Study and Review of Cryopump and Pumping behavior of Different Gases

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***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. In this paper we will review the some previous paper related to the cryopump and understand how cryopump work. In this we will review the all parameters related to cryopump which will help for design of cryopannel and how pumping speed of pump has measured

Key Words: **Cryopumping, capture coefficient, heat load, Cryopannel, GM Cryocooler, Activated charcoal**

1. 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

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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

2. LITERATURE SURVEY

Forschungszentrum Karlsruhe[1]

The author aimed to give basic overview of cryopumping. Cryopumping is combination of adsorption and cryogenic. The cryopump is only method for producing high vacuum and by cryopumping, pumping of helium and hydrogen is possible in simple way. Cryosorption define as the physical adsorption process under vacuum conditions and low temperatures. Hence, gas can also be retained by adsorption even in a subsaturated state, i.e., at considerably higher temperature than would be required for condensation. This fact is important in cryopumping helium, hydrogen, and neon, which are difficult to condense. The surface at which is gas is adsorb is should be porous. The cryosorption phenomenon is depend on many factor temperature, surface area of adsorption, pore distribution of adsorbent, pore volume of adsorbent

According to the author was unanimously revealed that activated charcoal, especially of the coconut type, exhibits the best dynamic performance characteristics.

The vacuum technology design of cryopump emphasize maximise the pumping speed of cryopump in given area and cooling capacity. The basic equation or relation can be derived from combine parameter like temperature of gas, inlet cross section of pump and properties of gas like mass of the gas and gas constant and also a capture coefficient included which can be vary by design of cryopump.. The capture coefficient is the ratio of the actual pumping speed of the cryopump to the theoretical pumping speed S_{id} and indicates the efficiency of the pump.

Thu Kyaw et al.[2]

In this article author developed theoretical estimation of isosteric heat of adsorption. In cryosorption phenomenon for cryopump gas is adsorbed on the surface of material and at that time heat liberate for adsorption is called isosteric heat of adsorption. Author study the behavior of adsorption and confirm its value with the help of experiment.

The theoretical design for heat of adsorption is done with considering the behavior of no-ideal gas and adsorbed phase volume. Accurate thermal behavior of adsorbed phase volume can be described from low to high pressure by the multi layer adsorption process. The design model of heat of adsorption can be tested for selected combination of adsorbent and adsorbate. The designing model show the excellent result and date of this model can be compare with adsorption isotherm and isosteric heat of adsorption.

Prajapati.M.B. et al. [3]

In this article author give the basic of cryopumping and its relevant term. Author describes and design cryopump of 1000l/s capacity. Further its give all parameter related to its pump. According the author cryopumping speed is given by following formula

$$S_{th} = A_k.S_a.\alpha.\left(1 - \frac{p^{0}}{p}\right) \qquad \text{........(2.1)}$$

Where, S_{th}=pumping speed

A_k = size of cryopannel

S_a = surface area related to pumping speed

α = probability of condensation

p^0 = ultimare pressure

p = pressure in vacuum chamber

Surface area related to to pumping speed is given by

$$S_a = 3.65\frac{\sqrt{T}}{\sqrt{M}} \text{ l/s cm}^2$$

T = Gas temperature in Kelvin

M = Molecular mass(for air 28.96gm/mol)

$$S_a = 3.65\sqrt{\frac{300}{28.96}} = 11.47 \text{ l/s cm}^2$$

The size of cryopannel required for 1000l/s capacity pump is

$$1000 = A_k.11.74.0.062.\left(1 - \frac{0.0001}{0.01}\right)$$

$$A_k = 1375.22 \text{ cm}^2$$

Author also gives the information about total heat load on cryopump. According to the total heat load include solid heat load, gaseous heat load, radiative heat load, enthalpy change between molecule and phase transition temperature and phase change enthalpy.

Solid heat conduction load involve that heat which are come from part of cryopump in vacuum chamber through conduction, this include heat come from pipes, supply line, instrumentation, cable etc.

Kashtrirajan Srinivasan et al. [4]

In this article author designed and tested the Cryopump whose cooling is G-M cryocooler base. Cryopump is based on cryosorption concept. Author claim the pumping speed is around 1.5 times the commercial pump in specified pressure range. This uses a matter of high adsorbing capacity along with an adhesive of high thermal conductivity. The calculated pumping speeds of these pumps for dissimilar gases such as nitrogen, argon, hydrogen, and helium are high than the industrial cryopump in the pressure range from 5 $\times10^{-6}$ mbar to 5 $\times10^{-5}$mbar. In a cryosorption pump, an epoxy is used to adhere the adsorbing material on the metallic panel because the epoxy should have high thermal conductivity due which heat transfers maximum cold from the adsorbing material via the panel. The thermal conductivity of epoxy is high because carbon content is more the other and no glass content. A specially prepared knitted carbon cloth is prepared for adsorption of gas and tested in laboratory. It is observed that this material has a surface area of around 3000 m^2/g for helium adsorption at 4.5 K. This adsorption surface area is much larger than those of the activated carbons used in commercial cryopump. For instance, the typical granular charcoal has the surface area in the range from 1600 to 1800 m^2/g for similar experimental conditions.

For the cryocooler based cryosorption pump, the pumping speed for the specific gas is measured as,

$$S_p = (Q/P) \quad \ldots\ldots\ldots\ldots(2.14)$$

Where Sp is the pumping speed in l/s, Q is the throughput of gas flow in mbar l/s, and P is the pressure inside the chamber in mbar

A. Schwenk-Ferrero et.al[5]

Sticking coefficients for cryopannel, coated with activated carbon at about 7.5 K during pumping operation were determined from pumping speed measurements. For this purpose, the transmission probabilities of the cryopump elements were derived by a Monte Carlo calculation. The interaction of cryosorption and cryocondensation is illustrated by mixture pumping test results. The influence of competitive sorption is also discussed It becomes obvious that the sticking coefficient of the pure hydrogen, which can be estimated to be close to 1, is reduced when helium with that poor sticking coefficient is present in the mixture. However, the decrease is even more than according to the nominal molar helium content and the deteriorating influence of helium is less critical for mixtures with deuterium than it is for protium. The figure also illustrates that in the investigated composition range the overall sticking coefficient of a protium/ helium mixture may even become smaller than that of pure helium, whereas the helium curve and the deuterium/helium mixture curves do not intersect. Nevertheless, the saturation point (maximum coverage, zero sticking coefficient) is very much the same of about 0.7 Pam3/cm2 for all investigated systems, which is in close agreement to the helium values reported in literature (compare [9] for details). This is a strong hint that the mixture behaviour is dominated by the helium fraction.

G Grooses, D Wandrey et.al[6]

In this paper author gave the information about measurement of pumping speed and how the pumping speed have measured. According to the author the every vacuum pump made by different manufacturer give different performance even they have same size and specification. The main reason behind it that different manufacturers use different type of procedure for pressure measurement and pumping speed measurement and also by different apparatus. The procedure provided by ISO, AVS are identical. Author is specially focus on the measuring of pumping speed of turbomolecular pump because of pumping speed of this pump is stable. For measuring the pumping speed of the pump pressure measurement is important therefore the method are used for measuring the pumping speed flow meter method and orifice measurement method. In this experiment both method are used and compare to it. In the case of measuring the pumping speed of turbomolecular pump major difference in method which are provided by AVS and DIN is location of pressure measuring gauge. In AVS pressure gauge is near the pump inlet and due to this pumping speed is high. In the both method calibrated pressure gauge are required to measure the initial pressure. Two type of vacuum gauges are used firstly gold wire ionization for specially high stability operated with good precision and second is spinning operated gauges. After experiment we can concluded that for turbomolecular pump the inlet pressure below 10^{-4} mbar can be used restricted type and above this value flow meter are preferable for pumping speed.

S. Nesterov et.al[7]

In this article author describe the hydrogen pumping simulation for a cryopump. The simulation of cryopump is mainly focus on the different performance by cryopump when different geometries of cryopannel will used. Author used monte calro method for hydrogen pumping simulation for cryopump. Generally monte caro method describes pumping speed of pump when the gas are not accumulated on the surface of pump. The main aim of the author is to develop computer program that predict distribution of cryodeposit and pumping speed for given pump. This programme also provide the how the pumping speed affect by pump configuration and amount of gas accumulated if user proved sticking coefficient. Author constructed the pump which have mainly two parts, first stage array made by inlet baffle and radiation shield and second stage array consist by cylindrical cryopannel of copper with 45 degree truncated cone. In the complete process of simulation no of various equation are required to solve for finding straight line trajectory of molecule and also equation of all internal surface. After that we require the point of intersection of molecule to surface and each point are tested for random number generated if random no is less than or equal to sticking coefficient than molecule are captured otherwise molecule are not captured. After experiment conducted The results show that during the initial period of accumulation a thin layer of argon plays a positive role causing the pumping speed to increase about 10%. This effect seems to occur because hydrogen molecules that strike the argon are held closer to the charcoal which will adsorb them than when there is no argon build-up. The Monte Carlo simulation was used to find the capture coefficient values for argon and hydrogen for a given cryopump assuming constant sticking coefficients of 1 for argon and 0.58 for hydrogen. The results, calculated the capture coefficient .408 for argon and 0.224 for hydrogen gas. When we will calculated the pumping speed using the capture coefficient the speed diffrent from the 10 percent only.

So the conclusion of this article is The program developed allows one to find the influence of the accumulated deposit on the sticking coefficient for the given pump configuration and The results show that this model can be applied to predict the performance of new cryopump designs and to evaluate their features.

Sung Hwa Jhung et.al[8]

in this article author was studied the adsorption of hydrogen gas on different porous material with pressure range of 0-760mmhg.in the study it is found that adsorption of hydrogen id dependent on the micro porosity rather than porosity, but for adsorption capacity pore size and pore architecture was also necessary. The adsorption of hydrogen on the surface of material is mainly by physisorption phenomenon. Author conducted experiment on commercially available HZSM-5 (PQ, $SiO2/Al2O3 = 50$) and HY (Zeolyst, USY, CBV760, $SiO2/Al2O3 = 60$)

the hydrogen degassing is measured at under the vacuum of 10^{-5} torr and temperature range of 373 to 676 K. the adsorption capacity of material simply calculated with help ideal gas law. After the adsorption of hydrogen up to about 1 atm, the physisorbed hydrogen was evacuated for 10 min at 77 K and hydrogen was re-adsorbed to estimate the amount of chemisorptions by the difference of the two adsorption capacities. The heat of adsorption (ΔH_{ads}) was calculated with the Clausius-Clapeyron equation using the adsorption isotherms at liquid nitrogen (77 K) and liquid argon (87 K) temperatures. The heat of adsorption (ΔH_{ads}) was measured by using the Clausius-Clapeyron equation for AlPO-5 and SAPO-5 to calculate the strength of the hydrogen adsorption. After conduction of experiment, the heat of adsorption is about −5.5 ∼ −6.1 kJ/mol irrespective of the chemical composition of the AFI-type molecular sieves. Moreover, these values are close to the ΔH_{ads} on graphite (4 kJ/mol), meaning that their adsorption behaviours are mainly based on physisorption in nature.Moreover, the ΔH_{ads} values in this study are very similar to that of Li-ZSM-5 ($\Delta Hads = -6.5$ kJ/mol). The adsorption capacities of AFI molecular sieves including AlPO-5 and SAPO-5 do not depend on their silica concentrations, which may show that the electrostatic field is not a major factor for the adsorption capacity. The heat of adsorption and adsorption-desorptionreadsorption experiments shows that the adsorption is mainly composed of physisorption. Among the porous materials studied, SAPO-34 has the highest adsorption capacity of 160 mL/g due to high microsurface area, micropore volume and narrow pore diameter.

Mr Sumit Suhagiya et.al[9]

In this article author conducted the performance studied on the evolution of conceptual design of single panel cryopump and simulate the experiment on the ANSYS tool and both data have compare for manufacturing purpose. The cryopump consist of cryopannel as pumping surfaces. The pumping surfaces or the cryopannel can

be arranged circularly and suspended from the header. These cryopannel are enclosed by 80K cylindrical shield. The shield can be closed by annular shields on both the sides. Baffles are installed to prevent the cryopannel from the high temperature radiation from the pump inlet. Baffles are also cooled by 80K gaseous helium. The

80K cylindrical shields are enclosed by the pump housing. The cryopannel are covered by activated charcoal sorbent material which is fixed to the metallic substrate of the panels by inorganic cement. Panels are cooled by 4.5K ScHe. The shields and cryopannel is vacuum insulated from the pump housing. After that author find out the different heat load for cryopump. The heat load includes radiation heat load, throughput load, and residual gas load. Author also calculated the pressure drop and mass flow rate. After conducting experiment and when date compare with ANSYS tool author find the the theoretical calculation was in acceptable manner and cryopannel design was done successfully. conducting experiment and when date compare with ANSYS tool author find the the theoretical calculation was in acceptable manner and cryopannel design was done successfully.

3. PROBLEM IDENTIFICATION

After study the different literature following problem are observed related to cryopump.

1. There is lesser amount of work is done for proper design of cryopannel of of the cryopump.

2. The work done related to the capture coefficient of cryopump is also less.

As per literature presented, there lot of possibility proper design the cryopannel of cryopump and also find the capture coefficient of cryopump and how the different parameter can affect the pumping speed of the pump.

4. CONCLUSIONS

The study done by us here offers a review on previous literature and journals based on different ideas and modification with the help of analytical and computational methods. Now in this section we conclude here the main parameters analyses by us by the study of this previous literature.

1. In the cryopump focused on mechanism of pumping i.e. it's by cryocondensation or by cryosorption.

2. Focus is also given for finding the capture coefficient.

3. The literature also shows the uses the different type adsorbent material.

4. The literature also shows the method for measurement the pumping speed.

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