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Apparatus for the use of Zeolite as an Adsorbent in the Pressure Swing Adsorption (PSA) Technology for Oxygen Concentrator

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ABSTRACT

The equipment for using zeolite as an adsorbent in the Pressure Swing Adsorption (PSA) method for oxygen concentrator is presented in this research. Worldwide, oxygen is generally utilized for a variety of chemical reactions as well as medical applications. The need for medicinal oxygen has skyrocketed in all hospitals worldwide during the COVID-19 pandemic. To minimize the amount of processing power needed and make the most use of the adsorbent capacity, the PSA process must operate efficiently. Additional details about the zeolite's role as an adsorption medium to help PSA in the synthesis of oxygen may be found in this paper.

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1. INTRODUCTION

Oxygen is one of the essential ingredients to support life on earth and oxygen is abundantly available in gaseous form in our atmosphere at a concentration of about 21%. Today the need for oxygen in purer form has increased rapidly with the emergence of a variety of new manufacturing processes and the need for medical applications. Especially, oxygen has been well-demanded during the COVID-19 pandemic. The need for medical oxygen has increased sharply in all hospitals in the world (Anggraeni *et al*., 2020).

During the COVID-19 pandemic, the Ministry of Industry (Kemenperin) continues to coordinate with related parties such as the industrial sector and academia to provide support in meeting the needs for medical oxygen gas for handling COVID-19 patients. Based on data from the Ministry of Health, as of July 6, 2021, the need for medical oxygen has increased to 2,333 tons/day, while the national capacity is at 1,758 tons/day. This means that there is a deficit of around 575 tons/day. Therefore, it is necessary to find additional sources of oxygen, either by increasing available production capacity or looking for other sources both localized and imported (see www.kemenperin.go.id/artikel/22640).

The use of pure oxygen in the industry is found in industries that produce steel, chemicals, petrochemicals, glass, ceramics, paper, and the recovery of non-ferrous metals. The application of pure oxygen in medical applications, especially surgery, outpatient care, and Chronic Obstructive Pulmonary Disease (COPD) patients to help patients breathe.

The use of zeolite as an adsorption medium can help increase energy use efficiency, increase process efficiency, increase processing rate, improve product quality, and reduce the environmental impact of the oxygen purification process. This paper reviews the use of Zeolite as a Pressure Swing Adsorption (PSA) adsorbent. In general, oxygen is used in various chemical processes and medical purposes around the world.

2. METHODS

This study is a literature survey. We took data from internet literature. Data was then compiled and analyzed to make summary. Detailed information for the way how to search data in explained elsewhere (Azizah *et al*., 2021).

3. RESULTS AND DISCUSSION

3.1. The Role of Oxygen

Oxygen used in the medical sector aims to:

(i) Oxygen to help the patient's breathing.
(ii) Used during conditions in the operating room to maintain the breathing of the patient who is being anesthetized (in medical surgery).
(iii) Used for the recovery of patients in the treatment room.
(iv) Used in patients in conditions curing pulmonary diseases or patients in critical condition (ICU, ICCU, NICU, PICU).
(v) Used to help newborns who are experiencing difficulties in breathing independently.
(vi) Used to help the breathing of victims exposed to fire smoke and or patients who are poisoned by CO gas or other gases.

The quality and content of oxygen required as medical oxygen gas must contain an average of 93% (Medical grade Oxygen 93) with the following conditions by WHO about Technical specifications for Pressure Swing Adsorption (PSA) Oxygen Plants: Interim guidance:

(i) According to Ph Eur: contains oxygen between 90.0%V/V and 96% V/V and other residual gases should only be nitrogen and argon.

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(ii) According to the USP: oxygen produced from the air with molecular sieve technology must contain oxygen of at least 90.0 % V/V and at most 96 % O2 V /V and the remaining gases should only be nitrogen and argon.

3.2. PSA Technology

PSA Technology can be explained in simplification in the following:

(i) This technology uses an adsorbent medium (zeolite, or porous medium) laid out in two adsorption columns for the desired separation of molecules.

(ii) The installation of 2 operation columns allows the generation flow rate to be carried out continuously.

(iii) This technology uses 4-step processes: Adsorption, Production, Blowdown, and Desorption.

A good design for adsorption-based gas separation processes depends on the dynamic behavior of the adsorbent/gas system. A commonly used assumption is that absorption in porous adsorbent media will be limited by mass transfer. The mass transfer of gases in porous adsorbents can become complex due to the presence of one or more mechanisms. Possible mechanisms are microporous diffusion (surface diffusion) mechanisms, Knudsen diffusion, macroporous diffusion, Poiseuille flow, transport across the surface barrier, and external mass transfer. In addition, changes in adsorbent temperature caused by the heat of adsorption can further complicate the dynamic behavior of gas absorption in the adsorbent medium.

This PSA technology has several advantages such as short start-up time, easy start and stop, low energy consumption, and relatively low operating costs, and can be made automated. For application in highland areas such as in China. PSA technology is the most economical technology [6]. One application of PSA technology is in development for medical oxygen concentrators that are planned to be used in manned space missions. Currently, the compressed oxygen tank placed on the International Space Station has several disadvantages including that this tank is dangerous, heavy, and the oxygen supply is limited. In addition, the continuous use of pure oxygen during medical treatment causes the allowable oxygen levels in the spacecraft to be rapidly exceeded. However, the current availability of PSA concentrator oxygen is too heavy and uses too much power for use in space. The development of lighter and more efficient medical concentrator oxygen devices is a comprehensive effort that must be realized immediately (Fu *et al*., 2021).

The separation technology using PSA consists of several columns containing adsorbents that are carried out with several stages of operation with a pressure step (pressurization) and a pressure removal step (depressurization) that runs successively alternating each other to produce a continuous flow of pure product gas and purity as expected (Mosca *et al*., 2010).

Gas preparation before entering PSA is by reducing the moisture content in the Silica Gel dryer:

(i) The purpose of this process is to reduce the moisture content and other impurity gases such as CO2 gas. (data: Air at 100% humidity has a water vapor content equivalent to 3%).

(ii) The high water content will interfere with the absorption performance of N2 and AR in the adsorbent and reduce the working efficiency of the adsorbent column.

(iii) The moisture content should be removed through Silica Gel or Alumina Gel. To obtain better efficiency, the silica gel regeneration process can be done with the help of a heating coil in the internal silica gel bed.

3.3. Zeolite as a PSA Adsorbent

Zeolite made from aluminosilicate crystals is widely used in adsorption, catalysis, membrane, and sensor technology. The separation of gases through the adsorption process occurs in zeolite which has a porous structure. This is due to the interaction between the dipole moment of the gas molecule and the electric field in the pores of the adsorbent (separation to the equilibrium point) (Mosca *et al*., 2008).

Zeolite can be classified according to the ratio of Si and Al. This classification is based on the range following ranges (Mosca *et al*., 2009).

(i) Low Silica Zeolite (1 < Si/Al < 5),
(ii) Medium Silica Zeolite (5 < Si/Al < 10) and
(iii) High Silica Zeolite (Si/Al > 10

Zeolite adsorbent is widely used in gas separation processes on PSA technology and is suitable for the purification of oxygen gas from the air by using low-silica-grade Na-X type zeolite (Mosca *et al*., 2010). Zeolite X which is low in silica in the form of bonding with Li^+ (Li-LSX) has a higher level of selectivity to N_2 gas than NaX type zeolite, this is due to the higher polarization power of Li+ cations so that type x zeolite is widely used as zeolite adsorbent in the air separation process (Mosca *et al*., 2010).

Zeolite adsorbents consist of several small-sized zeolite crystals formed into larger pellets or beads. Type zeolite crystals such as Na-X, mass transfer is expected to occur quickly due to the relatively large dimensions of the zeolite pore opening (0.74 nm).

3.4. Design of Unit Oxygen Concentrator Arrangement

Detailed information regarding the oxygen concentrator arrangement is shown in **Figure 1**. The equipment consists of several points: Compressor, Cooling tubes, POT KO Fund, Dryer Tube (Silica Gel Dryer), Adsorption Column, Oxygen storage tube, Filter, Regulator O_2, User Indicator, and User O_2 Mask The adsorption column is designed to be able to take advantage of the adsorption heat from the column under operation to warm the column that is in the desorption stage. Thus, the removal of nitrogen gas will be perfect. The installation of both columns is shown in the configuration as per **Figure 1**. The two columns are placed as close as possible to facilitate heat exchange between the two columns. The heat difference of around 10°C can be used to increase equipment efficiency.

The inlet gas feed is also designed to be able to cool the zeolite fixed bed. The method used is to put an incoming feed pipe in the middle of the zeolite, so that it also cools the zeolite that is operating to absorb nitrogen gas. It is hoped that the cooling of this feed pipe will also increase the efficiency of nitrogen gas absorption. **Figure 2** is for the design of the zeolite column. Around the column, a gas product output pipe that has a higher temperature is also placed in a column that is being desorbed, so that the column will be heated and make the release of nitrogen gas from zeolite more and produce better efficiency.

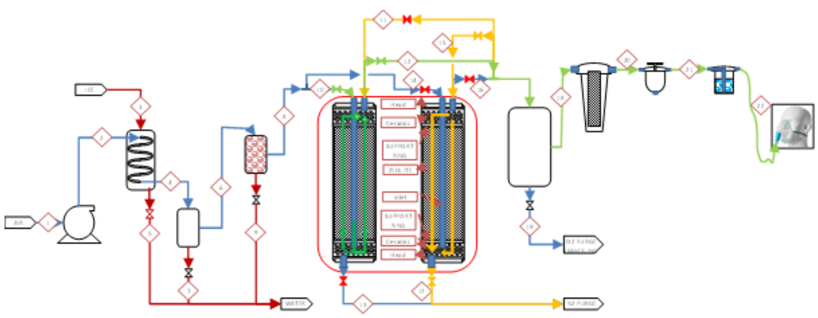

Figure 1. Unit O_2 concentrator arrangement.

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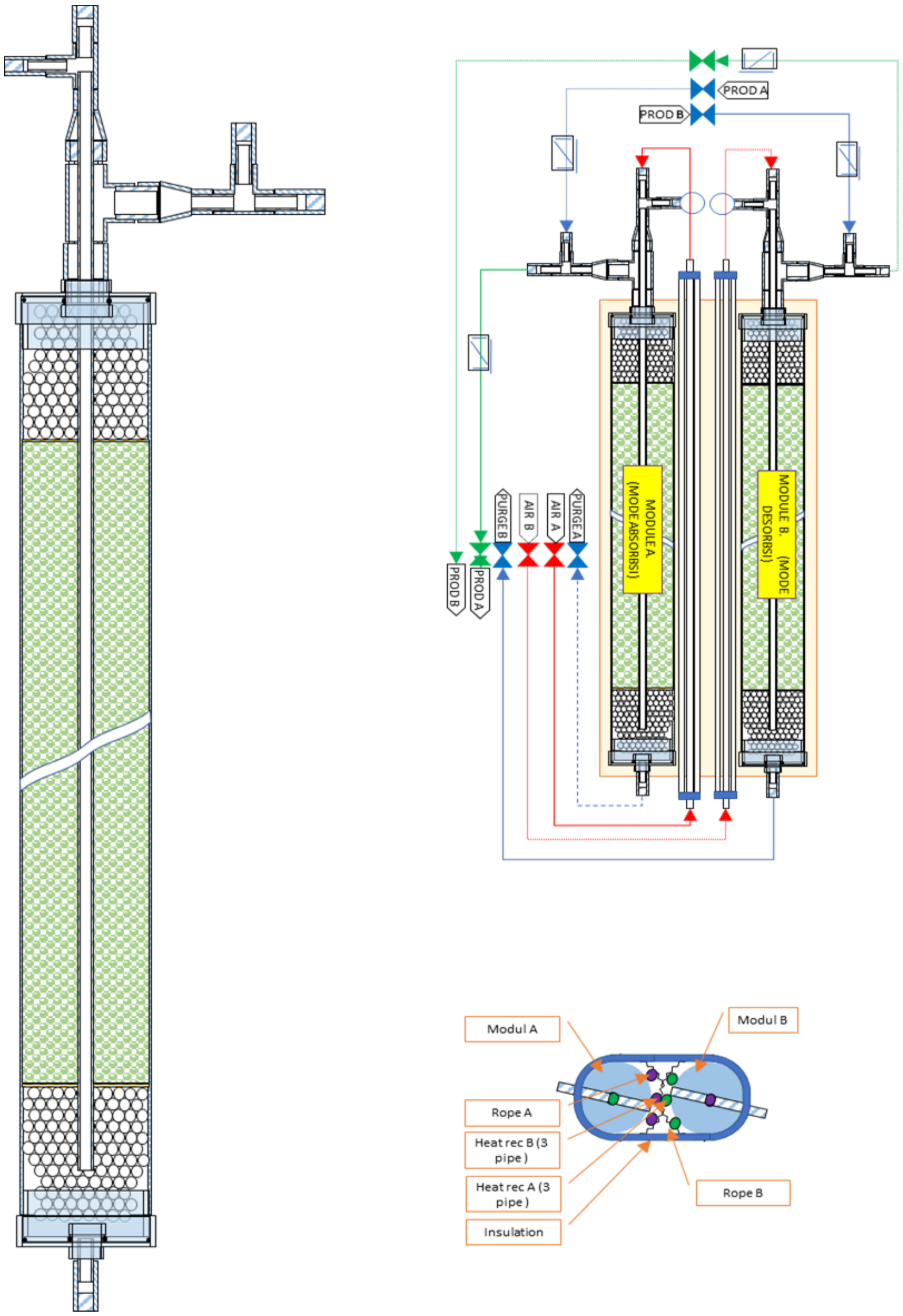

Figure 2. Column equipment design O_2 concentrator (Adsorption).

Description of how the equipment works.

(i) a unit of oil-free type compressor will be operated to produce compressed air of 4 kg/cm^2.G and a pressure of 25 °C with a moisture content of about 2.2%.

(ii) The air from the compressor is then sent to the cooling tube unit which contains ice water as a cooling medium. The air coming out of this cooling unit is targeted to reach 10 °C. Thus, it can reduce the moisture content in the compressed air to about 1.1%.

(iii) This cold air is then put into the KO POT Tube to trap the water vapor that has condensed. Thus, the air will be drier.

(iv) This air is then passed to the Silica Gel Dryer unit to be able to produce water vapor-free air (dry air).

(v) This dry air is then passed to the adsorption column for the separation process of O_2 from other gases. Air at the initial stage will be fed into the adsorption column A for the

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absorption of nitrogen gas and argon gas by zeolite media. The rest of the oxygen-filled air will continue to pass through the column to the oxygen storage tube.

(vi) Under the same condition as the adsorption column B, we lowered the pressure to remove nitrogen gas and argon gas trapped in zeolite. The operation of the two columns will alternate between column A and column B

(vii) The collected oxygen is then sent to the Filter to eliminate the possibility of zeolite particles being carried away.

(viii) Clean oxygen is lowered the pressure to the appropriate pressure for the patient/user to use through the O_2 Regulator.

(ix) Oxygen will flow to the Indicator User unit to see the movement of oxygen to the user.

(x) Oxygen ready to use via User O_2 Mask tool.

4. CONCLUSION

This paper shows the apparatus for the use of Zeolite as an adsorbent in the Pressure Swing Adsorption (PSA) technology for oxygen concentrator. In general, oxygen is used in various chemical processes and medical purposes around the world. During the COVID-19 pandemic, the need for medical oxygen has increased sharply in all hospitals in the world. Efficient operation of the PSA process is required to utilize the adsorbent capacity as much as possible and reduce the processing power requirements. This paper can give additional information regarding the zeolite as the adsorption for supporting PSA in oxygen production.

5. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

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