

Review on Design of Secondary Oil Removal System for kW Class Indigenous Helium Refrigerator/Liquefier Plant at 300K

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Abstract: The indigenous Helium Refrigerator/Liquefier (HRL) plant being designed at IPR will have oil removal system for removal of compressor oil. After bulk oil removal in the Primary oil removal system (PORS), still significant oil is left in the helium stream which is removed first by a series of coalescers and then by an adsorber bed at 300k and 14 bar. At the charcoal bed the amount of oil at the inlet is about 1 PPM by volume and outlet is 0.01 PPM or about. This work is related to the static adsorption capacity and adsorption kinetics for organic compounds on coconut shell based activated carbon using Dubinin-Radushkevich. The adsorber bed design includes calculation size of adsorber bed, the pressure drop and MTZ length calculation using Rosen Model and Axial Dispersion Model. Finally it passes through a filter to restrict the carbon dusts coming out of the charcoal bed.

Keywords: *Adsorption, Adsorbent, Adsorber Bed 300K, Helium Purifier, Activated Charcoal.*

I. INTRODUCTION

Cryogenics, the science of producing and maintaining low temperatures; cryogenics field relating with the temperature below 123 K. The low temperature is required for several experimental processes, to obtain such lower temperature cryogenics are used like liquid helium means it is required to liquefy helium gas. Before the liquefaction of the helium gas, it is essential to remove impurities from the gas.

Due to the properties of helium, its compression is accompanied by a high temperature rise. A pressure ratio of 14 would in an ideal isentropic compression process generate a temperature ratio of 2.8, i.e. the helium temperature would rise up to 840 K. Any deviation from the ideal increases this temperature difference. So oil is used to take up some heat of compression and try to achieve isothermal compression and decreases the compression work. But the disadvantage of oil in contact with the helium is, it creates an undesired contamination of the gas. The oil must therefore be removed by a series of coalescing filters and a final adsorber with activated charcoal filling.

A. Adsorption:

Adsorption has been defined as operation/process in which the gas molecules (the adsorbate) stick to the surface of the solid (adsorbent) in one or more layer. Adsorption is a surface-based process while absorption involves the whole volume of the material. The adsorption process is broadly classified into two processes i.e. Physical adsorption and chemical adsorption. If the gas molecules penetrate into the solid, the process is usually called absorption. If the gas molecules stick to the surface of the solid in one or more layers, the process is called adsorption. If there is a very strong reaction between the solid and the gas, the adsorption process is called the chemical adsorption. If only weak intermolecular forces, called van der waals forces are brought into play, the process is called physical adsorption. The substance attached to the surface is called adsorbate, and the substance to which it is attached is known as adsorbent [1].

B. Adsorbent:

To be technically effective in commercial separation process, whether this be a bulk separation or purification, an adsorbent material must have a high internal volume which is accessible to the components being removed from the fluid. Such a highly porous solid may be carbonaceous or inorganic in nature, synthetic or naturally occurring, and in certain circumstances may have true molecular sieving properties. The adsorbent must also have good mechanical properties such as strength and resistance to attrition and it must have good kinetic properties, that is, it must be capable of transferring adsorbing molecules rapidly to the adsorption sites. The high internal surface area of an adsorbent creates the high capacity needed for a successful separation or purification process. Adsorbents can be made with internal surface areas which range from 100m²/g to over 3000m²/g. For practical applications, however the range has been restricted to about 300-1200m²/g [2].

C. Adsorption Isotherm:

If a quantity q of a gas or vapour is adsorbed by a porous solid at constant temperature and the steady state equilibrium partial pressure is p then the function $q(p)$ is the adsorption

isotherm. Isotherms can take one of the several forms (known as types I to V) illustrated by fig 1. Each of these types is observed in practice but by far the most common types are types I, II, and IV.

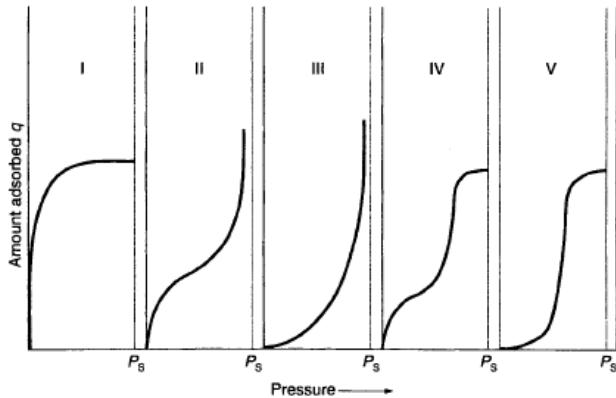


Fig.1 Five types of Isotherms

An inherent property of type I isotherm is that adsorption is limited to the completion of a single monolayer of adsorbate on the adsorbent surface. Type I isotherms are observed for the adsorption of the gases on microporous solids whose pore sizes are not much larger than the molecular diameter of the adsorbate; complete filling of these narrow pores then corresponds to the completion of a molecular layer. Type II isotherms do not exhibit a saturation limit. Near to first point of inflexion of such isotherms a monolayer is completed following which adsorption occurs in successive layers. Adsorbents which have a wide distribution of pore sizes from type II isotherms, condensation of the adsorbate vapour occurring within the larger pores. The adsorbents display a higher capacity for adsorption as the adsorbate saturated vapour pressure is approached. Similarly type III isotherms, which are continuously convex with respect to the partial pressure axis, shows a steady increase in adsorption capacity with increasing relative pressure. Type IV isotherms are similar to type II isotherms except that adsorption terminates near to a relative pressure but then a point of inflexion is reached and a saturation limit is approached as the relative pressure is further increased.[2]

D. Fixed Bed Process:

Vessels and columns which hold the adsorbent in a fixed position appear initially to provide distinct advantages over their counterparts in which the adsorbent is allowed to move. First, such equipment is simple and relatively inexpensive to fabricate.

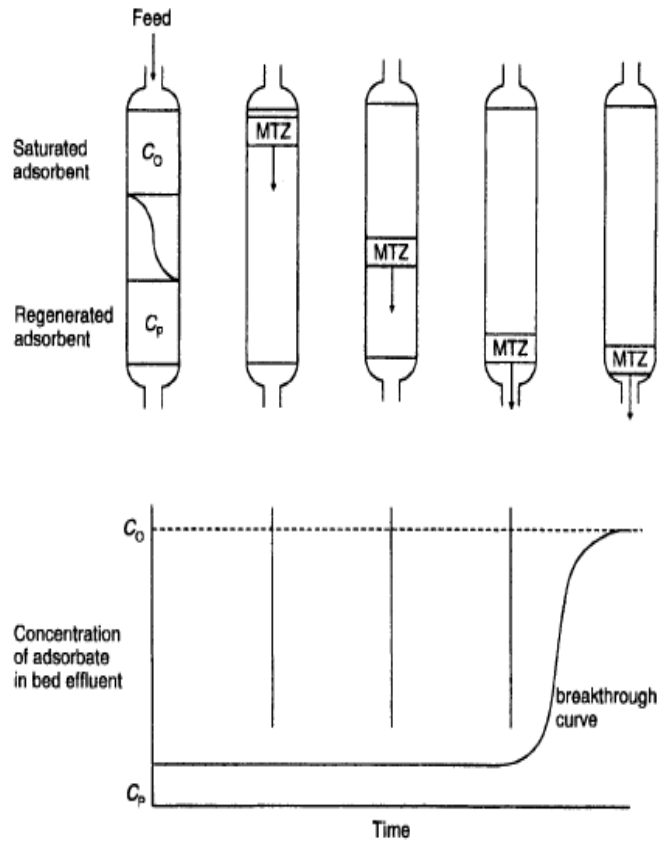


Fig.2. Sketch showing the concentration profile, mass transfer zone, and breakthrough curve in packed bed adsorption

Secondly, minimal attrition of adsorbent occurs when it remains in fixed position. However, despite their simplicity, fixed beds have a disadvantage, i.e. as fluid is passed through a fixed bed of adsorbent the transfer of adsorbate molecules from the feed to the solid initially occurs at bed entrance. Once the adsorbent in this region becomes saturated with the adsorbate molecules, the zone in which the mass transfer occurs move progressively through the bed towards the exit, as shown schematically in fig.2. Upstream of the MTZ, the adsorbent will be in equilibrium with the feed and unable to adsorb further adsorbate molecules. Downstream of the MTZ, the adsorbent will not have been in contact with any adsorbate molecules and therefore, despite having the capability of doing so, will also be unable to adsorb adsorbate molecules. Thus, if the time selected for progress of MTZ through the bed is long the bed will be large and it will contain a large inventory of expensive adsorbent. In addition the pressure drop will be proportionately large [2].

II. ADSORBENT SELECTION

Activated carbon is the most widely used sorbent. Its usefulness derives mainly from its large micropore and mesopore volumes and the resulting high surface area. The

pore size distribution of a typical activated carbon is given in Fig 3, compared with several other sorbents. For having a good rate of adsorption it is very important to know about the physical property of adsorbents [3].

A. Comparison & Selection of Adsorbent:

Now a days, there are many adsorbents used for different application in the adsorber bed. Here, we need to get adsorbed the main impurities is industrial oil for the purification of the helium at 300K.

Khaled Okiel a, Mona El-Sayed b,* , Mohamed Y. El-Kady (2010) has conducted experiment for Treatment of oil–water emulsions by adsorption onto activated carbon, bentonite and deposited carbon. The main objective of this study is to examine the removal of oil from oil–water emulsions by adsorption on bentonite, powdered activated carbon (PAC) and deposited carbon (DC). The results gave evidence of the ability of the adsorbents to adsorb oil and that the adsorptive property of the three adsorbents (bentonite, PAC, and DC) has been influenced by different factors. The effects of contact time, the weight of adsorbents and the concentration of adsorbate on the oil adsorption have been studied. Thus concluded Oil removal percentages increase better by activated carbon due to its porous capacity and other properties.

Kidnay, A.J. & Hira, M.J. (1967) preformed some experiments at 76K on Neon, Hydrogen & Helium and develop adsorption isotherm at pressure range varying from 0 to 95atm. They reported that for adsorption, the amount adsorbed is higher for charcoal than Zeolite. The Polanyi adsorption potential theory, as modified by Dubinin, was used in an attempt to obtain a general correlation of these isotherms. The results, while not completely general, should allow the prediction of the high pressure isotherms of neon, hydrogen, and helium on charcoal at any temperature with an accuracy sufficient for most engineering calculations.

Jufang Wu, Analytical Chemistry, Department, Modeling adsorption of organic compounds on activated carbon—A multivariate approach, Activated carbon is an adsorbent that is commonly used for removing organic contaminants from air due to its abundant pores and large internal surface area. This thesis is concerned with the static adsorption capacity and adsorption kinetics for single and binary organic compounds on different types of activated carbon.

So, it is finally observed that the Adsorption capacity of Activated charcoal is higher than the any other adsorbent as temperature decreases and increase in pressure[6].

Activated carbon produced from the Coconut Shell exhibit a predominance of micropores. Therefore, coconut shell based SC11 activated carbon (charcoal) is selected because it provide better adsorption capacity than any other adsorbent & also provide micropore structure in granular size which will

provide effective trapping of small gas molecules with higher surface area 200-1200 m²/g [7].

III. MASS OF ADSORBENT

In Indigenous Helium Liquefaction Plant, the helium which is going to use should be pure and is supplied to adsorber bed at 300K temperature & 14bar pressure. But the helium supply contain the oil impurities which is averaging to about 1 PPM.

The potential theory of adsorption first introduced in 1914 by Polanyi and later modified by Dubinin for adsorption on Microporous adsorbents is still regarded as fundamentally sound and accepted as its correct and better than all the other theories. DR theory is the nothing but the modified form of potential theory of adsorption[4].

So, DR calculation Model theory is selected for the calculation of the pore size.

DR- equation for single adsorbate

$$\frac{W}{W_0} = \exp \left[- \frac{\epsilon}{E} \right]^2$$

Where,

E= characteristic adsorption energy = E₀β

E₀= Adsorption energy of the reference vapour

β= affinity coefficients, similarity coefficients or relative differential molar works of adsorption

W₀= total volume of the micropore

W=volume that has been filled when the relative pressure is P/P₀.

ε=RTln (P₀/P) =Adsorption Potential

It can be find adsorption capacity from this equation. This Mass of hydrogen adsorbed describe the adsorption capacity of the coconut shell type activated charcoal, for different ppm level the adsorption capacity changes which is shown below.

Ethylene Glycol Adsorption Capacity of Coconut Shell at 300K

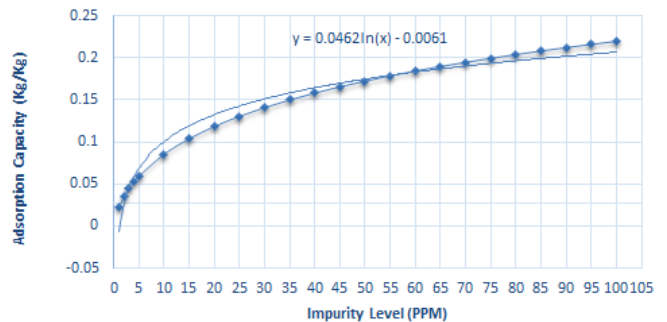


Fig. 3 Impurity Adsorption Capacity At 300K for Activated Charcoal of Coconut Shell Based

This graph of fig.3 describes that as the ppm level increases, in the beginning, the adsorption capacity increases rapidly but after some level it increasing very slowly.

Ethylene Glycol Isotherm for 300K on Coconut Shell

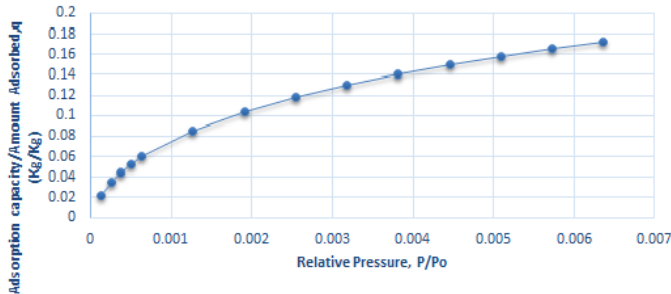


Fig. 4 Ethylene glycol Isotherm at 300K for Coconut Shell Based Activated Charcoal

Fig.4 describes the graph which says, as the relative pressure of impurity increases, in the beginning, the adsorption capacity increases rapidly but after some level it increasing very slowly. This graph is called as Ethylene glycol Isotherm (at 300K).

Characteristic Curve

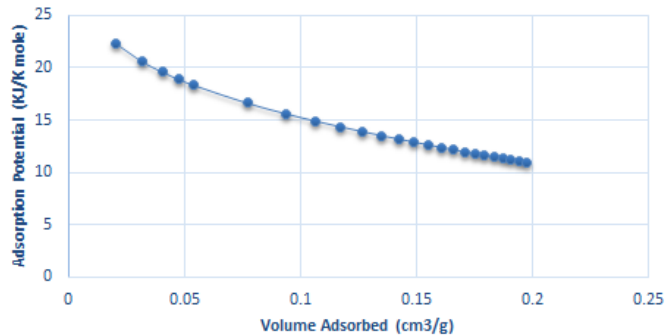


Fig. 5 Characteristic Curve of Ethylene Glycol at 300K on Coconut Shell Based Activated Charcoal

Fig.5 show the characteristic curve of Ethylene glycol at 300K, on the coconut shell based activated charcoal, which describe the adsorption capacity of charcoal with respect to volume get adsorbed of oil (Ethylene glycol) impurity from the helium gas. This graph says, as the amount of volume get adsorbed on the charcoal increasing, its adsorption potential is decreasing.

IV. PRESSURE DROP

From a fluid mechanical perspective, the most important issue is that of the pressure drop required for the liquid or the gas to flow through the column at a specified flow rate. To calculate this quantity we rely on a friction factor correlation attributed to Ergun. Other fluid mechanical issues involve the proper distribution of the liquid across the cross-section, and developing models of the velocity profile in the liquid film

around a piece of packing material so that heat/mass transfer calculations can be made. Design of packing materials to achieve uniform distribution of the fluid across the cross-section throughout the column is an important subject as well. Here, we only focus on the pressure drop issue [9].

The Ergun equation that is commonly employed is given below:

$$f_p = \frac{150}{Re_p} + 1.75$$

Here, the friction, f_p factor for the packed bed, and Reynolds number, Re_p are defined as follows;

$$f_p = \frac{\Delta p}{L} \frac{D_p}{\rho V_s^2} \left(\frac{\epsilon^3}{1 - \epsilon} \right)$$

$$Re_p = \frac{D_p V_s \rho}{(1 - \epsilon) \mu}$$

Pressure Drop, ΔP mbar

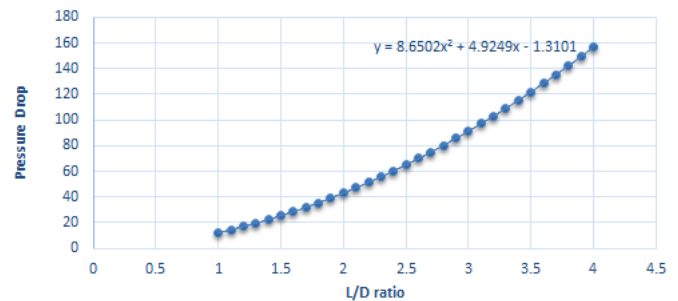


fig. 5 Length to diameter ratio of bed v/s pressure drop graph for adsorber bed at 300 K.

From the fig 5 it is seen that as we length to diameter ratio for adsorber bed increases the pressure drop increases significantly. Thus optimum length and diameter for available space is to be designed to achieve minimum pressure drop.

CONCLUSIONS

The current work deals with the design of adsorption based helium purification system. In context to the design requirements it can be concluded from the review that activated carbon especially coconut shell based seems to be more effective as compared to the different adsorbents discussed. In addition to this sample calculation gives us an overview of the approximate values of total required mass of charcoal to adsorbed 0.023Kg of Ethylene glycol impurity is 303.87 Kg, one can says 304 Kg, dimensions of the adsorber bed, and pressure drop. Calculating the parameters required for optimum design pressure drop comes to be 7 mbar for 0.8 m diameter and 1.9 m length for purifier bed.

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REFERENCES

- [1] Randall F. Barron, "Cryogenic Systems" by McGraw-Hill, Inc., second edition, Clarendon Press, Oxford, 1985.
- [2] Barry Crittenden & W John Thomas, "Adsorption Technology & Design", Butterworth-Heinemann, 2004.
- [3] Ralph T. Yang, "*Adsorbents: Fundamentals and Applications*", John Wiley & Sons, publication, 2003.
- [4] Wood, G. O. (2001). Affinity coefficients of the Polanyi/Dubinin adsorption isotherm equations: A review with compilations and correlations. *Carbon*, 39(3), 343-356.
- [5] L. Gajdos1, L. Pietrelli , A. Ciccarello, J. Derco, Elimination of Polyethylene Glycol from Aqueous Solution Using Activated Carbon, Slovakia, September 25, 2006.
- [6] Kidnay, A.J. & Hira, M.J., High Pressure Adsorption Isotherms of Neon, Hydrogen & Helium at 76K, in *Advances in cryogenic Engineering* Vol.12, pp. 730-740, Springer US, 1967.
- [7] Kidnay, A.J. & Hira, M.J. & Dickson, P. F. , The Adsorption Isotherms on Methane, Nitrogen, Hydrogen & their mixture at 76K, in *Advances in cryogenic Engineering* Vol.13, pp.400, Springer US, 1968.
- [8] Jufang Wu, Modeling adsorption of organic compounds on activated carbon, Analytical Chemistry, Department of Chemistry, Umeå University, SE-901 87 Umeå, Sweden and Swedish Defence Research Agency, Division of NBC Defence, SE-901 82 Umeå, SwedenIs.
- [9] www.igcl.com/php/activated_carbon.php
- [10] Roop Chand Bansal & Meenakshi Goyal, "Activated Carbon Adsorption", CRC Press, 2005.
- [11] R. Shankar Subramanian, "Flow through Packed Beds and Fluidized Beds".
<http://people.clarkson.edu/projects/subramanian/ch301/notes/packfluidbed.pdf>