Pressure swing adsorption a Cleaner techniques to reduce emission

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Abstract— Reduction of the absorber size of a medical oxygen concentrator (MOC) employing a generic pressure swing adsorption (PSA) technology is an ongoing research and development activity. The MOC typically produces a 90\textperthousand93\% O2-enriched product gas from ambient air at a rate of \textasciitilde10 L/minute (LPM) for individual use. Adsorbent columns packed with very small adsorbent particles are used to enhance the adsorption kinetics for rapid PSA cycle operation. An experimental mini-PSA set up was used to measure the performance of a simulated Skarstrom-like PSA cycle using a commercial sample of LiX Zeolite as the air separation sorbent.

I. INTRODUCTION

Pressure swing adsorption (PSA) is a widely used gas separation method for medium scale production of bulk gases and for trace removal like removing carbon dioxide from flue streams in chemical plants. It is relatively safe, simple and cost effective operation compared to cryogenic separation. The application of PSA has extended from commercial plants at tonnage scale [\textasciitilde1 to 150 tons per day (TPD)] to onsite generation and even to mobile usage such as portable medical oxygen concentrator for respiratory therapy, with production rate of \textasciitilde5 liters per minute. (LPM) (\textasciitilde0.01TPD). Due to the market demand of increasingly small size and lightweight MOC so as to increase mobility and to improve life quality, reduction of the absorber size of a PSA-based MOC is an ongoing research and development activity.

Many pressure swing adsorption (PSA) processes have been patented and commercialized for production of \textasciitilde90\textperthousand95\% O2-enriched gas from ambient air by employing a zeolitic adsorbent. Figure 5.1 shows the result of a patent search under the topic “air separation by adsorption” which plots a year by year tally of the number of U.S. Patents on the subject during the period of 1980 to 2005. An overwhelming number of 452 patents were issued. The field is very crowded but still active (\textasciitilde7 patents issued per year).

In principle, a generic PSA process for air separation cyclically carries out an adsorption step at a relatively higher pressure, where N2 is selectively (thermodynamic) adsorbed from a dry and CO2-free air stream on the Zeolite, thereby producing an O2-enriched product gas, followed by N2 desorption at relatively lower pressures where the Zeolite is regenerated for reuse. Various complementary steps are often included in the process cycle to improve the product specifications and the process performances. Three subclasses of the generic PSA technology based on the pressure levels of the adsorption step (PA) and the ultimate desorption step (PD) are common in the literature. They are pressure swing adsorption (PSA) where PA is super atmospheric and PD is ambient, vacuum swing adsorption (VSA) where PA is near ambient and PD is sub atmospheric, and pressure vacuum swing adsorption (PVSA), which is a combination of the two. A VSA process employing a Zeolite has also been commercialized where a N2-rich byproduct gas (99\textperthousand%N2) is simultaneously produced [1].

II. WORKING OF PRESSURE SWING ADSORPTION

Principle: - The system operates by adsorbing contaminants while under pressure. The contaminants remain trapped on the adsorbent, and clean air passes through.

Working: - If a gas mixture such as air, is passed under pressure through a vessel containing an adsorbent bed of Zeolite that attracts nitrogen more strongly than it does oxygen, part or all of the nitrogen will stay in the bed, and the gas coming out of the vessel will be enriched in oxygen. When the bed reaches the end of its capacity to absorb nitrogen, it can be regenerated by reducing the pressure, thereby releasing the adsorbed nitrogen. Let us see the whole process stage by stage.

1) Stage 1:
Compressed air is fed into the first bed. Nitrogen and argon molecules are trapped, while oxygen is allowed to flow through.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{fig1.png}
\caption{PSA Stage1 [2]}
\end{figure}

2) Stage 2:
When the adsorbent in the first bed becomes saturated with nitrogen and argon, the airflow feed is directed into the second bed.
III. ZEOLITES

Zeolites are micro porous crystalline structures that govern the molecules that are adsorbed during the PSA process. The shape-selective properties of Zeolites are the basis for their use in molecular adsorption. The different structures of the Zeolite indicate the type of molecules that the Zeolite will adsorb [2].

Zeolites have various ways of controlling adsorption. The size and shape of pores can control access into the Zeolite. In another case different types of molecule enter the Zeolite, but some diffuse through the channels more quickly while others are left behind and do not pass through. Cat ion-containing Zeolites, such as silver Zeolites, are extensively used in gas separation processes. These cat ions are indicated as the purple spheres in Figure. Molecules are differentiated on the basis of their electrostatic interactions with the metal ions. Zeolites can thus separate molecules based on differences of size, shape and polarity.

Commercial X-Zeolite, which is typically available as the Na⁺ form (known commercially as 13X), is not aluminum saturated and contains 86 aluminum atoms per unit cell, while the LSX Zeolite contains 96 aluminum atoms per unit cell.

Ion exchange is another aspect of Zeolites that aids in the separation process. Ion exchange involves adding metal cations to the structure of the Zeolite to attract certain molecules. Calcium is the most common metal cation exchanged in Zeolites, but new studies have found silver exchanged Zeolites to be more effective in air separation [2]. For Zeolites to be effective, metal cations must be bound to the structure such as calcium, sodium, and in our case silver. Silver exchanged Zeolites are a relatively new type of Zeolite used in separation. The silver metal cation is placed in the structure of the Zeolite structure as shown in Figure. Zeolite structure types of A, X, and Y are the dominant types used in commercial use for adsorption and ion exchange. With this type of arrangement nitrogen and argon are attracted to the silver ion by electrostatic forces because of their polarization properties.
A. LiAgX Zeolite

Research over of air separation using PSA shows Zeolite LiAgX currently has the best performance of removing nitrogen in air separation processes. At atmospheric pressure, the PSA process had an oxygen purity of 96.42% and recovery of oxygen from the feed stream of 62.74%. The product throughput used to calculate the amount of LiAgX Zeolites required to attain this separation is 0.054 kg O2/H/kg adsorbent at 2.5 minute cycles. The LiAgX has structure type X which is shown in Figure 7: Zeolite LiAgX structure

B. AgA Zeolite

Silver-exchanged Zeolite A shows a strong adsorption of nitrogen as well as argon. For the separation of oxygen from nitrogen and argon, the Zeolite structure A is the best structure. It allows for the best interaction between the ion in the Zeolite and the nitrogen and argon molecules. AgA Zeolite has a selectivity of argon to oxygen as 1.63 to 1 at atmospheric pressure. Nitrogen to oxygen selectivity is lower at 5.1 to 1 in this AgA Zeolite when compared to the LiAgX Zeolite previously discussed. From the adsorption isotherm data approximately 7 cm3/g of argon is adsorbed on the AgA Zeolite

IV. PROPOSED USE OF TECHNOLOGY

Pressure Swing Adsorption (PSA) was chosen to be used in the design based on its medium product capacity, safety, energy efficiency, and associated costs. Four adsorbent designs consisting of the arrangement of Zeolites in the adsorption column were anglicized. The four designs studied used Zeolites LiAgX and AgA were

- Design 1: Only LiAgX Zeolite
- Design 2: Only AgA Zeolite
- Design 3: Mixed ratio of Zeolites LiAgX and AgA
- Design 4: Both LiAgX and AgA Zeolites separating them for different sections

The best design was determined using a fixed column diameter and cycle time. The required length of the bed varied determining on the product recovery. The outlet flow of oxygen must be at least 1,500 L/min in the hospital design and 5 L/min in the portable design. In both designs, the purity of oxygen from air must be at least 99 percent.

Design 1: LiAgX Zeolite

A design over the length of the bed to achieve 99% oxygen was performed using purely Zeolite LiAgX as the adsorbent. Since argon is not as selective to adsorb on LiAgX as it is on AgA the more Zeolites are required to achieve the set product purity. The major concern of this option is the large amount of added volume in order to accomplish the separation, this increased volume increases the cost of the equipment as a large compressor and columns are required. In addition, it increases the amount of Zeolite needed thus the Zeolite cost

Design 2: AgA Zeolite

Using Zeolite AgA as the adsorbent creates the same dilemma as the previous design. In this case nitrogen molecules are not as highly adsorbed to the AgA Zeolite used as they are to the LiAgX Zeolite. Argon, however, is more favorable to adsorb on this Zeolite. This design does not minimize the costs associated with size and capacity of the device

Design 3: Mixed Ratio of Zeolites LiAgX and AgA

As shown in the figure above the design of the mixed adsorbents has a selected ratio 1:1 of Zeolite LiAgX (red) and Zeolite AgA (blue).

Nitrogen has a higher loading capacity on Zeolite LiAgX at a selectivity of nitrogen to oxygen of 12 to 1. In
the AgA Zeolite the selectivity of nitrogen to oxygen is about 5 to 1.

Nitrogen is more strongly absorbed on both Zeolites than argon. Thus, when argon is absorbed the remaining nitrogen molecules left to absorb will selectively replace the argon molecules. Since the selectivity of the nitrogen absorbance is lower in Zeolite AgA than LiAgX the presence of Zeolite AgA will require a longer column length to remove the nitrogen. Argon’s selectivity in Zeolite AgA is 1.63 to 1 argon to oxygen and in Zeolite LiAgX it is a 1 to 1 ratio. The presence of LiAgX Zeolite in the argon removal section requires the length of the column to be longer than if just having AgA Zeolite.

In conclusion, the use of Zeolite AgA would increase the length of the nitrogen removal section. In the argon section Zeolite LiAgX would increase the required length of the section to remove the argon as compared to using purely AgA Zeolite.

**Design 4: LiAgX and AgA Zeolites Separated**

![Fig. 11: LiAgX and AgA Zeolites Separated in Adsorption Column](image)

The last adsorbent design in the column consists of using Zeolite LiAgX in the nitrogen removal section and Zeolite AgA in the argon removal section. This was chosen, because Zeolite LiAgX has a higher selectivity of nitrogen to argon and oxygen than Zeolite AgA. Zeolite AgA was chosen for the argon removal section as its selectivity is 1.63:1 argon to oxygen, which is much greater than Zeolite LiAgX. The volume of the column, inlet air, and Zeolites required is dramatically lower and would save money on the overall unit. This will be the best option since the Zeolites are roughly the same price.

V. CONCLUSION.

The summary of the present literature review is as follows:
1) Pressure swing Adsorption is new technique for extracting pure Oxygen from atmosphere.
2) This technique can be used or introduced in general for power plant combustion chamber.
3) A certain extent of efficiency can be increased by using this system.
4) Many implements are carried out in power industry but this process modification is better option to increase overall output of plant.

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