Development of Portable Oxygen Concentrator- A Review

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Abstract. The Covid-19 Pandemic, with its first ever reported case in the Wuhan province of China in the year 2019, has led to a newfound global demand for Medical Oxygen supply at a sudden and unprecedented rate. In India, people battled to breathe as oxygen demand shot up with a sudden surge in COVID-19 cases the year 2020. The additional requirement of oxygen was tried to be fulfilled by various means such as oxygen generators installed at hospitals, transported medical as well as Industrial liquid oxygen, oxygen cylinder and oxygen concentrator. During the Covid-19 outbreak, large crowds gathered outside hospitals, and many patients were treated at home, breathing with the assistance of an oxygen concentrator and cylinders. However, cylinders must be refilled, whereas unlimited supply of medical grade oxygen can be obtained by oxygen concentrator if a power backup is maintained. In addition to this, safety, cost and size are the additional features of oxygen concentrator. It is a boon for the sufferer at the initial stage or even after treatment of covid-19, which is made available anywhere. In this paper, an attempt has been made to study an oxygen concentrator in which the principle of Pressure Swing Adsorption (PSA) method is used for oxygen separation. In addition to this, some trends of recently evolved developments in oxygen concentration methods are also reviewed for the readers' reference. This effort will help to develop the oxygen concentrator to fulfill the demand of oxygen at local level during the waves of Covid or similar incidences in future.

Key Words: COVID-19; Oxygen concentrator; Pressure swing adsorption; Zeolite

1. Introduction

The corona virus which causes Covid-19 can be kept away by using mask where as vaccine provides shield to the human being against the effect of corona virus on the body. And, external supply of medical oxygen grants the extra hours and days to patients for the medical treatment to save the life as he suffers from oxygen starvation. The medical oxygen is generated in specialized oxygen manufacturing plant which is purified up to the 93 percent. Human respiration needs a minimum oxygen concentration of 19.5 percent in the air.

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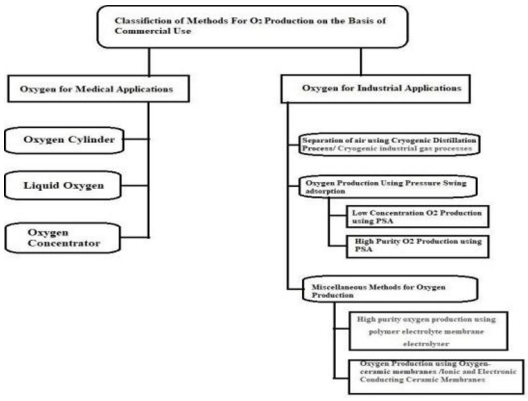
The air in the atmosphere, for the most part, has the right amount of oxygen for safe breathing. However, other harmful gases reacting with oxygen can cause its amount to decrease. There are a few distinct gases that make up the regular air in our environment. Nitrogen gas makes up roughly 78 percent of the air, while oxygen makes up only about 20.9 percent. The remaining percent is mostly argon gas, with quantities of carbon dioxide, neon, and helium mixed. The Occupational Safety and Health Administration (OSHA) estimated that humans require between 19.5 and 23.5 percent oxygen from the air [1]. Humans consume approximately 550 litres of pure oxygen every day [2]. When the body is deprived of oxygen, it goes into defensive mode: the heart's rhythm shifts, increasing the risk of acute pulmonary cardiac arrest; there's brain-to-body dysfunction, causing restlessness, disorientation, confusion, and dizziness [3]. Each patient in the Covid-19 study is unique. Some patients need 1 to 2 litres of oxygen per minute. This demand may increase t 3 to 4 liters per minute depending upon the deterioration of capacity of absorbing the oxygen in the lung. However, certain patients may require high flow nasal cannula (HFNC) support. Their oxygen consumption rate could be as high as 60 liters per minute. [4]. The varying demand of quantity of oxygen to the patient can be fulfilled by various means such as oxygen concentrator, cylinder, oxygen plant, etc. depending upon the severity of patient.

During pandemic, shortage of supply of oxygen was experienced as oxygen refilling centers are located at long distances in several states and therefore supply of oxygen at hospitals in time requires special transportation systems. Certain limitations of other sources of oxygen enhance the significance of oxygen concentrator as it provides continuous supply of oxygen. This convenient device provides one to ten liters of oxygen per minute, however they are not recommended for ICU patients who require more oxygen. This system absorbs and filters ambient air while producing medical-grade oxygen in an unending supply, as long as the device's battery is charged. While the concentrator does not need to be refilled, it does require a constant supply of electricity.

2. Classification of various methods for O2 production

There are several methods for producing the oxygen (O2). Oxygen is employed in a variety of applications across a wide range of sectors, mainly: Industrial and Medical. The methods of oxygen production can broadly be classified as given below:

Fig. 1 Classification of various methods for O_2 production



3. Medical use of oxygen

Oxygen is used on regular basis in different industries, including health systems and is available in market for industrial and medical use. Industrial use oxygen is different from medical oxygen in purity and quality. Thus, medical and industrial use is not interchangeable. Oxygen is used to treat illnesses like Covid-19 and hypoxemia [5]. J.C. Inkrott et al. (2021), proposed that for more than 20 years, the intensive care unit (ICU) environment has been in use. The physiology of high-flow oxygen (flows of 40-60 L/min, fraction of inspired oxygen [FIO2] up to 100%) for the adult population causes pharyngeal washout, which results in dead space in the pharynx. With modest concentrations of positive ions, it can yield exact FIO2s end-of-inhalation pressure (PEEP) [6].

Fig. 2 HHFNC set-up [6]

Moll et al., investigated that the oxygen from oxygen concentrator is medically safe for use in anesthesia. They have carried the study in association with nitrous oxide. In a semi-closed re-breathing circuit, the percent of oxygen from a concentrator was compared to the percent of nitrous oxide. Sixty patients were observed in the group of two (30 each) and they concluded that the oxygen concentrator can be used as a reliable source of oxygen during anesthetic procedures [7].

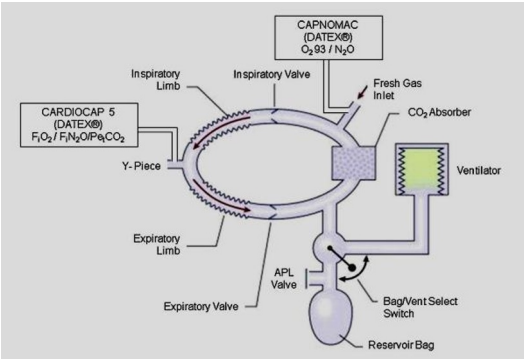


Fig. 3 Semi-closed re-breathing circuit [7]

Kamoun et al. (2020), developed an innovative proof of concept prototype system for crowd sourcing the supply of oxygen cylinders for COPD/asthma patients during crises. It is hoped that this contribution may spark new inventive crowd sourcing applications in healthcare in general and life-saving applications in crises in particular [8].

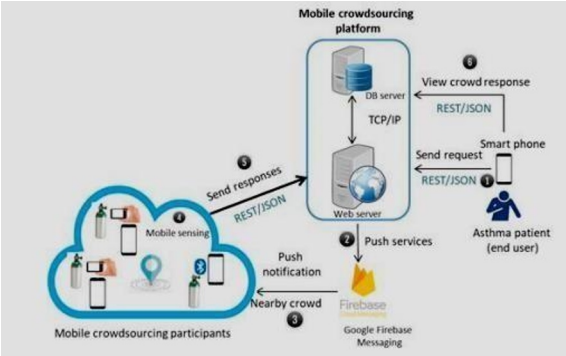


Fig. 4 General system architecture [8]

Oxygen devices and delivery systems by Georgia Hardavella et. al., explained the various applications of oxygen in medical use [9]. Oxygen is used in various forms in medical industries 1. Oxygen Cylinder 2. Liquid oxygen 3. Oxygen Concentrator.

3.1 Oxygen cylinder

Oxygen cylinders come in a variety of sizes, which affect the amount of oxygen they can hold. There are three ways to distribute portable oxygen using compressed oxygen cylinders: a home fill cylinder, a lightweight cylinder, and a portable cylinder. The cylinders are in different sizes ranging from small ambulatory cylinders (e.g. 53 cm height, 3 kg weight, 430 L oxygen) to large stationary cylinders (e.g. 71 cm height, 18 kg weight, 2122 L of oxygen). A compressed oxygen cylinder has a small capacity: for example, 400 L of oxygen at 200 bar filling pressure, lasted 2.5 hours depending upon the flow rate to the patient [9].

3.2 Liquid oxygen

Liquid oxygen is cryogenic liquefied gas having a boiling point of -183°C which provides a facility to hold a bigger amount of oxygen (gas) in a smaller container. Before the patient receives the oxygen through tubing into the nostrils through a nasal cannula, the medical liquid oxygen (minimum 99.5 percent purity) must first be vaporized to a compressed gas and then warmed at ambient (room) temperature inside the apparatus. The liquid oxygen gives the leverage that the patients using liquid oxygen can leave the place for long duration [9]. But due to the cryogenic nature of liquid oxygen, it changes the material property to become brittle to which it touches.

3.3 Oxygen concentrator

The concentrator pulls in room air and filters it to remove dust, germs, and other impurities. A compressor forces air into one of the two cylinders holding sieve material, which adsorb the nitrogen and releases the concentrated oxygen which further goes to oxygen storage tank. The direction of air flow is changed and pressurized air goes to the second cylinder. The same process is carried out which

liberates the oxygen. Simultaneously, the nitrogen trapped in opposite cylinder is discharged to atmosphere. The constant flow of oxygen is delivered due to cyclic process of generating the oxygen [9].

4. Industrial Methods of O2 Production

Separation of air using Cryogenic Distillation Process/ Cryogenic industrial gas processes.

In 1895, two Scientific Researchers developed a process to lower the temperature of air until it liquefied. Cryogenic distillation is used to separate oxygen from air by liquefying the air at very low temperatures, generally about -300°F. The Hampson–Linde cycle is a process for liquefaction of gases that was independently invented by William Hampson from England and Carl von Linde from Germany. Their study concluded the process where ambient air is initially compressed in multiple stages known as inter-stage cooling method and then is further cooled with chilled water. Residual water vapor, carbon dioxide, and atmospheric contaminants are removed by the molecular sieve adsorbent (Zeolite). Lowering the temperature of the air to cryogenic temperature values is achieved by heat exchange with product gases, after-coolers and expanders. The cool air then enters the "cold box," which contains a distillation column involving many stages, along with a column filled with argon for additional oxygen purification. By performing careful distillation of the liquid air, the molecular component gases could be boiled off one at a time, captured and stored. This process then eventually became the principal source for the generation of high-quality oxygen, nitrogen, and argon for industrial use. Recent advancements and developments in technology for production of high purity oxygen using cryogenic air separation technology has enabled the production of high-grade oxygen which is used for the gasification of hydrocarbon feed-stocks to synthesize gas for the production of fuels, chemicals, etc. reported by Smith et al. [10].

4.1 Oxygen production Using Pressure swing adsorption (PSA)

As the pressure of air swings between two containers, the system is called as Pressure swing adsorption.

The efficiency of oxygen production as well as oxygen recovery of a pressure swing adsorption (PSA) process can be enhanced for the production of oxygen from ambient air using selective adsorption of nitrogen.

The Efficiency of the process can be improved upon by operating the process at a super-ambient temperature. Carrying out the process at high temperatures provides for a more efficient environment for releasing the nitrogen gas from the adsorbent which completely off-sets the harmful effects caused due to lower selectivity capacity of adsorption of nitrogen from air at high temperatures [11].

4.2 Low Concentration O2 Production using PSA

In a study conducted on Reduction of Bed Size Factor of a Medical Oxygen Concentrator using Rapid Pressure Swing Adsorption for oxygen generation by Chai et al., in 2011 suggested that by reducing the dimensions of the adsorber material (zeolite) utilized in a medical oxygen concentrator (MOC) that employs a generic pressure swing adsorption (PSA) technology is currently an ongoing research and

development activity. A medical oxygen concentrator is capable of producing 90–93% oxygen-enriched product gas from ambient air while in taking the ambient air at a rate of ≤10 Liter per minute (LPM) for individual use. A standard industrial practice involves reducing the value of total cycle time of the PSA process.

so as to reduce the bed size factor (BSF) of the method. Adsorbent columns if filled very small sized adsorbent particles will enhance the adsorption capacity of the rapid PSA cycle operation [12].

4.3 High Purity O2 Production using PSA

High Purity Oxygen generation is also possible using Pressure- Swing Adsorption technique which uses silver exchanged zeolite, where oxygen/argon adsorption is present separately to improve the concentration of oxygen supplied by the PSA concentrator according to a Study on High-Purity Oxygen Production by Pressure Swing Adsorption by Danielle Ferreira, et. Al., [13]. Generating oxygen with purity higher than 95.0% from atmospheric air (78.0% N2, 21.0% O2, and 1.0% Ar) is challenging because of the similar physical properties of oxygen and argon. Silver-exchanged titan silicates have shown the potential to separate these gases based on their thermodynamic affinities according to research on Cycle Development and Process Optimization of High- Purity Oxygen Production Using Silver- Exchanged titan silicates by Hejazi et al., (2016)[14].

5. Recent development on oxygen concentrator

Since 2020, with the surge in oxygen demand and the surge in COVID19 cases, people have been struggling to breathe the oxygen. The development of the concentrator is carried out worldwide to resolve the issue. Therefore, the specific development in use of Oxygen Concentrator from 1970 to 2021 is discussed in the subsequent section.

Ever since 1970, electrically powered devices are designed to offer oxygen for patients. Harris and Stamp (1987) [15] have are reported operation details of concentrator such as the molecular sieve (MS) concentrator and the membrane oxygen enricher. Authors summarized the use of various concentrators. A schematic diagram showing the constructive and working details of standard magnetic separator (MS) type concentrator is shown in Fig. 5.

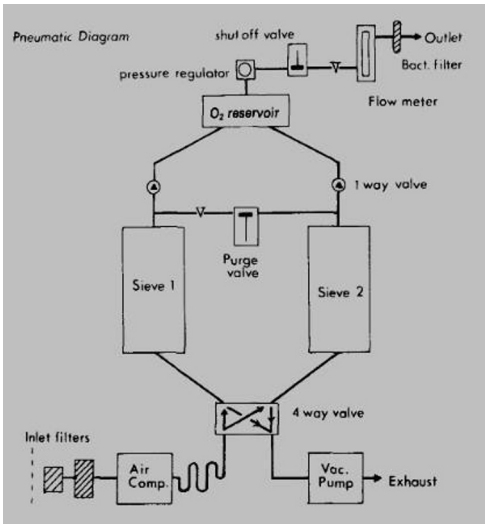


Fig. 5 Schematic diagram of standard MS type concentrator [15]

In last decade, Rao et al. (2010) [16] developed two-step Pulsed Pressure Oscillating Adsorption (PPSA) process for medical use of oxygen concentrator. When the bed at the feed end is pressurized, an oxygenated product is withdrawn from the end of the product and then closed during the depressurization. The descriptive equations are solved with the multi- physics software COMSOLVR. The investigation is carried out for the influence of the adsorption time, desorption time, bed length, particle diameter and pressure drop across the bed and concluded with an optimal combination of adsorption and desorption times that maximizes oxygen purity greater than 90%. Atacak et al. (2012) [17] presented an inexpensive oxygen concentrator with GPRS-based error transmission system to minimize the delays that can occur during the treatment time. The test showed that the planned system delivered the oxygen with a purity of about 94.7% for the flow rates of 13 L / min. It is concluded that the system performs well considering that a patient should be taking oxygen at 90% purity or greater for the flow rates of 23 L / min.

During critical situation of COVID19, oxygen concentrators are used to deliver medical oxygen to prevent hypoxemia-related diseases. Arora and Hasan (2021), presented the design with optimize flexible single bed of medical oxygen concentrator (MOC). A simulation-based optimization framework to optimize MOC systems based on flexible PSA and vacuum adsorption (PVSA) is also displayed. Different types of zeolites are used to determine the performance of system. They concluded that PVSA system with lithium based low silicon zeolite (LILSX) gives better performance with 90% pure oxygen at 21.7 L/min with the flow rate of 1-15 L/min. In their design, they suggested cyber- physical system (CPS) which could supply the oxygen not only in terms of flow rate but also the purity of oxygen, which is depending upon the requirement of oxygen, which is directly related to lungs infection of patient, as shown in figure 6.

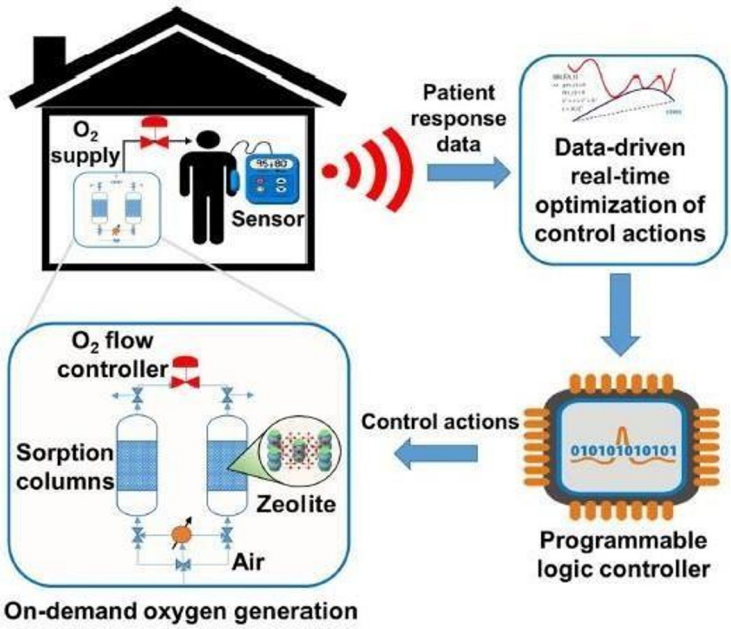


Fig. 6 Cyber-physical system using adsorption-based medical oxygen concentrator (MOC) [18]

From the various reported studies, it is observed the various approaches for development of oxygen concentrator for the enhancement of working results are presented. During initial study authors summarized the use of various concentrators. Later on, an optimal combination of adsorption and desorption times that maximizes oxygen purity greater than 90% is reported with use of GPRS-based error transmission system. Flexible MOC technology gives the way for the transition to a planned CPS with real-time oxygen demand detection and deliverance for better patient care.

In view of future utility and advances in information and communications technology, tele- monitoring approaches may be incorporated with medical instruments which installed at homes. It records the usage of oxygen concentrator and accessed remotely by health care supplier. The use of tele-monitoring system for home oxygen therapy with the cloud-based analytical system developed in Japan, recently reported by Naoto Buriok (2020) [19] which recognized as a new medical technology.

6. Working Principal and Construction of Oxygen Concentrator :

An oxygen concentrator is designed to separate the oxygen from ambient air by utilizing a process known as Pressure Swing Adsorption (PSA). The air compressor draws the atmospheric air through primary air filter and compressed air is taken to air dryer for getting the moisture free air for the further process. The pressurized air is diverted to one of the cylinders containing zeolite after filtering it for fine dust and foreign material. The zeolite column adsorbs the nitrogen and releases the oxygen. The cycle changes from first cylinder to second cylinder and pressurized air diverted to second cylinder in which the procedure of separation of oxygen is taken place. The part of released oxygen is used for flushing the first cylinder and major part is taken to

oxygen tank which is further use for treating the patent. Basically the entire process is cyclic. The solenoid valves play a vital role to control the direction of air and oxygen in two columns of zeolite. The schematic diagram of oxygen concentrator is as shown in Fig.7 [20].

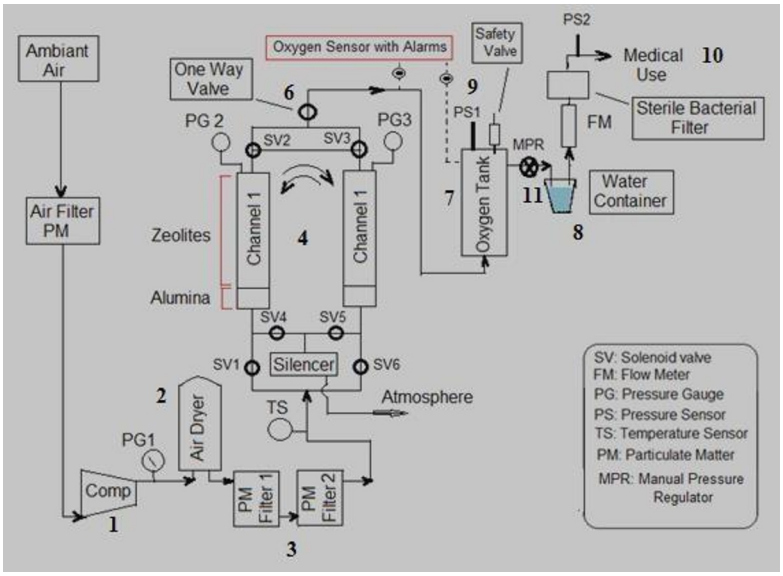


Fig 7 Flow diagram of oxygen concentrator

1. Air compressor	2. Dehumidifier	3.Particulate Matter Filter
4. Adsorption Tower A&B	5. Solenoid Valve	6.Non-Return valve
7. Oxygen Tank	8. Humidifier	9.Pressure Sensor
10. Oxygen Outlet	11.Manual Pressure Regulator	

7. Conclusion

During the first wave of Covid-19, in the year of 2020 year, the demand for medical oxygen increased four times i.e. 2,800 Ton per day. Further, with the second wave, the demand has gone up to approximately 5,000 Ton per day. The study of researchers revealed the various methods of producing the oxygen to fulfill the demand of it as the existing system of oxygen supply such as oxygen cylinders, ventilators, etc., cannot be met the demand for medical oxygen. The review of various methods along with classification for producing the oxygen is carried out. It is observed that the use of oxygen concentrator using the principle of Pressure Swing may be the solution to saves the lives at least at primary stage of corona infection to the patients. The fabrication of it even at local level is possible to manage the crises of requirement of oxygen.

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