

Out of breath in pandemic – Is pressure swing adsorption (PSA) technology a solution for saving lives?

Vishakha Jain, Vikas Bhatia

Department of Medicine, AIIMS, Hyderabad, Telangana, India

ABSTRACT

In these unprecedented times of COVID-19 pandemic, globally there has been a shortage of medical supplies, hospital beds, health care workers, etc. This was accentuated in India with a shortage of oxygen in the second wave of pandemic. The reasons for shortage were mainly imbalance between demand-supply and these also led to implementation of ingenious solutions in the form of oxygen generators based on PSA technology. The technology was an off shot from OBOGS developed by DRDO and DEBEL for light combat military air crafts. This review discusses the scientific technology behind medical oxygen plants based on PSA, its applications and its advantages to combat the dearth of oxygen.

Keywords: COVID-19, India, oxygen generator, oxygen shortage, pandemic, pressure swing adsorption, PSA

Introduction

The whole world is fighting COVID-19 pandemic and at present many countries are struggling with the third and fourth wave of the pandemic. India has witnessed an exponential surge of patients suffering with COVID-19 with about 4,00,000 new cases being reported every day and about 3000–4000 deaths due to COVID-19 every day in the second wave.^[1] According to World Health Organisation (WHO) 15 per cent of COVID-19 patients require medical oxygen therapy because of respiratory distress.^[2] In the second wave, the health care system in Indian subcontinent was been swamped due to patients suffering from COVID-19. Many cities in India had been out of oxygen supplies and there had been never seen before situation of help on social media, electronic media to supply oxygen cylinders to hospitals.

The first wave of pandemic saw increase in medical oxygen demands internationally which was supported by India

exporting 9,301 metric tonnes of oxygen across the world between April 2020 and January 2021 as compared to 4,502 metric tonnes of oxygen exported earlier. During the first wave, the demand for liquid medical oxygen (LMO) increased from 700 metric tonnes per day (MTPD) to 2,800 MTPD in India.^[3] But during the second wave, it has alarmingly increased to 5,000 MTPD especially so in the second week of April, 2021.

During the second wave of COVID pandemic, India produced more than 7,000 metric tonnes of liquid oxygen per day, which enough to support the current requirement of medical oxygen in the country.^[3] But there were lot of issues which need to be considered apart from just adequate production of medical oxygen. There had many challenges in supply chain and logistics which had led to uneven distribution and crisis of oxygen in some states in India.^[4] The existing cryogenic tankers for transport of LMO were not being able to meet the demand.^[5] To mitigate this crisis, government cut down the oxygen supply to industries after the surge in COVID-19 cases and increasing demands of medical oxygen and diverted all oxygen to health care system. It also decided to import 50,000 metric tonnes of oxygen. To further support the health care systems, the centre sanctioned the

Address for correspondence: Dr. Vishakha Jain,
Department of Medicine, AIIMS, Hyderabad, Telangana, India.
E-mail: vishakha.jain1079@gmail.com

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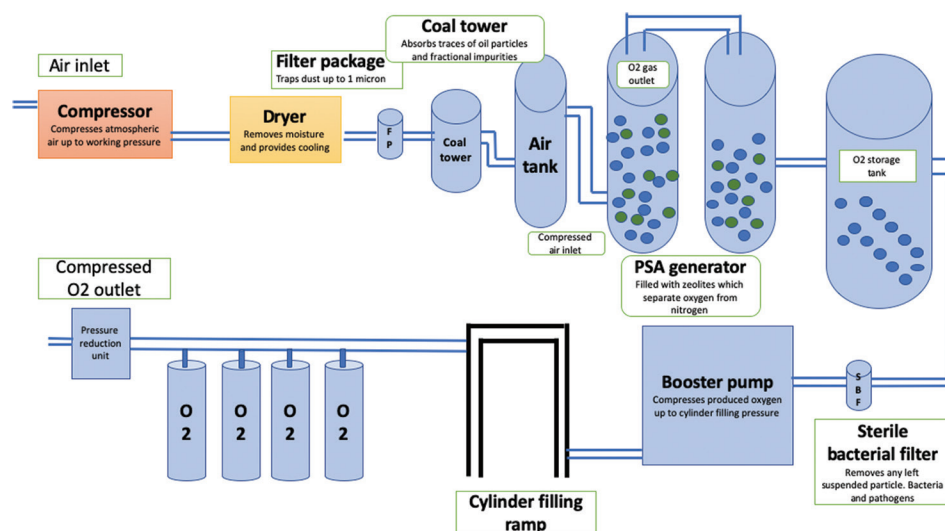


Figure 1: Set up of PSA technology-based MOP

Table 1: Projection of total oxygen requirement and total flow rate depending on hospital bed strength (considering that 15% of total bed strength is reserved for critical care beds in intensive care unit)

Hospital bed strength	No of standard beds $\times 0.75$ LPM	No of beds in operation theatre (OT) $\times 7$ LPM	No of Intensive care unit beds $\times 30$ LPM	Total oxygen requirement (LPM)	Total flow rate (Nm ³)= Total LPM $\times 0.06$
100	$85 \times 0.75 = 63.75$	$3 \times 7 = 21$	$15 \times 30 = 450$	534.75	32.085
200	$164 \times 0.75 = 123$	$6 \times 7 = 42$	$30 \times 30 = 900$	1065	63.9
500	$410 \times 0.75 = 307.5$	$15 \times 7 = 105$	$75 \times 30 = 2250$	2662.5	159.75
1000	$850 \times 0.75 = 637.5$	$30 \times 7 = 210$	$150 \times 30 = 4500$	5347.5	320.85

Table 2: Projection of total oxygen requirement and total flow rate in a dedicated COVID-19 hospital with 200 bed strength

Total bed strength	Non critical oxygen beds $\times 5$ LPM	Intensive care unit beds with ventilator $\times 12$ LPM	Intensive care unit beds High flow nasal canula (HFNC) $\times 60$ LPM	Total oxygen requirement (LPM)	Total flow rate (Nm ³) = Total LPM $\times 0.06$
COVID-19 hospital 200 bed	$80 \times 5 = 400$	$20 \times 12 = 240$	$6 \times 60 = 360$	1000	$1000 \times 0.06 = 60$

installation of more than 501 Pressure swing adsorption (PSA) oxygen plants in public health facilities across states.

History of PSA technology

Military aircrafts operate at altitudes where there is not enough oxygen for humans to retain consciousness without supplemental oxygen supplies. For several decades, combat aircraft relied on canisters of compressed liquid or gaseous oxygen to provide pilots sufficient oxygen. However, the finite oxygen supply limited mission duration. This led to the development of On-Board Oxygen Generation Systems (OBOGS) for limitless oxygen supply.^[6] The system works by purifying air drawn from the plane's engine compressor (called 'bleed air') before it reaches combustion. That air is run through a series of scrubbers, or 'sieve beds', that remove nitrogen. The resulting gas going to the pilot is approximately 95% oxygen and 5% argon.^[6]

India is fourth in the world to develop and augment this technology and it has been used in our light combat aircraft

Tejas.^[7] Pressure swing adsorption (PSA) technology developed by defence research and development organisation (DRDO) separates oxygen from air and the nitrogen in this air is adsorbed in molecular sieves at moderate pressures, thereby concentrating oxygen.^[7,8] The initial zeolite molecular sieves do not discriminate between oxygen and argon resulting in oxygen purity limitation of 93 per cent to 95 per cent as both oxygen and argon concentrate in these oxygen generators. Currently, zeolites of Type A (5A) and Type X (13X- NaX, LiX) are used in on-board oxygen generators. High purity Advanced Molecular Sieve Oxygen Concentrator that generates up to 99 per cent oxygen directly from engine bleed air has been reported and such concentrators employ in series a zeolite molecular sieve for nitrogen adsorption and a carbon molecular sieve for argon separation from oxygen-argon mixture received from the zeolite bed.^[8] The process of oxygen concentration developed by Defence Bioengineering and Electromedical Laboratory (DEBEL) involves four adsorbent beds, two containing zeolite molecular sieves and two containing carbon molecular sieves [Figure 1].^[8]

PSA technology and COVID-19 pandemic

The medical oxygen plant (MOP) is an off shot of PSA technology used by DRDO for their military aircrafts. The MOP technology is capable of generating oxygen with concentration of 93 ± 3 per cent (first generation zeolites) and 99 per cent with High purity Advanced Molecular Sieve Oxygen Concentrator which can be directly supplied to hospital beds or can be used to fill medical oxygen cylinders. The concentrator system is fitted with a filter to remove particulate material, if any and the output is stored in a storage tank. An oxygen compressor/booster is connected to the system to fill cylinders which can be transported to nearby areas for use. The space requirements to set up a PSA oxygen generator varies between $6 \times 6 \times 5$ meter for smallest plant to $18 \times 18 \times 8$ meter for largest plant. It runs on a 3 phase power supply ranging between 20 kw and 220 kw and power backup for at least 30 minutes.

The capacity of an oxygen generator plant is calculated using the formula^[9]:

Total LPM = (No. of beds \times 0.75 LPM) + (No. of beds in OT \times 7 LPM) + (No. of beds in intensive care unit [ICU] \times 30 LPM).

Total flow rate (Nm³) = Total LPM \times 0.06.

Patients suffering from SARS-CoV2 infection usually have higher oxygen requirement. The PSA system is designed for a capacity to cater 5 litres per minute (LPM) per person for up to 200 individuals amounting to total capacity of 960 LPM (57.6 M3/hour) [Tables 1 and 2].

Advantages of PSA oxygen generators

PSA technology of oxygen generation can make hospitals independent to support their oxygen requirements to a certain extent.^[10] The PSA technology can make district hospitals and secondary care centres independent and these will be beneficial to the family practitioners working in these centres. As reported by Ministry of Health and Family Welfare, Government of India (MoHFW, GOI), these oxygen plants will augment medical oxygen capacity by 154.19 metric tonnes in our country. The following are the advantages of PSA oxygen generators:

Standards of medical oxygen—Indian Pharmacopeia, European Pharmacopeia, British HTM, US FDA standards all permit medical gas (93% oxygen) produced using the PSA process to be utilized in hospitals and medical facilities.^[11,12]

Cost effectiveness—Filling up of liquid oxygen in oxygen cylinder costs Rs. 17–75 per cubic meter. Adding to this cost is the cost of transport to take the cylinders to a plant for refilling as well technicians round the clock for oxygen cylinders handling. Whereas in oxygen generator gas cost is only Rs. 10–20 per cubic meter. Also there is low maintenance and operational cost. According to WHO PSA comes at a much lesser total cost than a

liquid oxygen tank, at U\$\$ 2–8/KL as against U\$\$ 10–30/KL.^[9] Approximate set up cost for a PSA would be approximately one crore rupees if all the components of the PSA, booster, UPS, generator, and distribution system with accessories and maintenance cost for 10 years are taken into account.^[9]

Reliability—In these unprecedented times of this pandemic, there has been a shortage of medical oxygen globally and oxygen generators are the a reliable source of clean oxygen supply 365 days round the clock. It will also circumvent the logistic hassles of supply of liquid oxygen. These produce oxygen with steady purity and pressure of 5 kg/cm²g for supplying oxygen through pipe line directly to beds.

Safety—There is an inherent risk of fire hazard because of storing and transporting oxygen cylinders. Hospitals are oxygen enriched areas and leakage of oxygen from cylinders or cryogenic spills can lead to disastrous eventualities. PSA oxygen generator plant decreases this risk and makes hospitals safer.

Fully automated systems—Advances in the industry standards remote monitoring and operation of the medical oxygen generation systems can be done from a computer workstation, tablet, or smartphone from anywhere in the world.^[10]

Present situation of oxygen supply and PSA plants in India

As of December 2022 many countries globally are struggling with the third and fourth wave of pandemic and we are on the possible brink of another wave of Covid-19 wave in India. But thanks to the effort of government of India during the second wave and the futuristic vision to empower district hospitals and medical colleges, the medical oxygen production capacity was increased to more than 9000 metric tonnes. These humongous efforts were possible due to installation PSA plants across all districts in India. As of April 2022 there are about 3756 commissioned PSA plants across the country with a combined daily capacity of about 18000 metric tonnes of medical oxygen. The swift and effective action from the center has prepared country to have operational readiness in terms of oxygen supply and tackle another wave of covid 19 epidemic if it hits our country.

Conclusion

An indigenously developed and repurposed system of OBOGS using PSA technology can be a self-sustainable solution for the increasing oxygen demand in this pandemic time. In the long run, this technology can make small to medium sized hospitals in the rural and urban regions independent of the challenges and logistic issues related to supply—demand chain of liquid oxygen. It will be a leap forward towards a safe and replenishable source of medical oxygen.

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Conflicts of interest

There are no conflicts of interest.

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