Chapter 9
Print ISBN: 978-93-48859-41-9, eBook ISBN: 978-93-48859-27-3

Affordable Oxygen Concentrator with PSA Technology

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DOI: https://doi.org/10.9734/bpi/erpra/v1/3772

Peer-Review History:
This chapter was reviewed by following the Advanced Open Peer Review policy. This chapter was thoroughly checked to prevent plagiarism. As per editorial policy, a minimum of two peer-reviewers reviewed the manuscript. After review and revision of the manuscript, the Book Editor approved the manuscript for final publication. Peer review comments, comments of the editor(s), etc. are available here: https://peerreviewarchive.com/review-history/3772

ABSTRACT

Atmospheric air typically consists of a mixture of gases, including nitrogen (78%), oxygen (21%), and trace amounts of other gases such as carbon dioxide (0.03%) and hydrogen. An oxygen concentrator is a device designed to extract and concentrate oxygen from ambient air by selectively removing nitrogen through a process known as Pressure Swing Adsorption (PSA). PSA technology is commonly used in oxygen concentrators, as it efficiently separates oxygen from the air using two adsorbent materials, typically zeolite. This process makes PSA-based concentrators more reliable and energy-efficient for delivering oxygen at medical-grade purity.

PSA works by exploiting the molecular properties and affinity of gases for a zeolite (such as Natrolite) under varying pressure conditions to separate oxygen from the air. The oxygen concentrator utilizing this PSA technology is both cost-effective and efficient. Experimental results show that the system can produce oxygen with a purity of approximately 94.7% at flow rates of 0.5-3 L/min. This meets the needs of patients with Chronic Obstructive Pulmonary Disease (COPD), who require oxygen with a purity of at least 90% at similar flow rates.

When compared to commercially available oxygen concentrators, the proposed system stands out for being highly cost-effective, lighter in weight, and producing less noise. Additionally, it demonstrates long-term efficiency with high oxygen purity. These features make it an ideal solution for individuals who cannot afford expensive oxygen concentrators available on the market.

Keywords: Atmospheric air; mixture of gases; oxygen concentrator; separating oxygen; pressure swing adsorption; zeolite.

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1. INTRODUCTION

An Oxygen Concentrator is a therapeutic device that filters out oxygen from atmospheric air by particularly removing nitrogen such that an oxygen-rich air supply is produced by the process of pressure swing adsorption [1,2]. Pressure swing adsorption (PSA) technology is a process used to separate specific gas from a mixture of gases (ambient air) under pressure and molecular properties and affinity of gas to an adsorbent material [3-6]. There are many techniques for the separation of gas from a mixture such as cryogenic distillation etc., but PSA technology is widely used to separate nitrogen (N2) from the atmospheric air, concentrating the remaining oxygen (O2) to a known purity [7,8].

Virendra Kumar. et. al., (2023) suggested that Nanosized zeolites have the potential to be a game-changer in the delivery of pure oxygen to the patient in the face of current and future pandemics caused by a wide range of viruses and bacteria.

Economical Synthesis of Oxygen to Combat the COVID-19 Pandemic (2023) - This paper reviews various medical oxygen synthesis and storage methods, including PSA technology, and discusses their economic aspects.

Ion Transport Membranes for Oxygen Production (2021) - This study explores the use of ion transport membranes for producing high-purity oxygen at low costs.

C.A. Grande [9] suggested the fundamentals of the PSA process while focusing specifically on different innovative engineering approaches that contributed to continuous improvement of PSA performance through circulating air over an adsorbent media, this process produces concentrated oxygen as the output gas, making it well-suited for air separation.

C.C. Chao and S.J. Pontonio, (2002) suggested a range of operating conditions from which to determine how to best utilize the zeolite to develop larger PSA processes. Also, it was found that this novel zeolite is in fact an enhanced zeolite with a fast adsorption rate capable of supporting rapid PSA processes.

Urich M.D [10] explained the adsorption and desorption rate of nitrogen on zeolite 5A is less than zeolite 13X.

2. METHODOLOGY

There are five steps involved in the oxygen concentrator process shown in Fig. 1:

1. Takes air from the atmosphere and compresses the air by compressor.
2. A coolant system is employed to reduce temperature
3. Removal of nitrogen from the air by allowing air to pass through sieve adsorbent using PSA technology.
4. Store the gas from the output of the sieve canister in an oxygen tank [11].

5. Deliver pure oxygen to the patient via an oxygen mask.

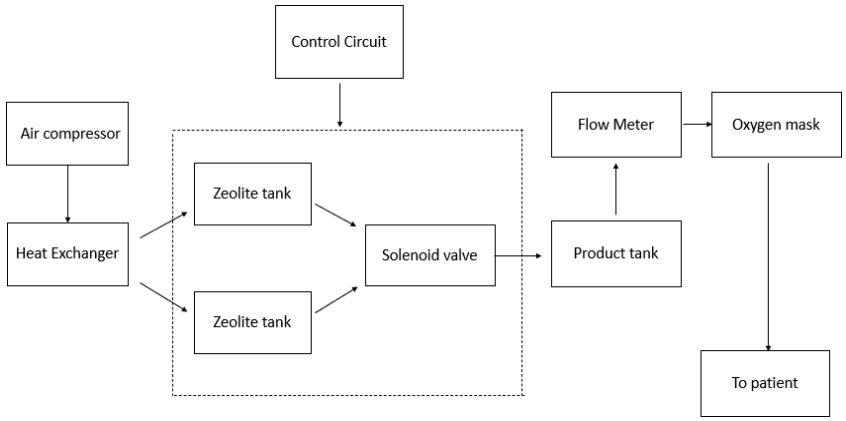

Fig. 1. Block diagram of oxygen concentrator

3. HARDWARE IMPLEMENTATION

The above Fig. 2 clearly describes the process of composing a set product involved in the oxygen concentrators. This can be explained as follows.

Oxygen concentrators are medical equipment that advise people with low levels of oxygen in the blood. They are powered by connecting the appliance to an electric outlet or by using a battery. If a battery is used, it will need to be recharged by plugging it into an electrical outlet [11]. Most hubs are also equipped with an adapter so you can use the unit while driving.

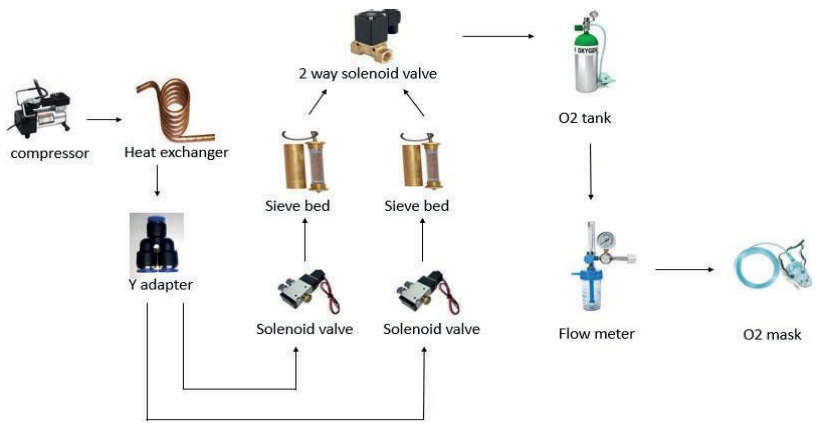

Fig. 2. Oxygen Concentrator flow diagram

The oxygen concentrator takes in air, cleans it, and disperses the newly formed air. Before entering the concentrator, 80 percent nitrogen and 20 percent oxygen. Oxygen concentrators use this air and come out as 90-95 percent pure oxygen and 5-10 percent nitrogen [11]. Since it is difficult to obtain this percentage of oxygen without the help of medical devices, nitrogen is separated to give the patient the highest possible oxygen dose.

3.1 Compressor

A compressor is a gaseous device that converts power into potential energy stored in high-pressure air (compressed air). The energy composed in the compressed air can be used for focusing the kinetic energy of the air as it is discharged and the container depressurizes the air. The compressor absorbs the ambient air from the atmosphere and adjusts the pressure at which it is needed. A compressor is necessary for delivering pressurized air to the sieve chamber such that the adsorbent material adsorbs nitrogen [11]. The power of the air compressor is measured in horsepower (HP). The pressurized air as an output of the compressor is given to a coil of copper tube for reducing the temperature.

3.2 Solenoid Valve

The solenoid valve is an electrically controlled valve that has an electric coil with a portable ferromagnetic core (plunger) in the middle. It has a plunger that ends off a small cavity. Electric current over the coil generates a magnetic field. It is an electromechanically fulfilled valve [11]. They differ in the component of the electric current used and the vitality of the magnetic field that is created. They can be used in the extensive design of automated operations, on-off management, and adjustment development of control systems.

3.3 Sieve Materials

Zeolite is a natural chemical material for separating oxygen and nitrogen in the ambient air. Zeolites are large penetrable beads having a surface area of about 500 square meters per gram (GSM). At large pressures in the list, nitrogen is in a compact grasp, chemically along with the zeolite. Zeolites that are used are hydrated aluminosilicate mineral of natrolite that has an affinity towards nitrogen. The zeolite size used is 13x which has a diameter of (0.3-1.5) mm [11] The chemical formula for zeolite used here is [Na12 (AlO_2)12(- SiO_2)12.27H2O]8. It absorbs nitrogen from the ambient air to give oxygen as the output.

3.4 Pneumatic Connection System

Pneumatic tubes (or) Pipes that are used to suck and blow air act as propel cylindrical container system networks. They are widely used to carry compressed air. Pneumatic pipes are often made of an extruded set of nylon polymer along with polyurethane, and polyvinylchloride that have the ability to withstand high pressure [11].

3.5 Pressure Swing Adsorption

Pressure swing adsorption (PSA) technology is a process used to separate gas from a mixture of gases (atmospheric air) under pressure and according to the specific molecular properties and affinity of gas to an adsorbent material. PSA is a technology large enough to separate nitrogen (N_2) from the atmospheric air, concentrating the remaining oxygen (O_2) to a known purity [11].

The pressure swing adsorption process split into oxygen and nitrogen from the air Due to different adsorption of oxygen and nitrogen to the zeolite adsorbent Two different pressures near and above atmospheric pressure. The high quadrupole moment of nitrogen causes a high adsorption affinity for oxygen and argon. Zeolite material [11]. The PSA cycle operates at ambient temperature between supermarkets Atmospheric pressure becomes a gas due to the large adsorption of nitrogen from the air.

4. SOFTWARE IMPLEMENTATION

An IDE for the Arduino microcontroller. Arduino is a free software electronics prototyping platform based on flexible, easy-to-use hardware and software. It's in- tended for artists, designers, hobbyists, and anyone interested in creating interactive objects or environments. This IDE allows for program writing, code verification, compiling, and uploading to the Arduino development board. Libraries and example codes will also be installed [11]. The Arduino Software (IDE) on the computer, according to its operating system. Windows, Mac OS x10.1, Linux 32 bits, Linux 64 bits, Linux ARM etc.

5. APPLICATIONS OF PROPOSED MODEL

Affordable oxygen concentrators using Pressure Swing Adsorption (PSA) technology have several key applications, particularly for individuals with respiratory conditions or those requiring supplemental oxygen. These concentrators offer a cost-effective and efficient solution for oxygen therapy, especially for home care and portable use. Here are some of the primary applications:

5.1 Home Oxygen Therapy for Chronic Respiratory Diseases

Conditions: Chronic Obstructive Pulmonary Disease (COPD), asthma, emphysema, bronchitis, pulmonary fibrosis, and other chronic respiratory conditions.

Affordable PSA-based oxygen concentrators provide patients with continuous or pulse-dose oxygen therapy at home, improving their oxygen saturation levels, reducing shortness of breath, and enhancing overall quality of life.

5.2 Portable Oxygen for Active Lifestyles

Conditions: COPD, emphysema, pulmonary hypertension, or any condition that requires intermittent or continuous oxygen supplementation.

Portable PSA oxygen concentrators are lightweight and easy to carry, allowing patients to maintain an active lifestyle. These concentrators are ideal for people who need oxygen while traveling, shopping, exercising, or performing daily tasks outside their homes.

5.3 Emergency Oxygen Supply

PSA oxygen concentrators can be used in emergency situations for individuals requiring immediate oxygen support, especially in areas with limited access to compressed oxygen tanks or when a consistent oxygen supply is needed for longer durations.

5.4 Oxygen Therapy for Sleep Apnea

Conditions: Obstructive Sleep Apnea (OSA)

Some patients with severe sleep apnea or oxygen desaturation during sleep can benefit from supplemental oxygen. Affordable PSA concentrators can provide a continuous oxygen supply during sleep to maintain oxygen saturation levels and reduce the risk of health complications.

5.5 Post-Surgical Recovery

Patients recovering from major surgeries, especially those involving the chest or respiratory system, may need supplemental oxygen during recovery. PSA concentrators can provide a cost-effective, reliable solution for home oxygen therapy during this period.

5.6 Supporting Elderly or Bedridden Patients

Elderly individuals or patients who are bedridden due to illness often require continuous oxygen therapy. Affordable oxygen concentrators are ideal for this use, as they are compact, efficient, and do not require frequent refills, making them easy to manage for caregivers.

5.7 Improvement of Oxygen Levels During Exercise

Some individuals with chronic respiratory conditions may benefit from supplemental oxygen during exercise or physical rehabilitation. PSA oxygen concentrators can deliver a steady supply of oxygen to improve stamina, reduce fatigue, and help patients engage in physical therapy or rehabilitation programs more effectively.

5.8 Oxygen for High-Altitude Environments

Individuals who live or travel to high-altitude regions may experience lower oxygen levels. Portable oxygen concentrators using PSA technology can be used to provide supplemental oxygen and prevent altitude sickness or hypoxia, especially for those with pre-existing lung conditions.

5.9 Medical Facilities and Clinics with Limited Resources

In medical clinics or healthcare settings with limited resources, affordable PSA oxygen concentrators can be used to provide oxygen therapy to multiple patients without the need for costly oxygen tanks or expensive equipment. They are particularly useful in rural or underserved areas.

5.10 Oxygen Therapy for Babies and Children

Conditions: Premature birth, chronic lung diseases, or congenital conditions affecting the lungs.

In cases where infants or children require supplemental oxygen, PSA-based oxygen concentrators can provide a reliable, consistent source of oxygen at home, reducing the need for hospital stays.

5.11 Aviation and Pilots

Use: Affordable PSA oxygen concentrators can be used by pilots or individuals traveling in aircraft at high altitudes, where oxygen levels are lower. These concentrators help maintain proper oxygen saturation levels during flight, particularly in small aircraft.

5.12 Oxygen for Medical and Wellness Spas

Some wellness centers or spas offer oxygen therapy to enhance relaxation, improve skin health, and boost energy levels. Affordable PSA concentrators are used to provide a controlled supply of oxygen for clients in these settings.

In summary, affordable oxygen concentrators with PSA technology offer a wide range of applications, from providing home-based oxygen therapy for chronic conditions to enhancing mobility and supporting overall health and wellness. They are valuable tools for improving the quality of life for individuals with respiratory challenges.

Advancements:

1. Financially beneficial so that everyone can be used.
2. Produce a sufficient amount of oxygen required.

Output:

The experimental results showed that the proposed system supplied the oxygen at a purity of about 94.7% for the low velocities of 0.5-3 L/min. It is concluded that the system provides good performance when considering that a patient with COPD should take oxygen at a purity of 90% or more for the low velocities of 0.5-3 L/min [11]. The proposed system image is shown in Fig. 3 and Fig. 4.

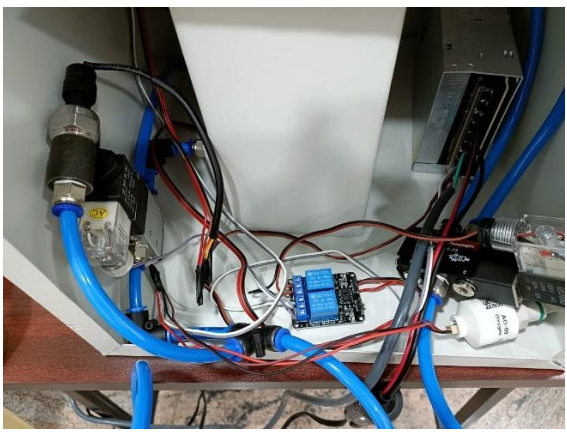

Fig. 3. Components of the proposed system

Fig. 4. Prototype model of proposed system

6. CONCLUSION

This proposed system is highly beneficial for home-care patients who require regular oxygen, such as those with asthma, bronchitis, emphysema, and other respiratory conditions. Compared to other oxygen concentrators on the market, this system is not only more cost-effective but also lighter in weight [11]. Based on experiments conducted with the system, it operates with lower noise levels, demonstrates long-term efficiency, and maintains high oxygen purity. These features make it an ideal option for individuals who cannot afford the more expensive oxygen concentrators available commercially. The oxygen concentrator market is dominated by portable devices, which are particularly useful for COPD patients due to their portability. As asthma prevalence increases and more people adopt portable oxygen concentrators, the market is expected to experience significant growth.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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DISCLAIMER
This chapter is an extended version of the article published by the same author(s) in the following journal.
Cardiometry, 25: 82-185, 2022.
Available:https://cardiometry.net/issues/no25-december-2022/cost-efficient-oxygen

Peer-Review History:
This chapter was reviewed by following the Advanced Open Peer Review policy. This chapter was thoroughly checked to prevent plagiarism. As per editorial policy, a minimum of two peer-reviewers reviewed the manuscript. After review and revision of the manuscript, the Book Editor approved the manuscript for final publication. Peer review comments, comments of the editor(s), etc. are available here: https://peerreviewarchive.com/review-history/3772