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Review Article

Role of oxygen concentrators in covid pandemic

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ABSTRACT

Background: The need for oxygen, as well as the scarcity caused by the second wave of the Corona epidemic, has caused everyone to reconsider the sustainability and self-sufficiency of oxygen. Medical oxygen therapy is a standard treatment for patients with severe Covid manifestations. Ensuring a consistent supply of oxygen to meet the rising demand for oxygen must be planned at the national, state, and institutional levels.
Aim: In this article we would like to emphasise the importance of oxygen adequacy.
Materials and Methods: This narrative review covers the methods of estimating oxygen requirements of a hospital, and the alternate oxygen sources available, highlighting the role of oxygen concentrators in a low resource settings.
Conclusion: Oxygen concentrators specially as pressure swing adsorption plants can be used by hospitals as a main source of oxygen being both economical, as well as reducing the dependency on refilling and transport.
Key Messages: Planning the oxygen resources for a hospital should include primary, secondary and reserve sources, among all these the oxygen concentrator plays a vital role both being economical in the long run as well as making the hospital largely independent of logistic issues.

1. Introduction

Addressing a pandemic within the constraints of available resources is a challenge for any health-care system in the world. It has emphasised the critical need of medical oxygen access, for example, a sudden spike of COVID-19 patients has led to a oxygen shortage in one of London's largest hospitals.[1] In some parts of Italy, medical oxygen consumption has tripled, necessitating the rapid development of new or improved methods to ensure a sufficient supply of oxygen.[2] Low-income countries like India and Peru have had to rely on industrial oxygen for medical purposes in cities where there was no liquid oxygen factory.[3]

Covid-19 has rapidly spread in India, with over twenty million cases reported by May 2021, motivating health professionals to look beyond the routine for oxygen solutions. According to WHO estimates, nearly 15% of Covid-19 patients require oxygen therapy.[4] The sharp increase in cases in 70 days to 11.5 million has coincided with a sharp increase in demand for oxygen, precipitating an acute oxygen shortage. The demand for oxygen increased from four million cubic metres in September 2020 to nearly 17 million cubic metres in May 2021.

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The Covid 19 pandemic has emphasised inadequacies of health-care systems, with oxygen shortages being the most serious of them. In cognizance of this preparing the oxygen budget should be a priority in all hospitals in order to save lives in future surges. In an emergency, the most important drug is oxygen, a lack of which results in death within minutes.

Among COVID -19 infected patients who become symptomatic, the majority develop only mild (40%) or moderate (40%) disease, approximately 15% develop severe disease requiring oxygen support, and 5% develop critical disease with complications such as respiratory failure, acute respiratory distress syndrome (ARDS), sepsis and septic shock, thromboembolism, and/or mucositis.[4]

2. Oxygen Supply for a Hospital

Hospital should have three sources of oxygen supply to provide continuous uninterrupted supply of oxygen - primary, secondary and reserve sources.

2.1. Primary source

This is the main source of oxygen which can be from a cylinder manifold system, liquid oxygen system or a oxygen concentrator system. The average requirement should be at least 2-4 times the calculated daily requirement to plan for exigencies.

2.2. Secondary source

This is an alternative source of oxygen as a backup for repairs, and maintenance of the primary source. This should have at least 4 hours supply of oxygen either as a manual manifold or a second vessel of liquid oxygen as an alternative to a primary liquid oxygen plant.

2.3. Reserve source

Another cylinder manifold to supply the high dependency units of the hospital.

3. Sources of Oxygen in a Hospital are

3.1. Cylinders

A manifold is used in conjunction with banks of large cylinders, typically size J. When filled, the cylinders do not require a power source or costly maintenance. Periodic maintenance, on the other hand, is required and is typically provided by gas suppliers during refilling. The use of oxygen cylinders may present the risk of a fall or rupture, as a result of frequent transport between manufacturing facilities, warehouses, healthcare facility stores, and, eventually, a patient's bed. During COVID-19, when there is a high demand for medical oxygen in cylinders, there may be a higher risk of disruption because they must be refilled on a regular basis.

The type and size of oxygen cylinders will give an estimate of the available oxygen supply of that hospital.(Table 1)

3.1.1. Liquid oxygen tanks

The oxygen is stored in a vacuum insulated evaporator (VIE) at a pressure of 5-10 atmospheres in a thermally insulated vessel at temperatures ranging from – 150°Cto - 170°C. At one atmospheric pressure, one L of liquid oxygen at 15°C can produce 842 L of gas. A typical VIE holds 5000–10,000 litres of liquid oxygen. A full 10,000 L tank of liquid oxygen could be equivalent to 1200 "J" type 6800 L cylinders. Liquid oxygen tank maintenance necessitates a high level of technical knowledge, adequate ventilation, well-maintained piping and auxiliary equipment, and trained personnel.

3.2. Oxygen concentrators: They are of two types

1. Pressure Swing Adsorption plants (PSA) (500 to 2000LPM production capacity).
2. Portable oxygen concentrators.

They necessitate a constant supply of electricity as well as routine maintenance. Power stabilisers or an uninterruptible power supply (UPS) may be required when power supplies are insufficient or susceptible to voltage fluctuations. They do not need to be re-supplied on a regular basis once installed, but they do need to be maintained on a regular basis. These devices produce up to 95.5 percent concentrated oxygen and can be used to provide oxygen therapy at any level of health facility.[5]

4. Calculating the Oxygen Requirements of a Hospital

Planning for the requirements of oxygen of a hospital will depend on the number of oxygen beds, ICU beds, and number of Operation theatres. It should be done in each Institute as per their bed strength and volume of work, also factoring in sudden surges in requirements and with solution for system failures in place.

As per the UNICEF oxygen system planning tool, (Table 2) an interactive source, which can be modified as per the state or national prevalence or the institutional oxygen protocol to be followed and will help in estimating the oxygen requirements of a hospital and is a valuable resource available online.[6]

To calculate the capacity of an Oxygen generator (PSA plant) for a Hospital the formula used is[7]

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

For example a hospital with 100 beds, 4 Operation theaters and 10 ICU beds would need (100X0.75 +(4x7) +(10x30) = (75+28+300) = 403 LPM.

Table 1: Oxygen cylinders size and capacity

Cylinder Size	D	E	F	J
Dimensions L x D in cm.	53.5 x 10.2	86.5 x 10.2	93 x 14	152 x 22.9
Water Capacity (L)	2.3	4.7	9.4	47.2
Nominal Pressure (Bar)	137	137	137	137
Nominal Capacity (L)	340	680	1360	6800

Table 2: UNICEF oxygen system planning tool [6]

S. No.	Name	Hypoxemia prevalence per bed type (%)		Typical oxygen flowrate (LPM)		Duration of oxygen therapy for typical hypoxemia case (hours)	
		Override	Global	Override	Global	Override	Global
1	OPD		1%		5		1
2	General		6%		5		72
3	Adult		6%		6		144
4	Pediatric		10%		2		72
5	Neonatal		20%		1		72
6	ICU		100%		6		96
7	OT		100%		8		6
8	ER		30%		6		16

Total flow rate (Nm^3) = Total LPM $\times$ 0.06.

4.1. Oxygen concentrators

Difficulties in transportation due to climate conditions, lack of or problems with connectivity, and absence of cryogenic plants in some countries, stimulated the use of oxygen concentrators, which were used in aircrafts, hospitals during the Gulf War and the war in Bosnia, and in humanitarian missions.[8–10] The use of oxygen concentrators, as a primary source of oxygen, connected to the supply network of hospitals, has been in use in Canada for more than 30 years.[11,12]

Oxygen concentrator is a device which extracts Oxygen from the atmospheric air by filtering and compressing it to the required density and delivers to the patient. The percentage of Oxygen delivered may range from 80-95%.

Types of oxygen concentrators: Portable oxygen concentrator/Pressure swing adsorption plant (PSA).

4.2. Mechanism of oxygen extraction from air

Oxygen concentrators, extract oxygen from air by differential adsorption Cryogenic Distillation, Membrane Separation & Pressure Swing Adsorption (PSA) and range from small to big devices supplying a single patient to a whole hospital via pipeline.

A Zeolite molecular sieve is used which are hydrated aluminium silicates of the alkaline earth metals in a powder or granular form. Many columns of zeolites are used in the Concentrator. Ambient air is filtered and pressurized to about 137 kPa by a compressor. Air is exposed to a zeolite molecular sieve column, forming a very large surface area, at a certain pressure. The sieve selectively retains nitrogen and other unwanted components of air. These are released back into the atmosphere after heating the column and applying a vacuum. The maximum oxygen concentration achieved is 95% by volume. Argon is the main remaining constituent. Concentrators are designed for continuous operation and can produce oxygen 24 hours per day, 7 days per week, for up to 5 years or more. Higher altitudes require higher flow rates for longer durations.

Fig. 1: FA valve with a flow meter that can be directly connected to a patient.

Humidification is required at flow rates ›2 LPM, and distilled water should always be added to the humidifier to prevent calcium buildup, water should be changed daily, and humidifier cleaned with soap and water every week and between each patient.[7] Most concentrators currently available produce an oxygen concentration between 82% and 96% volume fraction when operated within manufacturer specifications. It is safer to use oxygen concentrators with measurement of inspired oxygen concentration.

Fig. 2:

Patients at facilities in higher altitudes may require higher flow rates for longer duration for adequate therapy compared to patients at sea level. Humidification is not required when oxygen is used at low flow rates up to 2 LPM with nasal prongs or nasal catheters in children under 5 years of age. Humidification may be required for high-flow oxygen needs greater than 2 LPM or if oxygen bypasses the nose, such as when nasopharyngeal catheters or tracheal tubes are used.

Emergency Oxygen Cylinders, should be available as a fail safe for situations where the oxygen concentrator need maintenance and repair, when there is an interruption in power supply or there is sudden escalation of oxygen therapy, to ensure continuity of oxygen treatment.

Operation of oxygen concentrators depends on a reliable and continuous AC electricity power supply. It is recommended that back-up power supplies, such as an uninterruptible power supply (UPS) and/or battery bank systems, are considered during the procurement of oxygen concentrators.

The life of the zeolite crystal can be expected to be at least 20000 hours (which is about 10 years of use). Routine maintenance consists of changing filters at regular intervals.

5. Role of Oxygen Concentrators (PSA Plant) in Operation Theatres

Friesen's survey of 53 Hospitals in Canada using the PSA oxygen in their intensive care units, Operating rooms and emergency areas observed that most areas used 2LPM of Oxygen without any adverse effects.[11] Parker also has concluded that oxygen from oxygen concentrators is safe to be used in the ventilation system during low flow anaesthesia of 500 mL.min^{-1}, with continuous monitoring of oxygen concentration.[12]

Study with a metabolic lung model concluded that the efficiency of the concentrator is flow-rate dependent: O2 concentrations higher than 90% are only achieved with flow rates below 5 l/min and decrease to values lower than 50% at 12 l/min or more.[13,14] The use of oxygen concentrators is safe even in closed breathing systems without the risk of hypoxia when there is measurement of inspired oxygen concentrations.

Walker et al. in their evaluation of the oxygen circuits in different anaesthesia work stations recorded that there were no clinically significant differences between machine settings and actual measured oxygen concentration when using an Oxygen Concentrator as a primary source of supply, further underlining the safety of oxygen concentrators.[15]

Table 3: Difference between portable oxygen Concentrator and PSA plant

	Oxygen Concentrators	Pressure Swing Adsorption Plant
1	Mobile	Fixed
2	Do not require supply chain	Do not require supply chain
3	Requires electricity	Requires electricity
4	Require maintenance	Require maintenance
5	Directly connected to patient	Requires pipeline
6	Not capable of filling cylinders	Capable of filling cylinders
7	Low pressure system	Medium pressure system

5.1. Oxygen concentrators in covid pandemic

5.1.1. Photograph of portable oxygen concentrator

The shortages in oxygen and hospital beds in many parts of the world created renewed interest in the use of portable oxygen concentrators in patients requiring oxygen. The portable oxygen concentrator is a bridge between the patient requiring oxygen between 5-10 LPM and patient needing higher respiratory support and has saved undocumented number of lives.

WHO has developed draft guidance (unpublished) on using oxygen concentrator-based solutions for treatment of severe COVID-19 (excluding critical patients requiring ICU) Table 3.[16]

The estimates of oxygen need are based on assumptions about the proportion of admitted patients who need oxygen, and what flow rates they are likely to need. Data from low- and middle-income countries suggest that ~5% of

Table 4: WHO guidance on oxygen concentrator based solution

Adults	1 x 10LPM concentrator (or large cylinder) per 1-2 beds (or 1 x 5LPM concentrator per bed)
Children	1 x 10LPM concentrator (or large cylinder) per (up to) 5 paediatric beds (or 1 x 5LPM concentrator per 2 beds)

Table 5: Estimated requirement oxygen concentrators in a SARI ward.[16]

Severe Acute Respiratory Infection (SARI) ward (e.g. Covid)	**Small (~4 SARI beds) 8 admissions per month (2 per week)**	**Medium (~15 SARI beds) 30 admissions per month (1/day)**	**Large (~30 SARI beds) 60 admissions per month (2/day)**
Adult SARI Ward			
Recommended solutions	2 x 10LPM concentrators (or large cylinders) (split flow to 4-8 individual flowmeters) + 1 x large cylinder (available on demand)	4 x 10LPM concentrators (or large cylinders) for severe patients + 4 x 10LPM concentrators (or large cylinders) (split to 8-16 individual flowmeters) + 2 x large cylinder (available on demand)	8 x 10LPM concentrators (or large cylinders) for severe patients + 8 x 10LPM concentrators (or large cylinders) (split to 16-32 individual flowmeters) + 4 x large cylinders (available on demand)
Paediatric SARI Ward			
Recommended solutions	1 x 10LPM concentrator (or large cylinders) (split to 4-5 individual flowmeters, including one 0-5LPM flowmeter) + 1 x large cylinder (available on demand)	2 x 10LPM concentrators (or large cylinders) for severe patients (split flow to 4 individual flowmeters) + 2 x 10LPM concentrators (split to 8-10 individual flowmeters) + 1 x large cylinder (available on demand)	Not applicable

adults, ~10% of children, and ~20% of neonates admitted to hospital with acute illness will have hypoxaemia (low blood oxygen levels, SpO2).

However, very severely ill adults will need a dedicated oxygen source (e.g. cylinder or 10LPM concentrator).

As per the UNICEF and WHO, recommended solutions for oxygen, the oxygen concentrators should provide adequate supply to cover 99% of demand (using the back-up cylinder less than 10% of the time). Actual oxygen usage will be much less (1/3) most days, but anticipation of significant variation from day to day have to be factored in.

In low income and medium income settings the portable oxygen concentrator can be safely used with a back up of bulk oxygen cylinders to manage covid patients requiring oxygen upto 10LPM. This use reduces reliance on Bulk Oxygen cylinders, conserves their use and in the long term is more economical to the institute.

5.2. Financial comparisons between oxygen cylinders, liquid oxygen and PSA

Balys et al., compared the monthly costs of oxygen of volume of 64,800 m^3 of supply to the hospital with different sources of oxygen. The highest costs were calculated with the use of oxygen in cylinders due to the transportation, filling and production charges. The costs with the liquid oxygen scenario amounted to only 10% of the costs associated to oxygen cylinders, while production of oxygen onsite (PSA plant) was almost at a minimal level .The annual savings with the onsite oxygen plant were around 96% as compared to the annual expenditure on oxygen cylinders.[17]

6. Conclusion

Portable oxygen concentrators in a low resource settings can be safely used as a source of oxygen both in adults and children, while the PSA plants being set up in major Government hospital as a government initiative in India can be used safely. These sources of oxygen are economical in the long run and make the hospital largely independent of transport delays and refilling of Oxygen cylinders.

7. Source of Funding

None.

8. Conflict of Interest

The authors declare no conflict of interest.

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