Cryogenic viscous pump analysis based on hemisphere model

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ABSTRACT: Cryogenic viscous pump (CVP) is also known as fore pump that are mainly designed for the separation of hydrogen isotopes from the helium during the process of regeneration of cryo- pumps. This model will determine the amount of hydrogen which is extracted by supercritical helium cooled pump. It also includes flow rates and inlet conditions that are related to the hydrogen gas flow. This hemisphere model (HM) determines the amount and location which are extracted by the pump as the function of time. During the development of this model the calibration check done for its results, later it has been compared with the measurements of CFP prototype. At the result of this model, it will demonstrate the quantity of hydrogen which is very sensitive to the inlet temperature that is found outside of the Cryopump. Finally, this model will represent the efficient outcome.

1. Introduction

The model presented in this work deals with the modelling and analysis of the cryogenic viscous pump which is also known as the fore pump. This pump are mainly used for maintaining and creating the vacuum. The mechanism of Cryopumping especially shows the diffusion-absorption process, energy balance, momentum and also the equation of state [1-2]. Kinetic and thermal properties are treated by their functions of pressure, temperature and gas fluid mixture. Here for solving such sets of equation numerical techniques are used. Mainly hemisphere model development is based on the analysis of raw type of experiment data.

Rarefied gas surface interaction which is also called as gas surface interaction. If the gas molecules are starts to collide with the solid surfaces, then the molecule that are present will have several type of possible destinies. This interaction includes accommodation, molecular chemical absorption, elastic scattering, physical absorption as well as dissociated chemical absorption. The cryopumps are typically treated in the rarefied gas regime. This process of pumping will be developed from the physical and chemical absorption which are depends on the factors such as molecule and condition of species. Experimental and theoretical based investigations are done for the development of CFP.

2. Experimental Details

The experimental setup includes the prototype of the Cryogenic viscous pump, measurement system, mass flow controllers and also the roughing pump. The hydrogen will starts to flow through the inner
tube while the helium that are present will flows through the outer annular tubal part. The tube of the cryopump is in length of 51 cm long. It includes the additional of 0.046 m in long of the adaptor plate, cooling length is about 0.61 m. The inner diameter of the tube in tube cryopump is of 2.6 cm and outer diameter is about 7.82 cm. This hemisphere model (HM) is slightly different than the other types of model because it mainly describes the molecular flow rather than the conditions of viscous flow. Sufficiently low wall temperatures will results in saturation hydrostatic pressure where the mean path is as same as the diameter or larger than the pipe diameter.

Figure 1. Experimental setup for the Cryogenic viscous pumping

When the vapour pressure starts to fall below the 7Pa then it is referred to as ultra-high vacuum that will corresponds the mean path of the molecule. At the entrance of cryopump molecule will starts to travel in the random direction and point of molecule are place at the entrance of cryopump.

Figure 2. Working of cryogenic pump at the viscous flow region.

In this model hydrogen (H) helium (He) mixture will starts to flow in the inner tube. The tube wall separates the two flows which develops the temperature profile that determines the heat transfer between two fluids. The temperature of hydrogen flow decreases and it will results in the deposition of solid rather than the liquid hydrogen. The mass of the hydrogen deposited not only influences the momentum, energy, pressure and gas density it will also introduce the thermal resistance through the tubal wall. Inner surface of the cryopump will mainly specifies the computational and physical boundary for the flow of hydrogen which are inside the cryopump. The flow pressure and density cannot be set by the surface of the pump. In this situation the surface point will only below the triple
point temperature of hydrogen. The solid hydrogen that is present on the surface of the pump will have the vapour pressure that is correspond to the surface temperature and vapour density.

![Diagram](image1)

**Figure 3.** Configuration of cryogenic viscous pump.

![Diagram](image2)

**Figure 4.** Hemisphere model working at the vacuum regions.

Figures 2 and 4 shows the differences that are working in vacuum and in viscous flow region.

![Diagram](image3)

**Figure 5.** Hemisphere Model and the cryogenic viscous pump (Fore Pump)
The Figure 5 and 6 deals with hemisphere model and hydrogen molecule with its angle of point source to the numerical nodes. The physical analysis in the process done within the cryogenic pump that involves variety of phenomena. This analysis includes the separation that considered for surface chemistry, heat transfer, molecular kinetics and also the fluid mechanics. This consideration will provide unique perspective of the pumping process. Cryogenic absorption of hydrogen is mainly used for developing the CFP. The molecules are mainly absorbed by the gas surface interactions. This interaction is done because the pumps are work in rarefied gas regime. The molecules present in the rarefied gas regime will show the long mean free path that compared to the dimensions of the cryogenic pump. The absorbed molecule will not form the solid structure, it will only separates the individual molecule. The cryogenic pump which are working in viscous flow regime and the molecules are much more when compared to common cryogenic pumps. This relationship between molecules and pump surface show the bulk viscous flow.

In kinematic process the both molecules will enter and leave the solid phase at the same time. When the hydrogen vapour are present at higher pressure, more amount of hydrogen based molecule will convert in to solid phase than the molecule that leave and the deposition occurs.

One dimensional analysis is used for controlling the hydrogen gas flow and the trace of amounts of helium that is shown in the figure 8.
3. Testing and Results

The hydrogen gas and helium coolant conditions with the traced amount of helium are now summarized. In this condition one dimensional model is compared with the pure hydrogen gas experiments. It will predicts the performance of the cryopump when they are combined with the hydrogen flow along with the trace amount of helium.

Table 1: Condition of helium coolant and hydrogen gas

| Sample No | Condition of Helium Coolant (mHe[g/s], THe,in[K], PHe[bar]) | Condition of Hydrogen Gas (mH2[g/s], PH2[Pa], yH2[-]) |
|-----------|------------------------------------------------------------|------------------------------------------------------|
| 1         | 0.2, 12.1, 1.31                                           | 0.0012, 151, 1                                       |
| 2         | 0.43, 6.9, 1.39                                           | 0.001, 49, 1                                         |

In table 2, the result of the experiment in sample 1 shows the hydrogen that are not absorbed and in sample 2 most of the hydrogen are absorbed. It also shows that the helium coolant takes more amount of energy than the hydrogen flow. The model generates that the balance between the hydrogen and helium coolant are only results in problematic.

Table 2: Comparison of Modelling result and experimental data of hydrogen gas

| Sample No | Absorption of Hydrogen Gas | Pressure drop [Pa] |
|-----------|----------------------------|--------------------|
|           | Experiment | Model | Experiment | Model |
| 1         | 0          | 0     | Little     | Nearby Zero |
| 2         | 0.94       | 0.97  | 51         | 49     |
Figure 9: Temperature of the hydrogen gas, wall of cryopump and the helium coolant.

The figure 9 shows the drop of temperature of the hydrogen gas within the 0.2m of the entrance of pump.

Figure 10: Hydrogen gas and the axial bulk velocity which taken as the function of axial position for the sample 1.

This diagram shows the hydrogen bulk density and velocity as the product of the hydrogen mass flux. Because of the higher temperature of helium coolant, the temperature present in the pump is not cold enough for the deposition of the hydrogen. As the result the mass flux will always constant through the CFP.
Figure 11: Temperature that relates to hydrogen gas, wall of cryopump and the helium coolant with the function of axial position for the sample 2.

This figure shows the bulk temperature profile that is related to hydrogen gas wall of cryopump and the helium coolant for the experiment of sample 2. The vapour pressure that corresponds to pump wall temperature is always higher than the pressure of the hydrogen flow and there will be no absorption of the molecules of hydrogen on the surface of the cryogenic pump. If the bulk amount of hydrogen starts to enter the region of absorption, the vapour pressure that corresponds to pump wall temperature will lower than the hydrogen pressure. As result the hydrogen molecules will be deposited at the surface of the phase that is found on the cryogenic pump as the process of the cryogenic absorption of the hydrogen. As these molecules are absorbed the pressure of the hydrogen drops by the loss of the hydrogen molecules. This equilibrium will reach such that the amount of molecules of the solid phase will equals to the amount of molecule of hydrogen in the solid phase. At this certain point of process after the absorption reaches the limit, the process of absorption will over or finalized.

Figure 12: Axial and radial mass flux of hydrogen gas in the axial position for sample 2.

The figure 12 shows the hydrogen mass loss due to the cryogenic absorption. As described in the above diagram if the absorption begins the radial mass flux will be positive in number and the hydrogen mass flux will begin to decrease. The hydrogen absorption only takes place in the region where the temperature results in the lower hydrogen vapour pressure than the bulk of hydrogen gas. The absorption is mostly driven from the bulk hydrogen and the solid hydrogen vapour. If the density differences are away the process of absorption will stop. If the absorption is over axial hydrogen mass flux will stay as constant.
4. Conclusion

The advantages of the cryogenic viscous pump include the high ability of pumping speeds, creation or development of vacuum surfaces without the contamination, it has the ability to create complicated and large shapes that are used in pumping surfaces. These advantages are important in the manufacturing and in the semiconductor processes. The thermodynamic properties of normal hydrogen are provided with the temperature that are ranges from 13.597 K or above, the gas phase viscosity should be available in 18 K or above and the thermal conductivity of gas phase should be available from 14 K or above. This data of deuterium are strictly limited and the data of viscosity are not available. The model is developed and compared with the experimental data. This hemisphere model suggested for the conditions where the coolant temperature is low enough for the creation of molecular flow condition in the cryogenic viscous or fore pump. This model is based on the analysis of the experimental data.

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