DESIGN OF CRYOPANNEL AND STUDY OF PUMPING BEHAVIOUR OF DIFFERENT GASES

[1]Rupesh Barnasiya,[2]Krishna Dutta Pandey
[1]Research Scholar, [2]Assistance Professor
[1,2]Mechanical Engineering Department,
[1,2]Lakshmi Narain College Of Technology, Sanwer Road,Indor , M.P India.

ABSTRACT *:* Cryogenic pumping is a means of achieving high vacuum by maintaining a temperature below the freezing temperature of a gas on the surface of a sorbent surface. The pumping action is accomplished either by condensation or adsorption of gases on the sorbent surface. The temperature on the surface can be achieved by using cryogenic liquids or closed cycle refrigerator. The scope of this project includes design and analysis of the pumping element like cryopannel and other related parts. The pumping behavior of different types of gases such as Nitrogen,Helium, Argon, etc will be studied on activated charcoal surfaces and without the charcoal. In this project cryopumping study will be carried out using a cryocooler based cooling media.
The high vacuum environment necessary for many experiment like space experiments and degassing measurement system and very important requirement in plasma development technique. Cryopump is device which is used for producing very high vacuum environment. In the cryopump cooling will taking place by flow of coolant or by G-M Cryocoler. In this project we have developed the cryopannel according the cryocooler capacity of 1.5 watt at 10K temperature and conducted the experiment and calculated the pumping speed of cryopump with different gases.

IndexTerms **– Cryopumping, capture coefficient, heat load , Cryopannel, GM Cryocooler, Activated charcoal.**

I Introduction

Cryopumps belong to the class of entrapment or capture vacuum pumps and they retain the gas molecules by sorption 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 cryocondensation. 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
Cryogenic pumping is a means of achieving high vacuum by maintaining a temperature below the freezing temperature of a gas on the surface of a sorbent surface. The pumping action is accomplished either by condensation or adsorption of gases on the sorbent surface. The temperature on the surface can be achieved by using cryogenic liquids or closed cycle refrigerator. The scope of this project includes design and analysis of the pumping element and associated instrumentation. The pumping behaviour of different types of gases such as Nitrogen, Hydrogen, Helium, Argon, etc will be studied on activated charcoal surfaces. In this project cryopumping study will be carried out using a cryocooler based cooling media.
The main advantage of cryopumping is achieving high order of vacuum and pumping helium and hydrogen type gases easily. The main objects of the project are design and develop the pannel for given load and tested the pannel with the charcoal and without the charcoal with available gases. In cryopumping pumping of gases is achieve by two mechanisms by cryocondensation and by cryosorption. In cryocondensation gases are simply condense and adhesive to cooling surface and in cryosorption gases are adsorb on the some porous material. Here we used charcoal as porous material because charcoal has large surface area and also have fine pore size which is required for adsorption of gases. Cooling of cryopump can be achieve by two ways, first is flowing the cooling medium like nitrogen and helium gas and second is by G-M cryocooler. In our project we used G-M cryocooler for achieving the required cooling.
Towards this goal, the cryocooler based cryosorption pump has been developed. This uses a commercial cryocooler 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 design cryopannel panels. In this work, we present the results of pumping speed measurements using the American Vacuum Society (AVS) procedure for gases such as nitrogen, argon, 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. The pumping speed is given as follows

$$S = c \cdot S_{\text{id}} = c \cdot A_{\text{inlet}} \cdot \sqrt{\frac{R_0 \cdot T}{2\pi \cdot M}} \qquad (1)$$

Where S_{id} = Ideal pumping speed
C = Capture coefficient
The capture coefficient is given by the ratio of the actual pumping speed of the cryopump to the theoretical black hole pumping speed S_{id} and indicates the efficiency of the pump. The pumping speed calculation is always concern with gas which are be pumping.

II HEAT LOAD

Complete assembly of cryopump is on ambient temperature around 300K from outside but for pumping of gases on the temperature requirement is around 10K for pumping of helium and other gases. Panels of cryopump are maintained at 10K. So due to this temperature difference always there is some heat flow is happen. In heat load involved radiation heat load, conduction heat load, sensible heat load, condensation heat load and adsorption heat load. Extract of heat from this cryopump unit by cryocooler.

In design of cryopannel this heat load calculation is very important otherwise pannel temperature could be greater than required temperature and gas have not condensed or adsorpt on surface of cryopannel.

Total heat load is

$$Q_T = Q_{radiation} + Q_{conduction} + Q_{sensisble} + Q_{condensation} \quad (2)$$

Q_T = Total heat load

$Q_{Radiation}$ = Radiation heat load

$Q_{Conduction}$ = Conduction heat load

$Q_{Sensible}$ = Sensible heat load

$Q_{Condensation}$ = Condensation heat load

2.1 Radiation Heat load

Radiation load for cryopump is included radiation heat transfer between cryochamber and thermal shield and another radiation load is coming from the radiation shield and cryopanels. Radiation load between cryochamber and radiation shield is bear by 1st stage of cryocooler and radiation load between radiation shield and cryopannel by 2nd stage of cryocooler. This load does not affect to each other. Radiation load between two surface is given by Stefan Boltzman law and it said that radiation load is directly proportional to fourth power of absolute temperature and its emissivity.

Radiation heat load is given by

$$= \frac{\sigma(T_1^4 - T_2^4)}{\left(\frac{1-\epsilon}{\epsilon A}\right)_1 + \frac{1}{A_1 F_{1-2}} + \left(\frac{1-\epsilon}{\epsilon A}\right)_2} \quad (3)$$

1st stage radiation load

In 1st stage of cryocooler heat transfer is between cryochamber and radiation shield

$Q_{r1} = 5.67*10^{-8}*0.10156*(300^4-100^4) = 46.409W$

2nd stage radiation load

In the 2nd stage of cryocooler radiation load is due to heat transfer between radiation shield and cryopannel assembly. Using the same formula we can find out radiation load on 2nd stage of cryocooler

$Q_{r2} = 5.67*10^{-8} *0.1464*(100^4-15^4) = 0.923$ W

2.2 Conduction heat load

Conduction load in cryopump is coming from two side solid conduction load and gaseous conduction load. Here we neglect solid conduction load because in our experiment setup body which are at different temperature are not connected directly like there is no connection between cryochamber and thermal shield and there is not conduction load between thermal shield and cryopannel. Similarly conduction load between other parts of system to environment is neglected. The main conduction is load bring by gaseous conduction load. In gaseous conduction load is due to collision of gas molecule to hot surface and then cold surface continuously. This effect is associated with the mean free path, which denotes the average distance which a molecule travels between two successive collisions. Due to high vacuum level in the cryocooler configuration, the heat transfer is due to free molecular region. To calculate the same, following relations can be used

$$Q_{Conduction} = G*P*A_1*(T_2-T_1) \quad (4)$$

1st stage gaseous conduction load

$Q_{c1} = 0.59*0.76*5*10^{-4}*(300-100) = 0.04408$ W

2nd stage gaseous conduction load

$Q_{c1} = 0.363*0.9532*5*10^{-4}*(100-15) = 0.0242$

So in our experiment gaseous conduction load is very less because vacuum of order 10^{-6} mbar is maintained in cryochamber

2.3 Sensible and Latent heat load

Specific heat load is that load which is required for gases to bring down to its freezing point from the environment temperature. The value of this load is small because input of gases is in very less amount but for accurate design of cryopump, specific heat load is required.

The specific heat load for any substance is given by following realtion

$$Q_S = \dot{m}*C*\Delta T \quad (5)$$

Latent heat load included that load which required for conversion of one phase to another phase of material means vapour to liquid and liquid to solid. In our experiment latent heat load for conversion of liquid to solid have very small and neglected. Latent heat load for any substance is given by as follows

$$\text{Latent heat load} = \dot{m}*L \quad (6)$$

it is clear that for through put of 0.5mbar.lit/s , the maximum total heat load is for the Xenon gas and it is about 0.45 watt. In design of panel we include this maximum value so that our design should be in safe side. But practically value of through put for our experiment have less and heat load corresponding to that through put has in our range.

III Cryopannel Assembly

Panel is main structure of cryopannel assembly which are used for pumping of gas. After theoretical calculation and literature review we have find out surface area of cryopannel is not exceed the 0.5m^2. If the area would be greater than 0.5m^2 , it may affect the pumping speed, because due larger surface provide larger radiation load which further decrease the temperature of cryopannel surface and pumping speed is decrease. Capacity of cryocooler for second stage is limited up to 1.5watt at 4.2K.

The total 5 no of panel is attached to 2nd stage of cryocooler. The shape of panel is conical shape, because probability of condensation or adsorption of gas on Cryosurface is maximum due to symmetrical shape and other reason for selection of shape of cryopannel is due to its easy manufacturing.

Panel 1 is not consider as panel because it used for shielding to other cryopannel surface, but in actual it is also contribute in pumping mechanism.

Panel 2 surface area for panel no 2 is 0.048m^2 and weight of this panel 0.35kg. No of panel no 2 is one used

Pannel no 3 surface area of panel no 3 0.058m^2 and weight of Pannel no 3 is 0.4kg.

No of panel no 3 is used in our experiment is one

Panel no 4 surface area of this Pannel is0.092m^2 and weight is 0.647 kg

No of panel no 4 is used in our experiment is two

Pannel no 5 – surface area of Pannel no 5 is 0.101m^2 and weight of Pannel no 5 is 0.708kg

No of Pannel no 5 is used is two.

In our experiment panel no 2 is not mounted due some assembly problem in cryopump

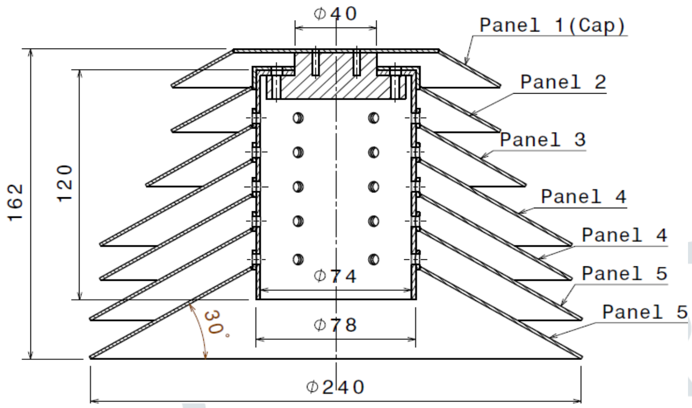

Fig.1 2-D view of cryopannel assembly

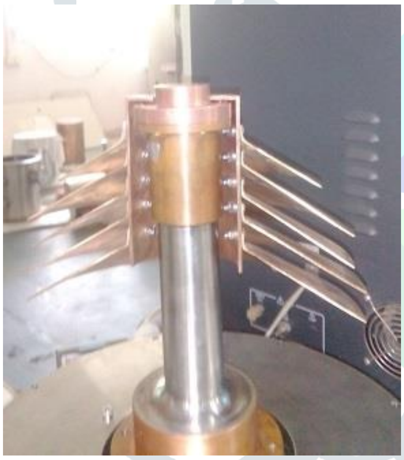

Fig.2 Cut section mounted on cryohead

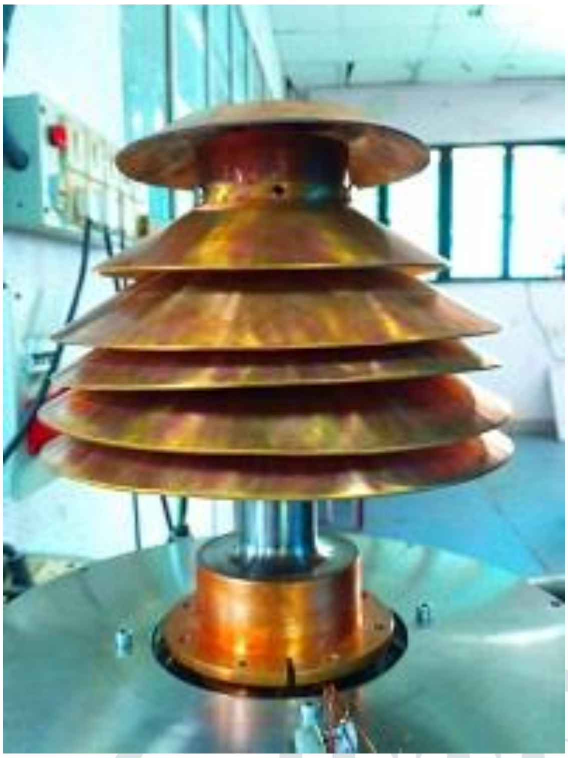

Fig.3 Full section of cryopannel mounted on cryohead

IV Experimental procedure for pumping speed measurements

The photograph of the cryocooler based cryosorption pump integrated 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 E-1 mbar. Subsequently, by using turbomolecular pumping system, the chamber pressure is reduced to ~ 1E-3 mbar. Pfeiffer Vacuum 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 17.5K in the second stage and ~ 90K in the first stage. The cryopanels mounted on second stage gets cooled . Temperatures of the first stage and second stage of GM Cryocooler are measured by silicon diodes. It is observed that although the second stage reaches a temperature of 17.5 K, the outer most cryopanel reaches a temperature of the order of 21K.

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

$$S_p = \frac{Q}{P} \qquad (7)$$

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

Fig.4 Experiment setup

V RESULT AND DISCUSSION

5.1 Pumping Speed without Charcoal

In this test pumping speed of pump will be measure without using the charcoal on the cryopannel.

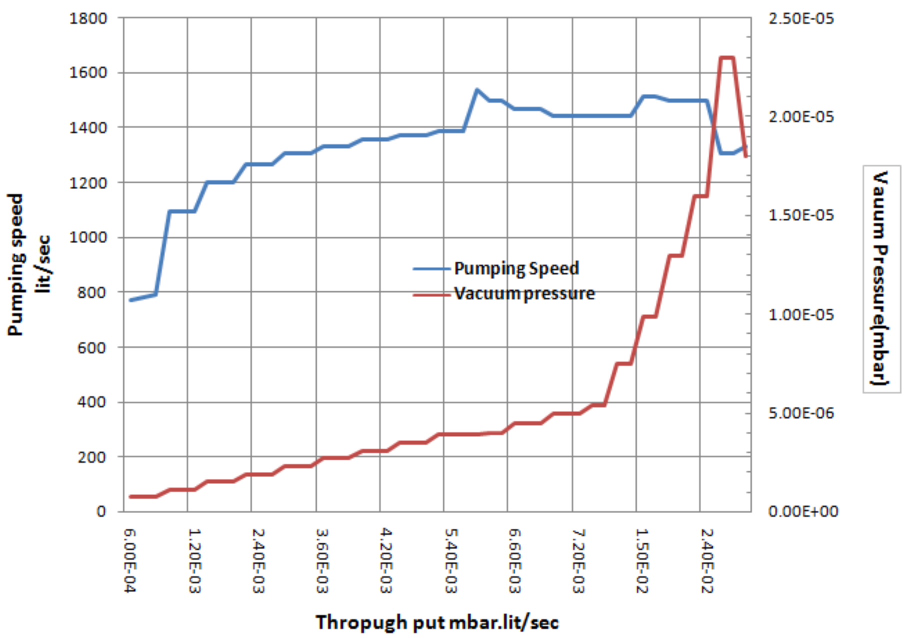

Fig.5 Pumping speed and Vacuum pressure of N_2

Fig 5 shows that pumping speed is increase as through put is increase and after some time become stable and then decrease because pump had saturated and monolayer is formed on approx complete surface area and pumping of gas further is difficult. The maximum pumping speed observed was 1538lit/sec.

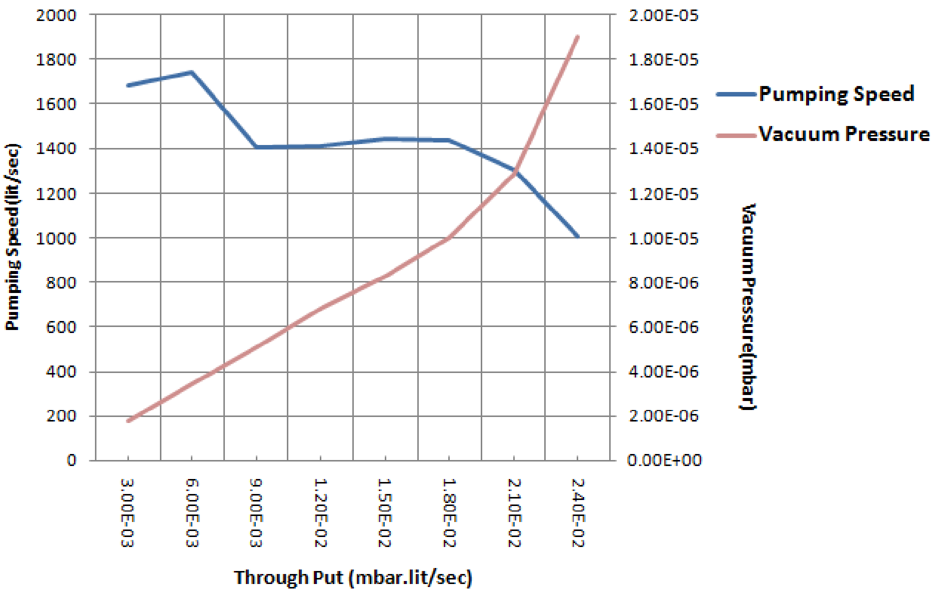

Fig.6 Pumping speed graph of argon

Fig 6 shows the graph between pumping speed, through put and vacuum pressure for argon gas. Graph shows that pumping speed first increase with small value and then decrease as through put increases and vacuum pressure is increases. The maximum pumping speed observed was 1740 lit/sec.

It was observed that cooling time for cryocooler was 3 hours which are more than theoretical calculated cool down time. It is due changing of properties of copper material with respect to temperature. It was also observed that temperature of upper pannel was 17.5 K which are more than design temperature. It is due to the loose fitting of cryopannel assembly on to the cryohead and due to this contact was not perfect and heat transfer losses are occurred.

In the experiment pumping speed of nitrogen was observed 1538lit/sec which is less than ideal pumping speed of nitrogen which is 7000lit/sec. so for this pump the capture coefficient for nitrogen was 0.219 which is very less. It showed that interaction between surface and nitrogen gas has less gas have not captured on surface. Similarly in the experiment pumping speed Argon was observed 1740 lit/sec which is less than ideal pumping speed of argon which is 5900 lit/sec. so for this pump the capture coefficient for nitrogen was 0.3 which is very less

VI Conclusions

In this experiment we have design the cryopannel of cryopump and tested for different gases. In this experiment we calculated different heat load which was associated to cryopump. We have mounted the cryopannel on cryocooler head of G-M cryocooler. We have not achieved the desire temperature onto the cryopannel surface. We have conducted experiment of pumping speed for nitrogen and argon gas and we have got lower pumping speed than theoretical pumping speed for nitrogen and argon

VII REFERENCES

[1]. Christian Day, “Basic and Application of Cryopump”, Forschungszentrum Karlsruhe, Institute of Technical Physics, PP (241-274), 2005

[2]. M.B.Prajapati, S.M.Mehta, “Design of Liquid Nitrogen Cryosorption Pump” ISSN 0975 – 668X| NOV 12 to OCT 13 | Volume – 02, Issue – 02, PP (445-449)

[3]. Ranjana Gangradey, Samiran Shanti Mukherjee, Jyoti Shankar Mishra et al. 2015 “Pumping speed offered by activated carbon at liquid helium temperatures by sorbents adhered to indigenously developed hydro formed cryopannel”, IOP Conf. Series: Materials Science and Engineering 101**(**012044) PP(1-7)

[4]. H.P.Chenga and Y.H. Shen, 2006, “Effect of heat on the pumping performance of cryopump”, Journal of Vacuum Science & Technology A: Vacuum, Surfaces, and Films, Volume 24 No 4 PP (1597-1600)

[5] Srinivasan Kasthurirengan, Ravi Verma et.al. 2017, “Development of a cryocooler based high efficiency cryosorption pump”,Review of Scientific Instruments, Volume 88 PP (086104-1 to 086104-3)

[6]. B.A.Hands. 1975, “Introduction to Cryopump Design”,Cryogenics Laboratory, Department of Engineering Science. University of Oxford, England,Volume 26 PP (11-16)