLFLOW+. It is a Window based program developed by (CERN). It can calculate steady-state pressure in an arbitrarily complex geometry when ultra-high vacuum condition is met.

2. Objective
The objective was to develop a cryo-adsorption cryopump to pump hydrogen and helium gases. The sorbents were from activated carbon family. Under this category Carbon spheres, granular carbon, carbon cloth etc were developed. The sorbents had pore surface area > 2000 m^2/gm. By physical adsorption gas molecules get trapped in the pores. To pump the said gases the adsorbent media is required to be cooled to 4K. Sorbents after undergoing characterisation at various facilities established OGMS, DGMS FADS etc, are coated on cryopanels. Sorbent coated cryo panels were then studied for pumping speed performance at SSCF.

3. Detailed description of SSCF
SSCF is in two parts. It has a test dome which is a setup as per AVS standard and connected to it is small scale cryopump.

The test dome ‘figure 1’, has a port for gas dosing, it uses a calibrated leak valve connected to an angled pipe thus giving a distribution of gas particle at the inlet of pump. The second port is for total pressure measurement and the third for partial pressure measurement from the Residual Gas Analyser (RGA). Partial pressure measurement gives pressure profile of the different gases at different temperature during cool down. The pump inlet diameter is 300mm and the same is for dome with the length of 450 mm.

4. Small Scale Cryopump
SSCF shown in ‘figure 2’ has a cryopump with sorbent coated hydro-formed cryopanel at the centre of cylindrical radiation shield. The panel is surrounded by chevron kind of baffles cooled to 80 K. The shields and baffles protect radiation heat load reaching the cryopanel at 4 K ‘figure 3’. All the three i.e. cryopanel, baffles, and cylindrical shield are enclosed by a vacuum chamber. Cryo panel is coated with Indian coconut granular charcoal using adhesives on the cryopanel. Temperature sensors are mounted in different locations in order to get the panel temperature profile. A complete assembled version of the SSCF is shown in ‘figure 4’.

Table 1: Description of Panel

Parameters	**Description/Values**
Length of the panel	~500mm
Width of the panel	100 mm
Thickness	Two 1.5 mm thick S.S plates are welded and hydroformed
Linkage with cryopanel	It has one inlet and out let pipe with wall thickness of 0.8 mm for minimum conduction heat load
Pumping Surface	Activated charcoal granule is coated with adhesive on S.S panel and the weight of charcoal is ~50 gm total coated charcoal
Panel Location	Panel is centrally located in to the vessel geometry and covered by the radiation shield
Total area of panel	(charcoal coated) = 0.1 m2

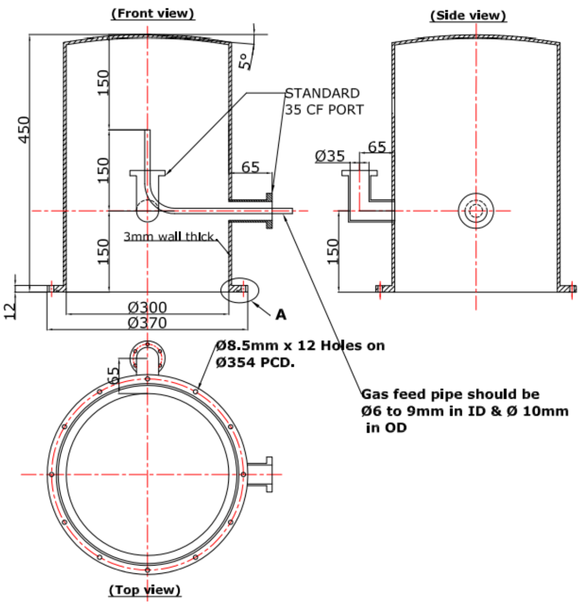

Figure 1: Design drawing of pumping dome chamber as per AVS standard.

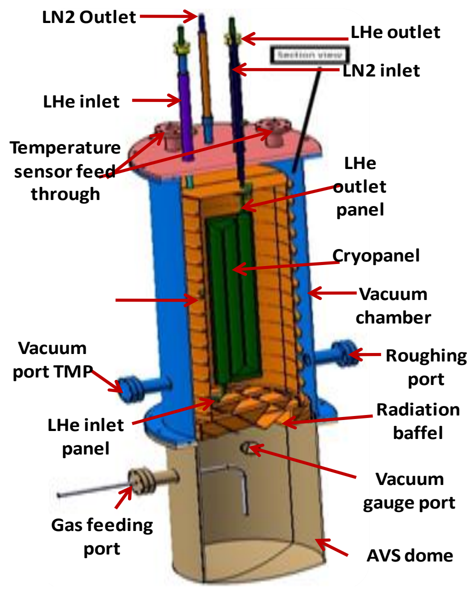

Figure 2: Cross sectional view of Small Scale Cryopanel Facility (SSCF).

5. Study of pumping performance of Cryopanel

5.1 Initial Preparations

The system is initially evacuated up to 1×10^{-5} mbar and baked to 100°C. Leak testing was carried out with the limit of $<1 \times 10^{-9}$ mbar-l/s. Cryopanel was cooled at liquid nitrogen temperature 'figure 5', to study pumping of gases like argon and nitrogen. The system takes around 10 minutes to cool down and vacuum pressure drops down from $2x10^{-7}$ mbar to $7x10^{-8}$mbar. No leaks were observed during the experiment and temperature uniformity over the panel was observed.

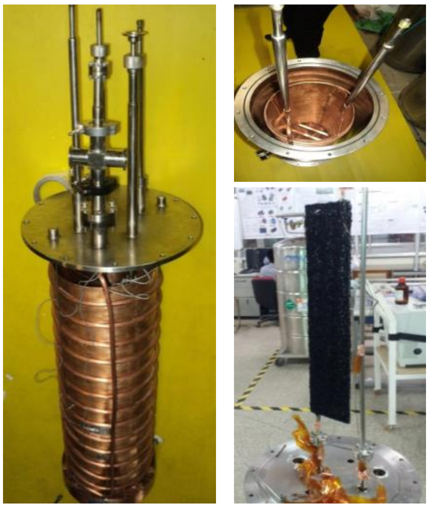

Figure 3: Radiation shield assembly mounted on top flange (left), and activated carbon coated panel (right-bottom)

Figure 4: Small Scale Cryo-pumping Facility (SSCF) assembled during pumping speed experiments.

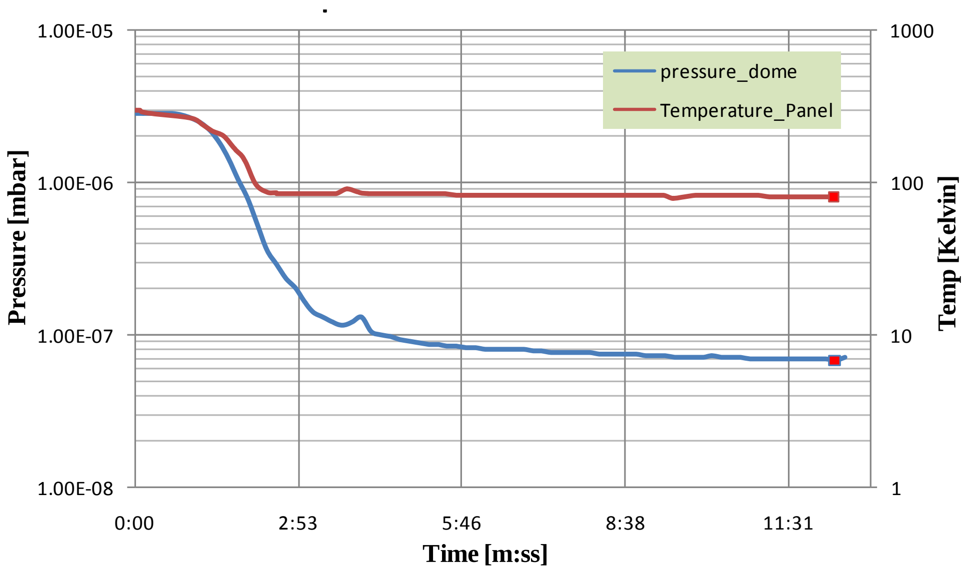

Figure 5: Cool-down results for SSCF with vacuum performance as part of quality test.

5.2 Results for Argon gas

As part of performance evaluation pumping speed experiments were performed for argon gas shown in 'figure 6'. On increasing the gas load the pumping speed remained constant up to $5.0x10^{-4}$mbar range, and decreases for gas load increasing beyond 1 mbar-l/s. A constant pumping speed below $5.0x10^{-4}$mbar shows that charcoal coated panel is pumping argon on increasing the gas load.

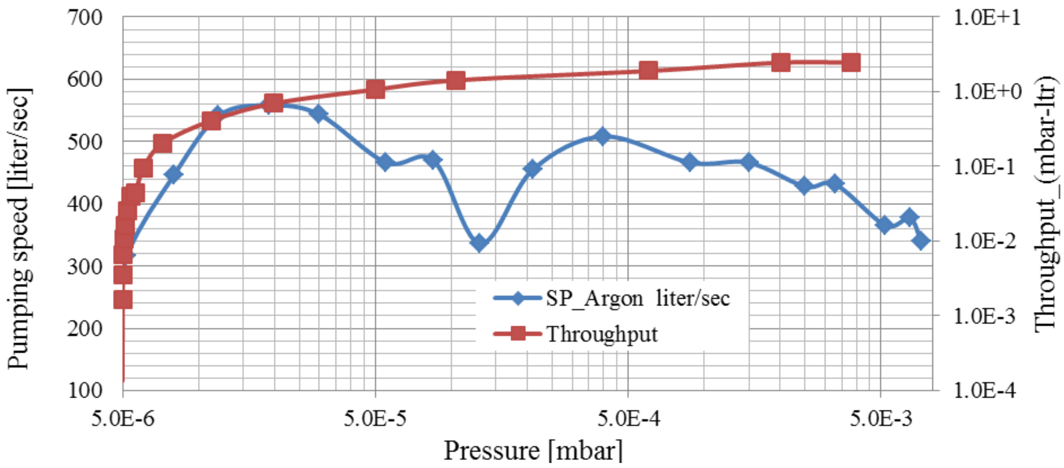

Figure 6: Argon Pumping speed variation over throughput and pressure

5.3 Pumping speed measurement for helium

On achieving stability of temperature in shields and baffles at 80 K, the panel was cooled by passing liquid helium and the system is isolated from external pumping. The outlet temperature was observed as low as 4.5 K during the pumping speed measurements. Test gas is inserted with calibrated leak valve at a desired gas load Q and corresponding pressures are measured. The gas dosing was increased in steps (Q1, Q2…), each gas dosage is maintained constant for certain period of time (2 to 5 minutes) and corresponding pressures are measured in the Q steps (P1, P2…..). The experiment of pumping speed measurement for helium gas was carried out twice. The results in 'figure 7' show repetitive trend. Pumping speed ranges from 3000 Liter/sec to 500 Liter/sec at different pressure range. Average pumping speed over the range of $1x10^{-6}$mbar to $1x10^{-4}$ mbar range is ~2500 Liter/sec 'figure 7' and 'figure 8'.

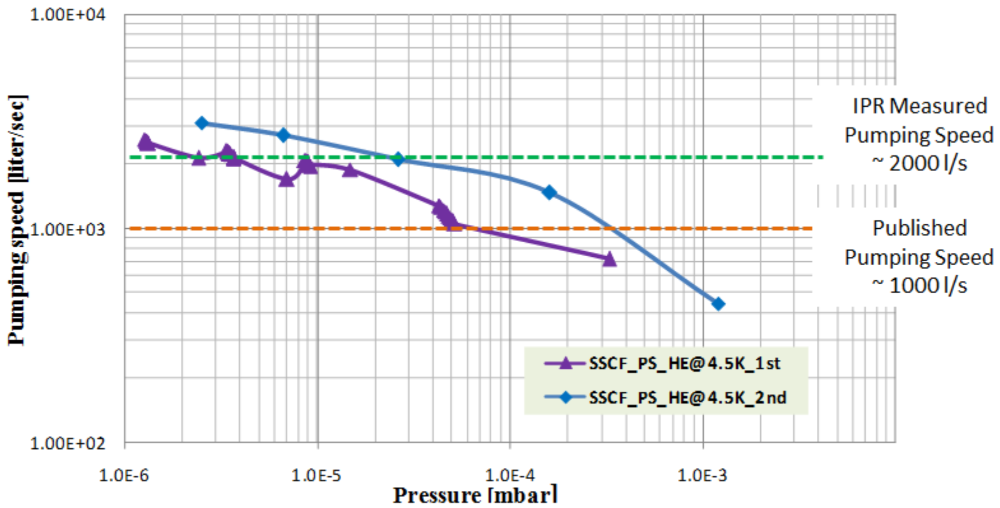

Figure 7: Pumping speed Vs pressure for helium @ 4.5K

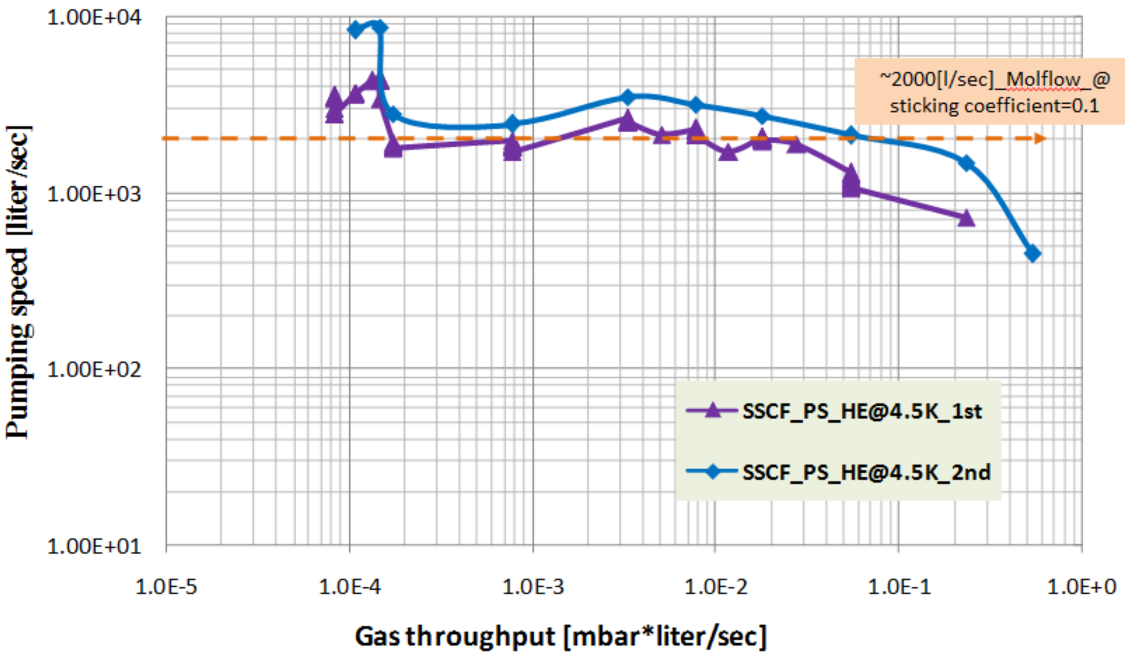

Fig 8: Estimation of pumping speed of helium for different throughput

5.4 Pumping speed measurement for Hydrogen

Study of pumping speed offered by sorbent for hydrogen gas was repeated twice and both the results are plotted against the pressure 'figure 9'. The observed values range from 8000 Liter/sec to 1500 Liter/sec. Average pumping speed over the range of $1x10^{-6}$mbar to $1x10^{-4}$ mbar range is ~2700 Liter/sec

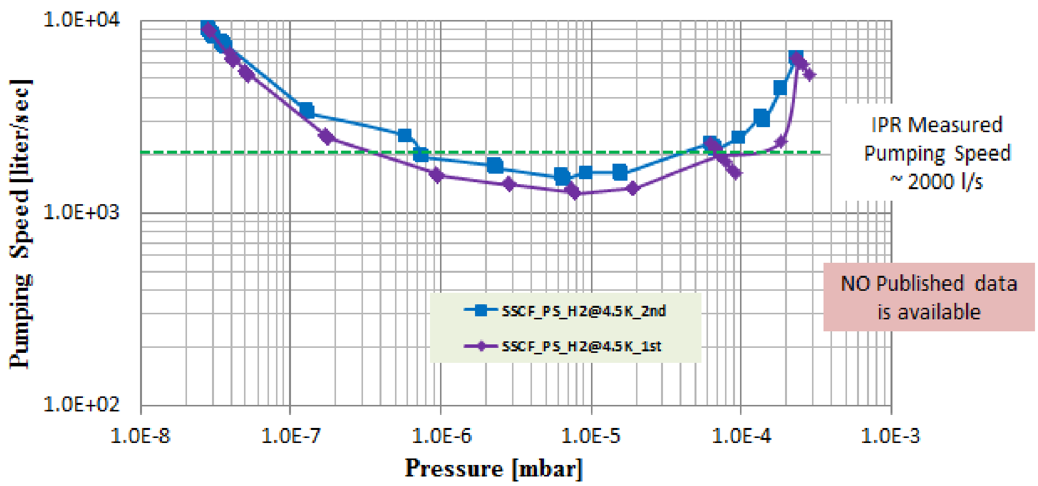

Figure 9: Pumping speed variation with pressure for hydrogen @ 4.5K

6. Commercial pump modelled in Molflow+

A commercial model CP-12 (Sumitomo make) of cryopump was simulated using Molflow+ where cryopumping surfaces as per Sumitomo catalogue are defined as the adsorbents as shown in 'figure

10'. The catalogue values and simulated pumping speed showed coherence. The exercise resulted in establishing methodology for simulating SSCF (Molflow+ model shown in 'figure 11'. At the pressure of $1.0x10^{-4}$ mbar pumping speed value is taken for comparison with the simulation result and there by sticking coefficient for each gas is estimated. The sticking coefficient of helium gas is 0.1 and for hydrogen it comes 0.3 with an error bar of less than 3% for both the gases. The prediction of sticking coefficient helps in estimating the pumping speed on full scale panel and in the multiple panel setups.

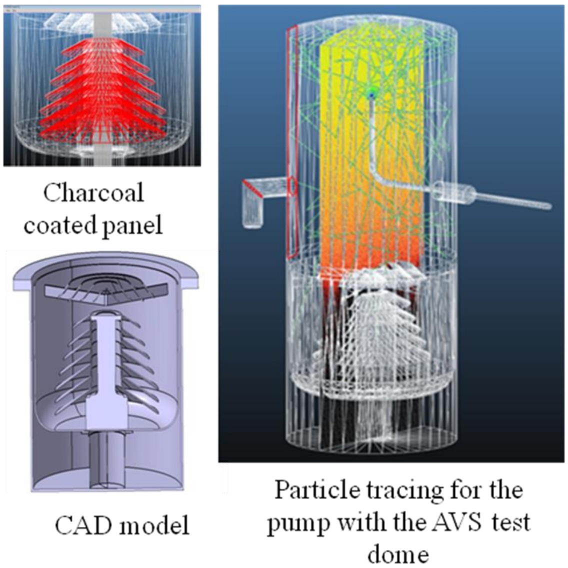

Figure 10: Molflow+ models for the commercial CP-12 cryopump.

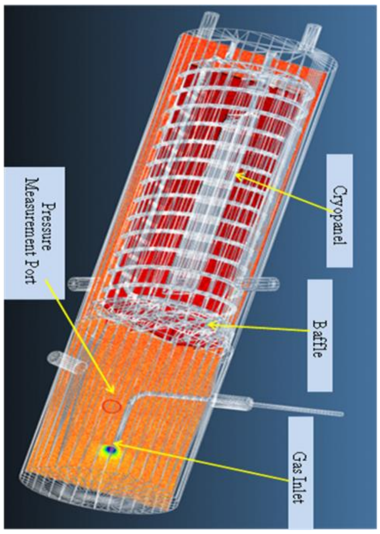

Figure 11: Molflow+ model for the Small Scale Cryo-pumping Facility (SSCF)

7. Conclusion

The development of SSCF involved characterizing the selected materials for operational requirements and drastic environmental conditions. The QA and QC of the materials was tested at the facilities FADS, OGMS, DGMS to qualify for vacuum and cryogenic environment. Simulation methodology for transmission probability analysis was established and tested on an experimental system with various geometrical configurations. The motive behind Small Scale Cryo-Pump (Pumping Speed 2000 L/s) was to check the pumping speed offered as per AVS standard, as a step towards quantifying with respect to standards. Finally, it is aimed to cover the physics and engineering validation arena to go ahead for Multi-Panel CryoPump (MPCP-08) development.

8. Acknowledgement

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