Oxygen Enrichment Unit Using Pressure Swing Adsorption Technology with Monitoring System

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Abstract

Oxygen is a necessary medication for the treatment of lung diseases. To adequately address the extraordinary rise in demand on our healthcare systems produced by the COVID-19 epidemic, imaginative changes are required. According to Chinese data, 40% of responders COVID-19 experience symptoms, 15% have severe symptoms requiring oxygen therapy, and 5% will be very sick requiring intensive care unit treatment. Home treatment and monitoring of asymptomatic or moderately unwell sufferers can be easily adapted to reduce the load on the healthcare system while preserving the safety and efficacy of therapy. According to the necessity of oxygen, we have contributed a medical device that filtration ambient air via molecular sieve beds to concentrate room oxygen using PSA (pressure swing adsorption) technology, which separates nitrogen from oxygen in the ambient air to therapeutic levels for patient administration. The supply of concentrated oxygen to the patient to improve and stabilize glycated hemoglobin levels is known as oxygen therapy for the treatment of hypoxemia. In developing-country contexts, this device is a suitable and preferable choice for providing point-of-care oxygen, particularly if cylinders and piped systems are ineffective or unavailable.

Introduction

Oxygen is a critical feature of human life, it is the basis of the cellular respiration process in humans and animals, where oxygen gas constitutes (%20.94) of the composition of the Earth's atmosphere, although it is often overlooked as a life-saving essential medicine due to its natural availability through the air. The patient's life or death depends on the prompt supply of medical oxygen. When it comes to the continual availability of medical oxygen, hospitals usually priorities it over the rest. Governments from all over the world responded to the COVID-19 pandemic's medical emergencies. The WHO (World Health Organization) says that 15 percent of COVID-19 patients require medical oxygen because of breathing difficulties. There is a chance hospital stay can reduce to a certain extent. Therefore, stable patients who are in home isolation, with oxygen saturation of 94% and this which we are looking forward to designing and carrying out oxygen enrichment unit using PSA (pressure swing adsorption) technology with monitoring for isolated patients in the home and reducing the burden on hospitals.

This technology we use for obtaining pure oxygen works by selective adsorption capability of a component on a suitable adsorbent to separate some gas species from a gas mixture under pressure according to the molecular characteristics of the species and affinity for an adsorbent material. Accordingly, the Oxygen production process needs specific sequential stages and accurate calculations of pressure and airflow inside the system to make this technology works effectively.

1-How does it work?

It is an air purifier that circulates room air via a series of filters to remove dust, germs, and other contaminants. Air is forced into one of two cylinders holding a molecular "sieve" substance, then concentrated oxygen and a tiny amount of other gas are passed. Nitrogen is desorbed and sucked out of the atmosphere in the other cylinder at the same time. The function of the cylinders is reversed in a timed cycle in the second stage, delivering a constant flow of oxygen to the patient. A typical oxygen enrichment unit may deliver oxygen flows of 0.5–5 Liter per minute (low flow oxygen enrichment units), while some models may generate up to 10 Liter per minute(high-flow oxygen enrichment units)[1]. Mainly the OEU (oxygen Enrichment Unit) consists of three phases before the patient: pre-treatment phase, treatment phase, and pre-patient phase.

2-Pre-Treatment Phase

This stage is the first and is responsible for providing all the appropriate conditions to ensure that the pre-treatment process is completed correctly to obtain the best percentage of oxygen. It is consisting of three stages: filtration, feeding, and cooling.

A. Filtration Stage

To keep the air compressor safe, prevent dust and odors from accumulating inside it, the air is filtered.

B. Feeding Stage

This stage starts with the air compressor, which comprises air into the device at a specific pressure, which varies depending on the amount of oxygen to be produced per minute.

C. Cooling Stage

A heat exchanger (copper coil), a cooling fan, or a filter containing silica gel accomplish this stage. To avoid collision with zeolite and to prevent condensation of water vapor, and thus to avoid zeolite damage.

3-Treatment Phase

This stage is the device's heart, and it oversees gas separation and generating a high percentage of oxygen. Two cylinders containing zeolite alternately work to produce a steady flow of the resultant oxygen in this stage.

A. *Gas Separation*

Separation is based on selective adsorption of one or more components of a feed gas mixture on a solid adsorbent to generate a gas stream richer in the less strongly adsorbed components, followed by desorption of the adsorbed components to clean the adsorbent for reuse. The following are the three most prevalent ways for separating oxygen and nitrogen from the air: Cryogenic distillation, Membrane Separation, and Adsorption processes[2]. The method used in the separation process is a type of adsorption process, and therefore because of the unique advantage of adsorption over other separation methods is the higher selectivity that can be achieved by adsorbents. in addition, adsorption phenomena play a vital role in many solid-state reactions and biological mechanisms.

PSA (pressure swing adsorption) works with a component's selective adsorption capacity on a suitable adsorbent. PSA technology separates some gas species from a gas mixture under pressure based on the species' molecular properties and affinity for an adsorbent material as shown in figure 1. The temperature of this procedure is close to that of ambient air. To adsorb the target gas species at high pressure, specific adsorptive materials such as zeolites, activated carbon, and molecular sieves are utilized as adsorbents. After that, the process switches to low pressure to desorb the adsorbed

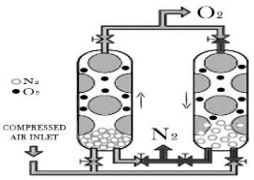

Figure 1 pressure Swing Adsorption Process

material.

B. Molecular Sieves

Adsorption takes place on solid material. The Adsorbent is an additional component in the adsorption process that plays a critical role. In industry, adsorbents such as Active Carbon, silica gel, silicates, activated clays, synthetic zeolites, natural zeolites (Clinoptilolite, Erionite, Mordenite), 4A, 5A, 13X molecular sieves, and activated alumina are employed.

Many adsorbents are employed in separation and purification procedures, including zeolites. Adsorbents are microporous materials that allow adsorbate molecules to move freely within the adsorbent while also providing a large surface area for guest molecules to interact with the solid surface.

C. Zeolites

Zeolites are crystalline aluminosilicates with three-dimensional microporous structures. They have been used as ion-exchangers, catalysts, and adsorbents in various fields such as oil refining, petrochemistry, agriculture, and water and wastewater treatment[3].

Synthetic Zeolites (13X): chemical formula (Na86[(AlO2)86 (SiO2)106] • H2O) and its properties are shown in Table 1 [4].

Table 1 Properties of 13x zeolite

Chemical Name	Na86[(AlO2)86(SiO2)106] •H2O
Pore Diameter	~10Å
Mesopore Volume	0.165 cm3 /g
Micropore Volume	0.17 cm3 /g
Langmuir Surface Area	571 m2 /g
Mass of Pellet Sample	2.37 g
Mass of Crushed Sample	2.49

D. Sieve Beds

A sieve bed is a filter inside the oxygen Enrichment Unit that Separates the nitrogen from the oxygen in the air. This filter uses a material, zeolite, to collect all the nitrogen in the air. We have used PVC pipes as an alternative to aluminum columns to be more economic. Using Steel wool, Abrasive cleaning pads, and Cotton as filters.

G. Assumptions for Local Equilibrium Model for Pressure Swing Adsorption

No flow maldistribution or dead volume ⇒ axial dispersion term is negligible. No concentration gradients within zeolite particles or film surrounding particles. Isothermal plug flow with constant velocity as shown in equation (1)[5].

$$(\varepsilon * (\partial C_{N2}/\partial t)) + (\rho_B * (\partial q_{N2}/\partial t)) + ((Q_{air}/A_{air})/(\partial C_{N2}/\partial t)) = D_Z(\partial^2 y/\partial^2 x) \quad (1)$$

$$\tau_c = (\varepsilon + \rho_B * (\Delta q_{N2}/\Delta C_{N2})) * (V_{bed}/Q_{air})$$

ρB = density of zeolite.

ε = void fraction.

ΔqN2 / ΔCN2 = adsorption isotherm.

V bed = volume of zeolite bed.

Q air = volumetric flow rate of air [5].

4-Pre-Patient Phase

At this stage, appropriate conditions are prepared for the patient.

A. Storge Stage

At this stage, the oxygen leaving the cylinders is stored to prevent pulsation in the flow and its arrival to the patient is a steady stream.

B. Pressure Regulation Stage

The pressure is reduced and held at a certain peak by a voltage regulator.

C. *Oxygen Enrichment Monitoring Stage*

The safety of the process is monitored by measuring the percentage of oxygen leaving the cylinders using the ultrasonic oxygen sensor, and through the measurement, it gives an alarm to the operator.

D. Flow Control Stage

The rate of oxygen flow is controlled according to the patient's condition by a flowmeter.

E. Filtration (Bacterial Filter)

Removes bacteria and contaminants.

F. Humidification Stage

It is a humidifier to moisten the oxygen before it reaches the patient, because the dry oxygen is due to the dryness of the nose, and if it continues, bleeding occurs in the patient's nose.

5-Control Phase

Not only in biomedical equipment, but in all devices around us, the software is critical. All devices and instruments, regardless of function, will soon contain software in some form. If we consider hardware to be the body of any piece of equipment, then the software is the spirit of that piece of equipment.

A. Software

The software is how we can reach the device's target. We decided to do timer programming. In our device, until we achieved our goal. Using a timer to control entry, the exit of air from the compressor to the cylinders via valves, and oxygen delivery from the cylinders to a tank to be stored. The timers are controlled by a pic microcontroller (pic18f452)[6].

B. Hardware

The hardware is the physical structure of any piece of equipment. This device is made up of several parts, which we will go over.

a- Power Supply (linear power supply): Using a dipped transducer, work is being done to convert a high voltage (220 volts) to a low voltage (12-24 volts) And converting AC voltage to DC voltage by using a rectifier circuit.

b- Interface Circuit: This circuit connects the pic microcontroller to the circuit that powers it. This circuit uses a transistor and a relay to power solenoid valves.

c- Solenoid Valves: This device has three valves. Two of them are located beneath the cylinders of the type normally close three-way two positions used to control the entry of air into the cylinders. The last one is an equalization valve, which is located above the cylinders is used to control the exit of air from the cylinders, as well as the oxygen tank and the exit of nitrogen from the cylinders.

d- Sensors: An oxygen sensor is an electronic device that measures the proportion of oxygen (O2) in the gas or liquid under investigation. The ultrasonic oxygen sensor detects gas flow and oxygen purity for oxygen concentrators by measuring the ultrasonic velocity difference between upstream and downstream. The most significant advantage of ultrasonic technology is that it does not require routine calibration and has a long life span.

The fundamentals of ultrasonic technology*:* Theory of ultrasonic flow detection: When an ultrasonic wave travels through a fluid, it carries flow velocity under the influence of fluid velocity. Fluid velocity can be calculated by detecting the received ultrasonic signal and multiplying it by the fluid flow rate.

6-Monitoring System

Continuous monitoring of patient parameters such as heart rate and rhythm, temperature, SpO2 (known as oxygen saturation, is a measure of the amount of oxygen-carrying hemoglobin in the blood relative to the amount of hemoglobin not carrying oxygen.), and a variety of other parameters has become a standard part of critical care. Electronic monitors are widely employed to collect and show physiological data when precise and timely decision-making is critical for effective patient care.

Non-invasive sensors are increasingly being used to collect data from less seriously ill patients in hospital medical-surgical units, labor and delivery suites, nursing homes, and patient's homes to detect unexpected life-threatening conditions or efficiently record routine but required data. We usually think of a patient monitor as something that watches for and warns against serious or life-threatening events in patients, critically ill or otherwise. Patient monitoring can be rigorously defined as "repeated or continuous observations or measurements of the patient, his or her physiological function, and the function of life support equipment, to guide management decisions, including when to make therapeutic interventions, and assessment of those interventions[7].

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