Theoretical Analysis And Study Of Process Parameters In Designing The High Pressure And High Flow Cryogenic Helium Gas Purification System

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Abstract- *Helium Purification System is an important sub-system in the the domain of space, atomic energy, defense and medical sciences. The purifier is designed to work at the temperature of 77K. The oil and moisture are removed by coalescing filters and a dryer, while nitrogen and oxygen are condensed by a phase separator and then adsorbed in several activated carbon absorption cylinders. The purifier will work in a flow rate of 50 Nm^3/hr at 210 bar in continuous operation of 6 hours. After purification, the purified helium has an impurity content of less than 5ppm.*

Keywords- Helium purifier; activated carbon, adsorption

I. INTRODUCTION

Helium, because of its unique properties, stands out to be indispensable in frontier technologies especially in the domain of space, atomic energy, defense and medical sciences. The single largest application of pure helium is in cooling superconducting magnets, key to high energy accelerators, superconducting cyclotron and Magnetic Resonance Imaging (MRI) scanners. In India, helium is an expensive and imported consumable. Therefore, a helium purifier is an integral part of any cryogenic center to conserve helium gas.

The basic theories regarding cryosorption based gas purification are well established and are widely available in open literature, but the finer aspects of technology still remain proprietary information. The work reported in this paper is an attempt to design and performance analysis helium purifier.

The impure helium is mainly from the tests of superconducting cavities and the failures of the cryogenic system. The impurities of the impure helium can solidify at low temperature, which will choke the tubes and damage the turbo expanders. The helium purification system can keep the purity of helium for 99.9995% and at 210 bar. The simplified process scheme of the purification system is in Fig.1, which includes gas bag, compressor, tube in tube heat exchanger, sub cooler heat exchanger, liquid air separator vessel, adsorber column, LN2 vessel and tublar heaters.

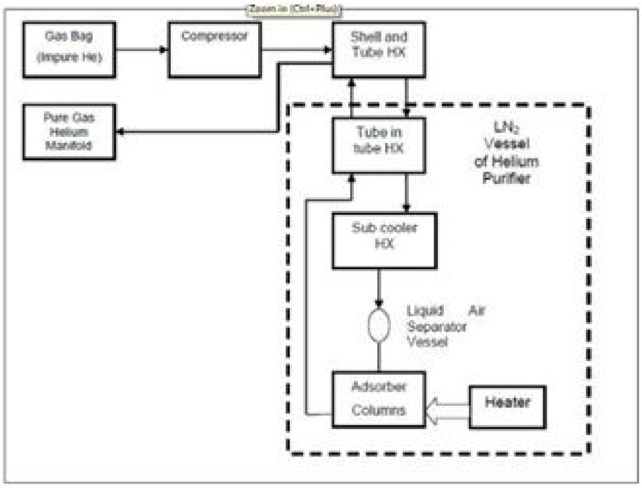

Figure 1 – Block diagram of components of helium purifier

Helium purifier is a key equipment of the helium purification system. Some countries have built their own high pressure purifiers. The design parameters of the helium purifier of are in table 1.

Table 1: Technical specification of purifier

Pressure	**210 bar**
Flow rate	**50 Nm^3/hr**
Run time	**6 Hr**
Input gas purity	**95 %**
Output gas purity	**99.995 %**
Temperature	**77 K**

II. WORKING PRINCIPLES OF THE HELIUM PURIFICATION

The impurities of the impure gas mainly include nitrogen and oxygen, with a minority of moisture, carbon dioxide, hydrogen and oil. Firstly, the impure helium will be gathered in the helium gas bag. When the gas bag reaches a high level, the impure helium will be compressed to the high pressure cylinder manifold. As the impure helium reaches a certain amount, the purifier begins to operate continuously with a throughput of 50 Nm3/hr at 77K, 210 bar. The impure helium flow to the gas bag and compressed by the compressor, then passes through the oil and water separator vessel, coalescing filters, dryer, outer heat exchanger, high pressure heat exchanger, condenser, liquid air separator and absorption cylinders. At last, the pure helium will be stored in the high pressure cylinder manifold. Most of the nitrogen and oxygen are liquefied in the liquid air separator and the rest are absorbed by the absorbents. The condensate is blown down about 120 min periodically. The purifier is designed for an uptime of 6 hours, the impurities at the outlet are detected by the analyzer. The regeneration starts by any one of the following three criterions:

1. The time in excess of the uptime
2. The impurity at the outlet in excess of 5ppm
3. Manual triggering of the regeneration

For the regeneration, liquid nitrogen is drained out and absorption cylinders undergo regeneration by heating and evacuation. Firstly, the purifier is depressurized and condenser is emptied. Then the absorbent cylinders are heated up. The liquid nitrogen in the dewar is emptied to the buffer tank when the pressure of the dewar increases. The absorbent cylinders are heat to 100℃ with an evacuation . The regeneration is completed by pressurization with pure helium. The purifier is equipped with an automatically process control system and a local operator panel. So the purification and the regeneration process can be controlled automatically and manually.

III. DESIGN OF HELIUM PURIFIER

The purifier includes dewar, outer heat exchanger, high pressure heat exchanger, condenser, liquid air separator and absorption cylinders. The dewar is fitted with a quantity of liquid nitrogen, in which condenser, liquid air separator and absorbent cylinders are submerged. The height of the purifier is 1600 mm, and the diameter of dewar is 680mm with a thickness of 5mm. The outer heat exchanger acts as dryer which brings down the water dew point to approximately 1℃. The helically coiled tube-in-tube heat exchanger is selected as the high pressure heat exchanger, which is compact and high efficient. The outside diameter of the inner tube is 24 mm with a wall thickness of 1.5mm, while the outside diameter of the outer tube is 32mm with a wall thickness of 2mm. The diameter of the coil is 665 mm. In order to decrease the drop pressure of the tube, the heat exchanger is divided into five layers. and the tube length is 12m. The liquid air separator collects the liquid air at the bottom of the separator. After the liquid air separator, the impurities of the gas are less than 0.58%. There are 5 absorption cylinders which are divided into two ways and connected in series. The absorbent in the absorber is coconut shell activated carbon with a good performance at 77K.

CFD Analysis of adsorber column

The designed adsorber column is model with CFD methods.The absorber column is u shaped pipe having 2 m length of legs and diameter 76.1 mm thickness 5.9 mm.Total 5 adsober column are used in seris. The adsorber column are filled with activated charcoal is about 17.125 kg.mixture of helium and nitrogen is passed through inlet and nitrogen is adsorbed in activated charcoal.Fluent 15.0 is used for analysis of adsorption process in adsorber column. The RNG k-å model with standard wall functions is used in the analysisThe boundary condition of inlet is velocity, as the outlet is pressure.the geometry of adsorber column is shown in figure .In the results Pressure countre and volume fraction countre are used.the figure shows the pressure drop across column.

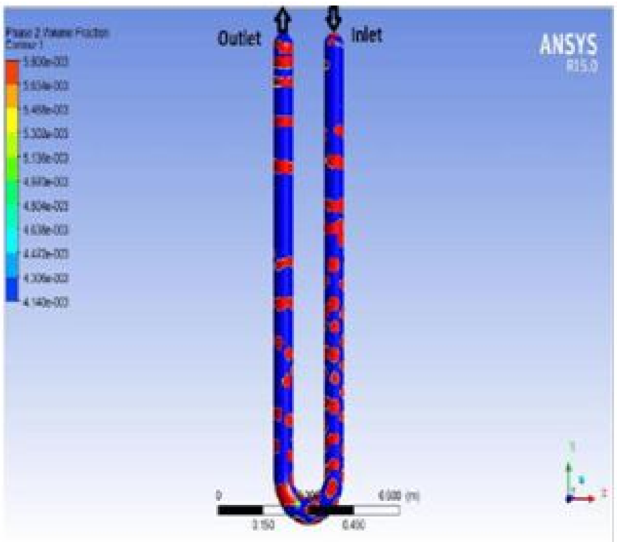

Figure 6.7 : Volume fraction contour of adsorber

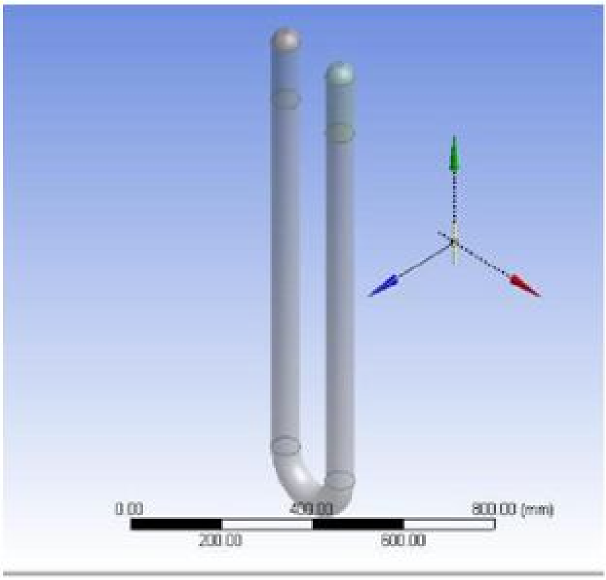

Figure 6.1– Geometry of Simulated Model of column 1 Adsober column

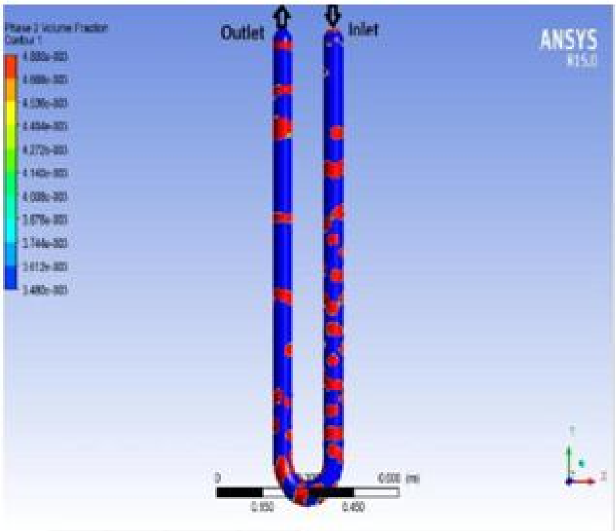

Figure 6.8 : Volume fraction contour of adsorber column 2

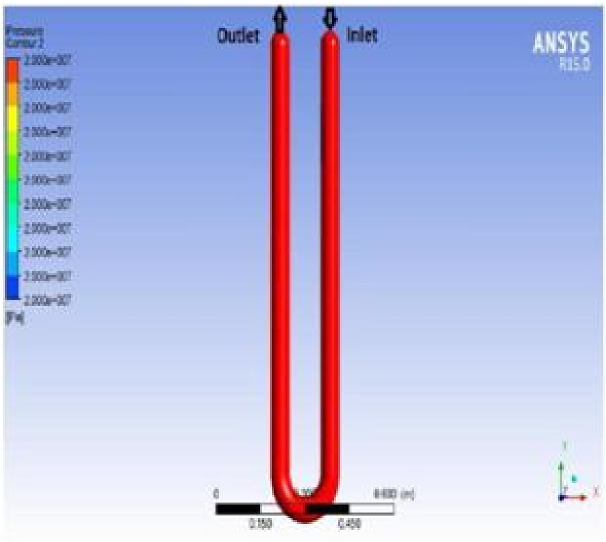

Figure 6.3 : Pressure contour of adsorber column

The pressure drop across five adsorber column is 54 x 10-5 bar.

Figure shows the drop of volume fraction in 5 adorber column.

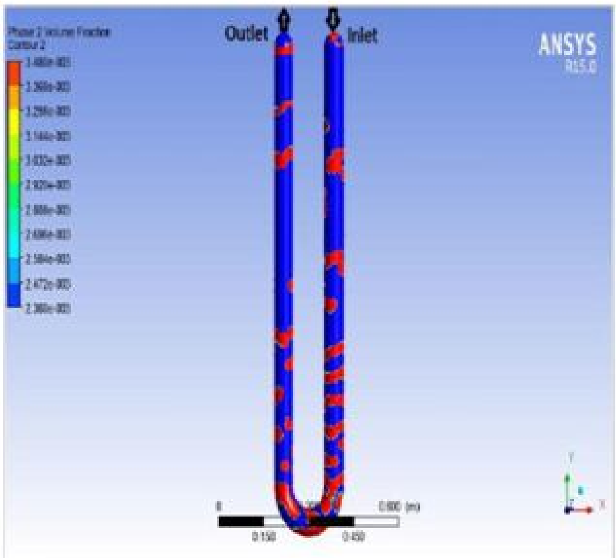

Figure 6.9 : Volume fraction contour of adsorber column 3

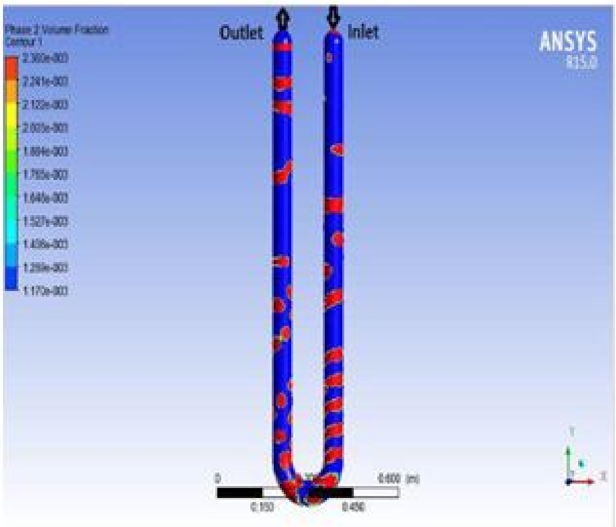

Figure 6.10 : Volume fraction contour of adsorber column 4

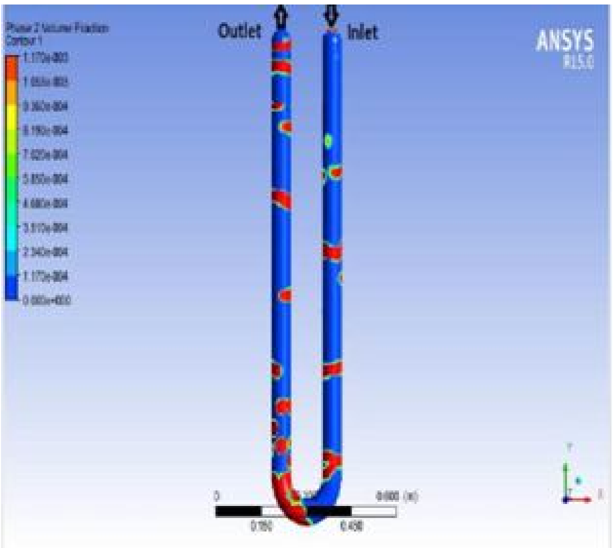

Figure 6.11 : Volume fraction contour of adsorber column 5

From the volume fraction countre the impurities are adsorbed and volume fraction of impurities are dropped continuasly , In last adsorber column outlet get 99.995 % pure helium.

IV. RESULT AND DISCUSSION

For the purpose of CFD analysis which is done on adsorber column following details shown in table have been used.

Table 5.1 Designed values of parameters of adsorber columns

Parameters	Designed Values
Adsorber Column Cross section	65 NB Sch 80 SS pipe (OD=76.1mm, t=5.9 mm)
Length of each Adsorber Column	2m U-shaped with each leg length of 1m
Number of Adsorber Columns	5
Quantity of activated charcoal used	17.845 kg
Theoretical pressure drop in adsorber columns	54×10^{-5} bar

CFD analysis of adsorber column for the pressure drop and volume fraction across it has been done which shows the following results.From pressure counters the pressure drop across all the columns is found to be negligible.From volume fraction counters impurity removed from the helium is found to be 99.99%.Following tables show the pressure drop and decrease in volume fraction in each column.

Table 5.2 Pressure drop in adsorber columns

No. adsorber column	Pressure Drop (Bar)
Column 1	10.1×10^{-5}
Column 2	10.1×10^{-5}
Column 3	10.1×10^{-5}
Column 4	10.1×10^{-5}
Column 5	10.1×10^{-5}

Table 5.3 :Volume fraction in adsorber columns

No. adsorber column	Volume fraction (Inlet)	Volume fraction(Outlet)
Column 1	0.58	0.48
Column 2	0.48	0.348
Column 3	0.348	0.236
Column 4	0.236	0.117
Column 5	0.117	0

V. CONCLUSION

High pressure purifier is a key equipment of the helium purification system. The working principles of the helium purification and regeneration are described. The design of the purifier is shown in details. It’s known that the high pressure heat exchanger and the adsorption cylinders are important parts of the purifier. Adsorber column are analysed in Ansys and show negligible pressure drop and 99.995 % pure helium at output.. The activated carbon has 95% micropore which can adsorb the impurities well at low pressure.

Until now, the helium purification system is under construction and the purifier is being manufactured.

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