TATA CONSULTING ENGINEERS LIMITED

Emergency Options For Medical Oxygen Storage & Alternative Mode Of Oxygen Generation

PRELIMINARY ASSESSMENT REPORT

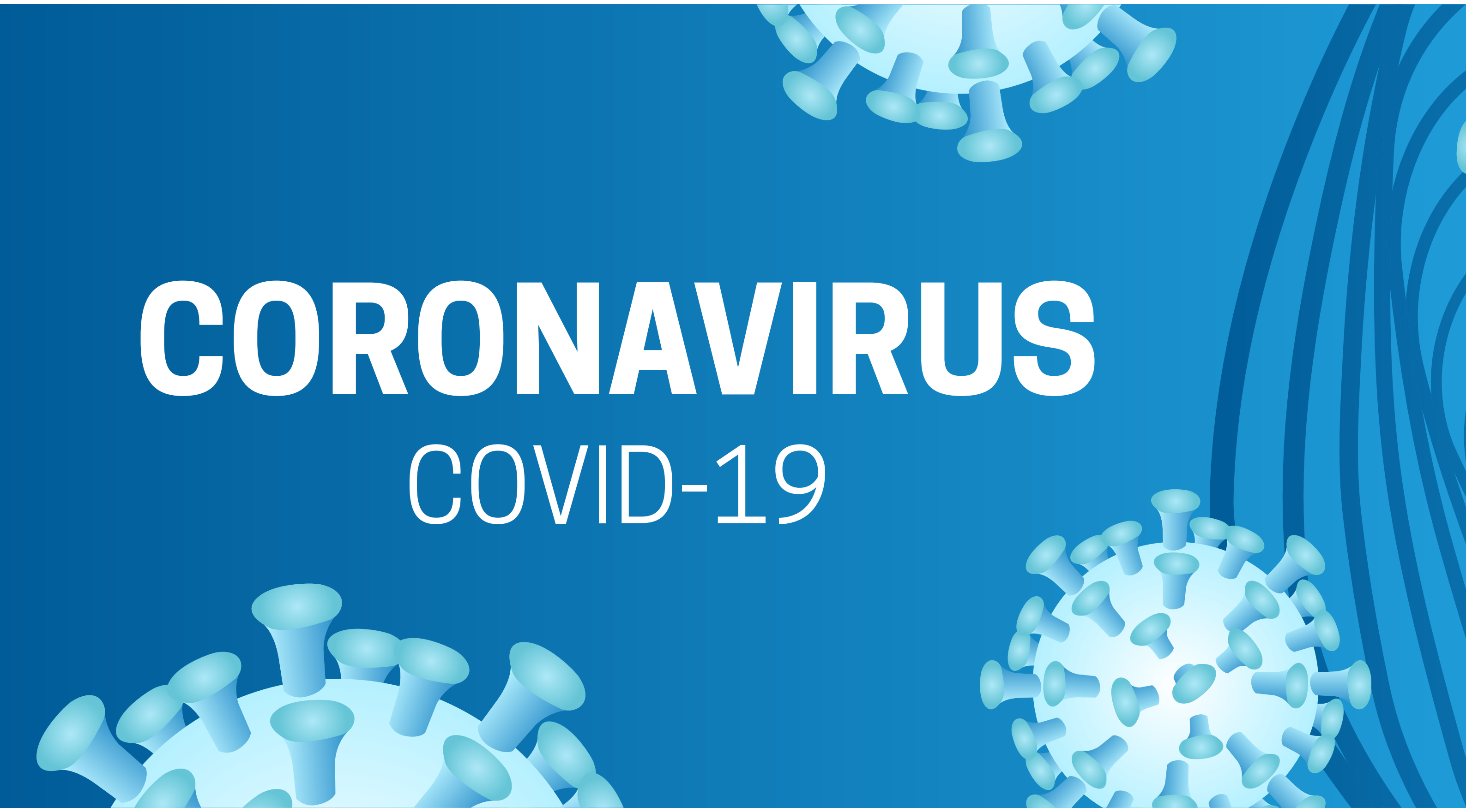
APRIL 2021

Background

The second wave of COVID19 has caught the population of India unaware and with its guards down. The steady fall in positive cases and low mortality rates had lulled the populace into a false sense of complacency of having overcome the disease. However, the trends defied the observed phenomena of multiple spikes in detected infections and deaths in all other countries. The tragedy of epic proportions unfolded quickly, and the situation rose to a super medical emergency almost in the blink of an eye.

New detections that had fallen to a low of 9,139 on February 15, 2021, have risen to 315,802 on April 21, 2021[1] . The total number of active cases on those same dates were 138,579 (with 76 deaths) and 2,290,728 (with 2102 deaths). The daily new cases being detected have surpassed the peak of the first wave many times over. The treatment facilities winded down in many regions during the long five-month decline are urgently required to treat seriously ill patients. Urgent interventions on a large scale are needed to enable these facilities to quickly bring the situation under control and protect as many human lives as possible.

In treating patients with severe breathing problems, oxygen works like a drug enabling them to hold on to life. From April 2020 to January 2021, the number of beds with oxygen support increased by 152% by utilising the Indian Government approved Rs 15,000 crore fund to boost the public health infrastructure[2] . The increase in these facilities was coupled with an increase in ICU beds by 32% and ventilators by 80% in the same period. The requirement for medical oxygen also increased correspondingly.



1. https://www.worldometers.info/coronavirus/country/india/

2. Is India's public health infrastructure ready to tackle the second COVID-19 wave? Here's what data says (downtoearth.org.in)

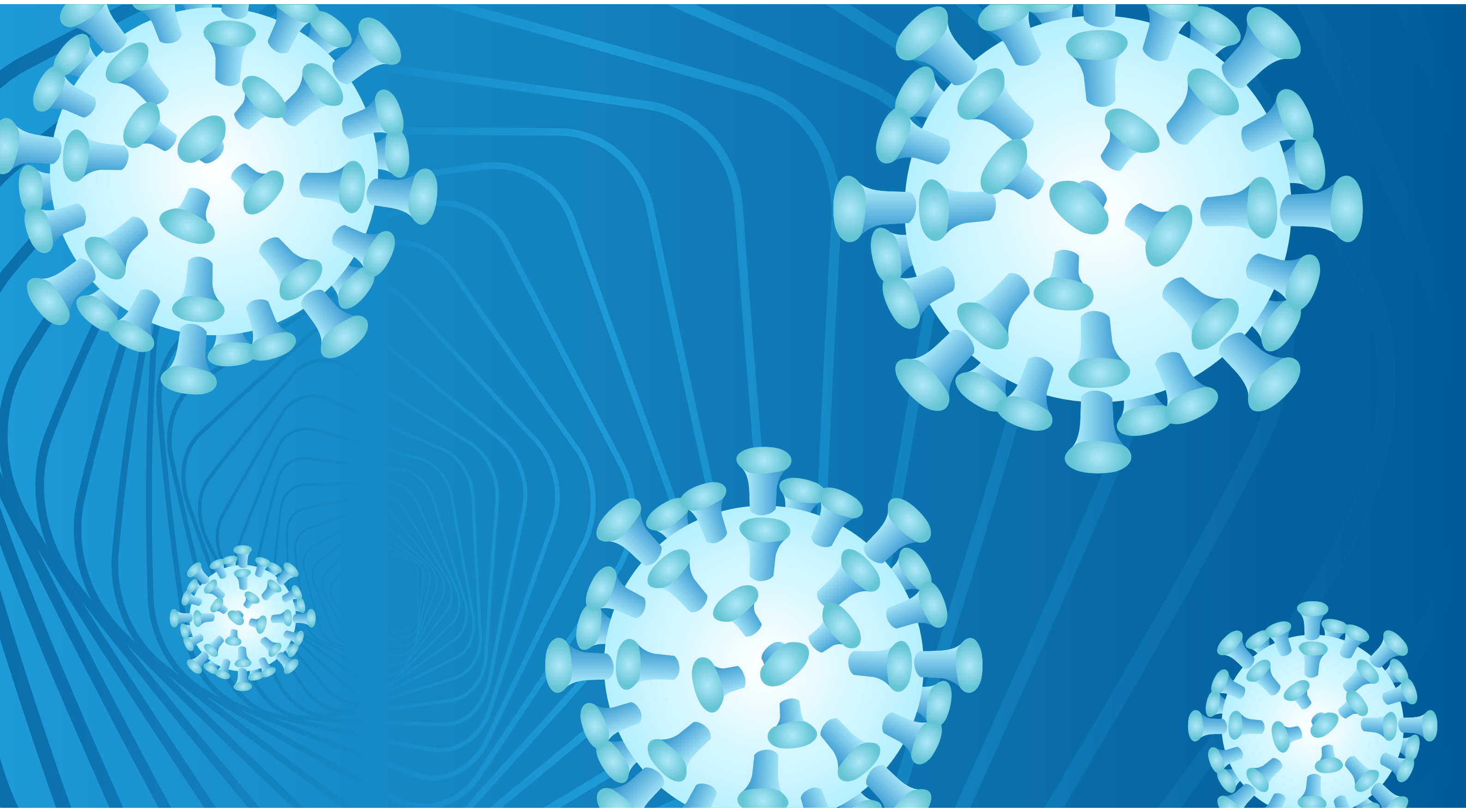
Oxygen Crisis

The second wave of the COVID19 pandemic is more infectious. It is causing breathing difficulties in more people, suddenly pushing the demand for oxygen to be administered to critically ill patients in hospitals or isolation units. The oxygen requirement of a critical COVID19 patient is estimated at 8kL/day for non-critical patients at an administration rate of 5-6lt/min and 86kL/day at the rate of administration of 60lt/ min for critical patients[3].

Many states have started reporting oxygen supply saturation or shortages. Maharashtra has already reported using its total capacity of 1250MT of oxygen for only 10% of the 6.4 lakh active cases on oxygen support. Madhya Pradesh had 59,193 active patients on April 16, requiring 250MT oxygen daily but without any manufacturing facility is dependent on Gujarat, Chhattisgarh, and Uttar Pradesh.

The oxygen requirement in Gujarat with 49,737 active cases is over 500MT. The Empowered Group-2 has identified 12 states of Maharashtra, Madhya Pradesh, Gujarat, Rajasthan, Karnataka, Uttar Pradesh, Delhi, Chhattisgarh, Kerala, Tamil Nadu, Punjab and Haryana where oxygen supply is expected to become critical.

Data shows that 20% of COVID19 patients turn symptomatic, and 3 of them go into critical condition. The oxygen requirement for positive case detections may vary from 10 to 15%. With about 2.2 million active cases, oxygen support will be required for about 2.5~3 lakhs of non-critical and critical patients resulting in oxygen demand of 10,250MT per day[4].



3. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7253105/

4. https://indianexpress.com/article/explained/explained-which-states-are-worst-hit-why-is-oxygen-transportation-difficult-7277038/

Motivation

In this second wave spread of COVID19, India is witnessing a shortage of medical oxygen in hospitals. While the oxygen is being made available from various industrial sources, the distribution of the same till patient bed remains a task as recently amended makeshift hospital facilities are not entirely covered through oxygen's central permanent piping infrastructure till the patient bed. Even if oxygen is made available, there is severe shortage of oxygen cylinders that can be refilled and used as a dedicated supply source for patients. The motivation of this note is to look for alternative ways of localised oxygen generation and oxygen bottling.

Supplying oxygen to critical COVID19 affected patients with breathing difficulties has become an emergency in India. As per the latest estimates, the available generating capacity in India considering industrial oxygen plants is more than 7000 Mt, but this quantity may not be adequate for the supply of medical oxygen in this acute situation. India is also planning to import 50,000 MT of medical oxygen to meet the spiralling demand. Bulk oxygen movement is carried out using cryogenic tankers. The Government is working out schemes for bulk transport by arranging additional tankers for nitrogen and argon transport using road and railway networks. However, the bottleneck lies in local transport and oxygen storage and making it available at remote locations with arrangements for enabling medical use.

The use of CNG cylinders is already being reviewed and processed for approval to use as storage for medical oxygen. Alternate and out of box solutions for storage and distribution of oxygen are being investigated in this report include the use of CO_2 fire extinguishers and LPG cylinders for medical oxygen service.

Also, alternative modes of oxygen generation may be required considering colossal demand, especially at remote locations. Even though Liquid Oxygen manufactured by Cryogenic Air Separation Plants, installed in Indian Refineries and Steel plants, is being diverted for medical use, this may not be enough to meet the increasing demand. Therefore, there is a need to look for additional sources through which oxygen can be generated quickly near the consumption point. Setting up of new 'Pressure Swing Adsorption (PSA) oxygen generation Plant typically takes about eight months. Therefore, the possibility of converting the existing PSA nitrogen plants to produce oxygen has been studied.

This report covers the following topics:

1. Suitability of fire extinguishers for storage of medical oxygen
2. Suitability of LPG cylinders for storage of medical oxygen
3. Conversion of existing PSA nitrogen Plants for the production of oxygen

Medical Oxygen

Specifications

1. As per World Health Organization (WHO) standards, medical-grade oxygen is defined as follows:
   - **European Pharmacopoeia (Ph Eur) specification:** Contains between 90.0%V/V and 96% V/V of O2. Remainder mainly consists of argon and nitrogen. This monograph applies to oxygen used on-site where it is produced. It does not apply to individual concentrators.
   - **United States Pharmacopoeia (USP) specification:** Oxygen produced from air by molecular sieve process. Contains not less than 90.0 % V/V and not more than 96 % O2 V/V. The remainder consists of argon and nitrogen mainly.

Oxygen Cylinder Requirements

The specification for using oxygen cylinders for medical purposes is available in the document: "WHO-UNICEF Technical Specifications and Guidance for Oxygen Therapy Devices."

- Refillable cylinders for compressed medical oxygen operate under safe conditions at high pressure (e.g., 50–200 barg). They are fitted with a primary valve, standard (pin index or bullnose) or integral, refillable. Nominal pressure is 137 barg for standard valve cylinders.
- The construction material is steel/Aluminum alloy/composite (carbon fibres), and the type of construction is seamless.
- Body and colour coding shall be according to ISO/ANSI/CGA/NFPA and sizes shall be as per ISO/US standards. Local country specific standards are also acceptable.
- Cylinders are supplied with optional pressure regulators to release the oxygen at the correct working pressure.

•

Material and Type of Construction for Oxygen Cylinder

Indian standard IS 7285 (Specification for Refillable Seamless Steel Gas Cylinders) is available for the design and fabrication of metal cylinders for gas storage which is also applicable for oxygen. The cylinders are required to be of steel material with the following chemical composition and physical properties according to Part 1 (normalised)/ 2(quenched and tempered) of this standard. The material specification is as below:

Table 1: Chemical Composition of Steel in % (Clause 5.2.1 & 5.4)

S. No.	Element	Contents
i	Carbon	0.45 , Max
ii	Manganese	1.20 - 1.70
ii	Silicon	0.10 - 0.35
iv	Chromium	0.20, Max
v	Nickel	0.20, Max
vi	Copper	0.20, Max
vii	Combined value of micro alloying elements: that is, V, Nb, Ti, B, Zr, Sn	0.15, Max
viii	Sulphur	0.02, Max
ix	Phosphorus	0.02, Max
x	Sulphur Phosphorus	0.03, Max

NOTE — Actual cast analysis shall comply with 5.2.2.

Table 3: Mechanical Properties (Clause 5.4)

	Properties	Heat Treatment Condition
		Normalized or Normalized and Tempered
i)	Tensile strength (Rg) kgf/mm2 (MPa), Min	68 (670)
ii)	Yield strength (Re) kgf/mm2 (MPa), Min	44 (430)
iii)	Elongation percent, minimum on gauge length = 5.65 √ So	18

NOTE — Alternatively, yield strength shall be 0.2 percent proof stress.

Significant Highlights of the Oxygen Cylinder Specification are:

1. Cylinders have a high-pressure rating, are of seamless construction conforming to IS 7285 Part 1/ 2, certified by Bureau of Indian Standards and approved by Chief Controller of Explosives (CCoE).
2. The cylinder shall be fabricated out of Manganese Steel / Carbon Steel and valves made of brass with chrome plating.
3. Working pressure of 150 barg at 15°C and hydraulic pressure of 250 barg.
4. Minimum two-year guarantee for the cylinders
5. The Colour coding of the cylinder shall be as per IS 3933.

Explore Use of CO_2 Fire Extinguisher Cylinders for Medical Oxygen

Plenty of the fire extinguishers are already available and in use across all the locations, be it in offices, malls, theatres, residential complexes, etc. Since offices, malls, theatres are not in operation, and people are working from home, every city already has the availability of these storage devices. These fire extinguishers can be used without worrying about fire safety as buildings are not occupied. Moreover, these are lightweight, easy to transport, and quick to fabricate in bulk. They can be potential candidates for converting and utilising for storing medical oxygen during emergencies like the COVID19 pandemic.

Some essential considerations for checking the suitability of CO_2 fire extinguisher cylinders as medical oxygen cylinders include a confirmation of its pressure rating specifications, the material of construction, and the available cylinder's capacity.

CO_2 Fire Extinguisher Specification

There are various types of fire extinguishers depending on the class of Fires. Fire extinguishers are covered under IS 15683, Specification for portable fire extinguishers – Performance and construction.

Various fire extinguishers are being used to extinguish different classes of fires and are categorised as under:

a). Based on the class of fire

1. Class A - Fires involving solid materials such as wood, paper or textiles
2. Class B - Fires involving flammable liquids such as petrol, diesel, or oils.

3. Class C – Fires involving gases
4. Class D – Fires involving metals
5. Class E - Fires involving live electrical apparatus
6. Class F - Fires involving cooking oils such as in deep-fat fryers

b). Based on the type of extinguishing media and capacity
1. Water-based extinguisher – 2, 3, 4, 6, and 9 litres
2. Foam based extinguisher – 2, 3, 4, 6, and 9 litres
3. Powder-based extinguisher (ABC/BC/D Type) – 1, 2, 4, 6, 9 and 12 kg
4. Carbon dioxide (CO_2) based extinguisher – 2, 3, 4.5 kg
5. Clean agent extinguisher – 2, 4, and 6 kg
6. Water mist type extinguisher – 2, 3, 4, 6, and 9 litres

Out of the above fire extinguishers, only CO_2 extinguishers shall be considered for storing medical oxygen. Other types of extinguishers have limitations on service pressure and test pressures (18 barg and 35 barg, respectively).

Cylinders for CO_2 extinguishers are rated to store the fluid at 169 barg and tested at 250 barg. CO_2 extinguishers are constructed out of Manganese Steel / Carbon Steel Cylinder in compliance with IS 7285.

CO_2 fire extinguishers are generally available in three different capacities 2kg, 3kg, and 4.5kg, and the specifications are tabulated below:

Capacity (kg)	2	3	4.5
Average Discharge Time (Sec)	9	9	10
Height (mm)	580	545	705
Diameter (mm)	108	140	140
Empty Weight (kg)	6.2	9.9	12.4
Filled Weight (kg)	8.2	12.9	16.7
Operating Temperature (Deg. C.)	-30 to +60	-30 to +60	-30 to +60
Service Pressure (barg)	169	169	169
Test Pressure (barg)	250	250	250

Pressure Suitability/Mechanical Integrity:

The suitability of CO_2 extinguishers is checked for pressure rating, and the material of construction. Technically, it seems to be feasible to use CO_2 extinguishers for medical oxygen storage.

Both CO_2 fire extinguisher cylinders and medical oxygen cylinders are already constructed in compliance with the same IS 7285 specifications. Therefore, as far as construction materials are concerned, the CO_2 fire extinguisher cylinders are suitable for medical oxygen usage.

Medical oxygen cylinders generally store the oxygen at ~150 barg. The CO_2 fire extinguisher cylinders are also suitable and rated to handle the fluid pressures up to 169 barg and are tested at 250barg. Therefore, from the viewpoints of mechanical integrity, operating pressure, test pressure, and design pressures, CO_2 fire extinguishers qualify for usage as Medical Oxygen cylinders.

However, other issues related to converting CO_2 fire extinguisher cylinders to medical oxygen cylinders related to fitting an appropriate valve, colour coding, flushing and cleaning, degassing, etc., by the Petroleum and Explosives Safety Organization (PESO) can be applied. Refer to Annexure – 1 for PESO guidelines.

Nozzle Suitability

The nozzle is screwed to the coupling that is welded on the cylinder body. CO_2 extinguisher nozzle construction may not be suitable for medical oxygen gas, and hence the nozzle needs to be replaced with an oxygen service nozzle. Also, the end connections (threading) of oxygen nozzles must match CO_2 extinguisher coupling. OEMs of oxygen nozzles can confirm the suitability of installation on CO_2 extinguishers. It may be necessary to modify the threading on oxygen nozzles to match the CO_2 extinguisher nozzle threading. Availability of nozzles for oxygen and replacement methodology, repair locations, and feasibility of quick replacement needs to be addressed before proceeding with such conversions.

The pressure ratings and material of construction are observed to be suitable for medical oxygen storage. However, permission must be obtained for ISI certification conforming to IS 7285 by BIS and approval by CCoE for storage of medical oxygen gas before deploying.

The ready availability of nozzles for oxygen service and quick replacement methodology must be further reviewed before the conversions and use as oxygen storage. The necessary clearance from related government agencies must be taken before implementing such conversion.

Residence Time:

While critical and severe patients would require high oxygen flow and be considered for mechanical ventilators, mild condition patients would require oxygen at roughly 0.5 ltr per minute to 2 ltr per minute. Such patients can be considered for getting supplies from these makeshift converted cylinders.

The maximum capacity (4.5 kg) of CO_2 fire extinguisher cylinder can supply oxygen for 13hrs to 54 hrs. As an emergency solution, it may be feasible to replace (and refill) the cylinders twice a day. It may be noted that these cylinders are readily available everywhere, including in smaller cities in interior India. Additionally, these cylinders are easy to handle due to their relatively small weight.

When CO_2 fire extinguisher cylinders are used for medical oxygen, the residence time for supply through one cylinder for three capacities of CO_2 extinguishers is tabulated below

CO_2 Extinguisher Capacity (kg)	Min. Residence Time (Hrs)	Max. Residence Time (Hrs)
2	6.7	26.7
3	10.6	42.2
4.5	13.7	54.6

For the higher oxygen requirements, it is recommended to make a bank of multiple converted cylinders. This is still possible to implement quickly and will help in emergencies.

Conversion of CO_2 Fire Extinguishers for Medical Oxygen

Another issue related to the conversion of CO_2 fire extinguisher cylinders or LPG cylinders (LPG is discussed in next section) to medical oxygen cylinders is related to the fitting of an appropriate valve, colour coding, flushing, etc., guidance from the 'Petroleum And Explosives Safety Organisation' (PESO) can be applied for these issues. PESO has issued a standard operating procedure and guidance (Procedure No. D-21013/PBL/18-Exp dated 22-04-2020) to convert nontoxic and non-flammable high-pressure industrial gas cylinders, i.e., Argon, Nitrogen, and Helium to cylinders for medical oxygen service during the COVID19 pandemic. The same can be suitably applied for converting CO_2 fire extinguisher cylinders or LPG cylinders into medical oxygen cylinders.

Suggested procedure from PESO guidance is reproduced in Annexure-1 for ready reference and information.

Since the fire extinguishers are easy and quick to fabricate and large numbers are already available they can be immediately transported to locations that severely lack oxygen availability. These are easy to convert for oxygen storage, easy to test, refill and transport. The pressure ratings and material of construction are observed to be suitable for medical oxygen storage. However, permission must be obtained for ISI certification conforming to IS 7285 by BIS and approval by CCoE for storage of medical oxygen gas before deploying.

The ready availability of nozzles for oxygen service and quick replacement methodology must be further reviewed before the conversions and use as oxygen storage. The necessary clearance from related government agencies must be taken before implementing such conversion.

Explore Use of LPG Cylinders for Medical Oxygen

LPG cylinders are widely available, and the network of supply chain has matured. As an alternative solution during emergencies, the use of LPG cylinders for medical oxygen can be explored. LPG cylinders are rated for a much lower pressure than conventional medical oxygen gas cylinders. However, the lower pressure could result in lower residence times, which should not be a concern for exploring its suitability for medical oxygen. The suitability of basic materials of construction is reviewed. Irrespective of the pressure rating and/or materials suitability checks, it is vital to note that the LPG is a flammable fluid. It CAN NOT be directly used by filling oxygen into it.

It must be ensured that all LPG cylinders must be made hydrocarbon-free before filling oxygen. The use of new cylinders is highly recommended to avoid issues of internal corrosion. The cylinders must be cleaned appropriately, inertized, hydro tested before using for oxygen service. It is also recommended to install suitable filters in the oxygen supply line from the converted LPG cylinders.

Material and Type of Construction for LPG Cylinder

LPG cylinders conform to IS 3196 and are manufactured from low carbon steel of welded construction. The steel sheet conforms to IS 6240/ IS 15914 as per the details given below.

IS 6240: Hot Rolled Steel Plate (up to 6 mm) Sheet and Strip for the Manufacture of Low-Pressure Liquefiable Gas Cylinders

Table 1 Chemical Composition (Clauses 6.1 and 6.2) Constituent, Percent

Grade	Constituent Percent					
	Carbon	Manganese	Silicon	Sulphur	Phosphorus	Aluminium
	Max	Min	Max	Max	Max	Min
(l)	(2)	(3)	(4)	(5)	(6)	(7)
1	0.16	0.30	0.25	0.025	0.025	0.020

NOTES:

1. Elements not listed in this table may not be added intentionally to the steel. All suitable arrangements are to be made to prevent such elements being added from scrap or other materials used during manufacture, which impair the mechanical properties and usability.
2. Steel maybe supplied with the addition of micro-alloying elements like niobium, titanium, and vanadium. The micro-alloying elements shall not exceed 0.1O percent when added individually or in combination.
3. The nitrogen content of the steel shall not be more than 0.009 percent. This has to be ensured by the manufacturer oy occasional check analysis.

Table 3 Mechanical Properties (Clauses 7.2 and 8.2.2)

Tensile Strength MPa	Yield Stress MPa	Percentage Elongation at Gauge Length s.Gs S:	Internal Diameter of Bend
	Min	Min	Max
(1)	(2)	(3)	(4)
350 - 450	240	25	t

NOTE - Where 't' is the thickness oftest piece.

IS 15914: High Tensile Strength Flat Rolled Steel Plate (Up To 6 mm), Sheet and Strip for the Manufacture of Welded Gas Cylinder

Table 1 Chemical Composition (Clauses 5.2, 6.1 and 6.2)

		Constituent, Percent					
S. No.	Grade	Carbon	Manganese	Silicon	Sulphur	Phosphorus	Aluminium
		Max	Min	Max	Max	Max	Min
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i	HS 235	0.16	0.30	0.25	0.025	0.025	0.015
ii	HS 265	0.18	0.40	0.30	0.025	0.025	0.015
iii	HS 295	0.19	0.50	0.35	0.025	0.025	0.015
iv	HS 345	0.20	0.70	0.45	0.025	0.025	0.015

NOTES:

1. Elements not listed in this table may not be added intentionally to the steel. All suitable arrangements are to be made to prevent such elements being added from scrap or other materials used during manufacture, which impair the mechanical properties and usability
2. Steel may be supplied with the addition of micro-alloying elements like niobium, titanium, vanadium and boron. The micro-alloying elements shall not exceed 0.10 percent when added individually or in combination.
3. The nitrogen content of the steel shall not be more than 0.009 percent. This has to be ensured by the manufacturer by occasional check analysis

Table 3 Mechanical Properties (Clause 7.1)

Grade	Constituent Percent					
S. No.	Grade	Tensile Strength Mpa	Yield Stress MPa Min	Percent Elongation at Gauge Length Min		Reference Heat Treatment Austenitizing Temperature
				< 3MM (see Note 2)	3 to 6 mm (see Note 3)	
i	HS 235	360 - 460	235	22	30	920 - 960
ii	HS 265	410 - 510	265	20	28	890 - 930
iii	HS 295	450 - 560	295	18	26	890 - 930
iv	HS 345	490 - 610	345	17	24	880 - 920

NOTES:

1. The above properties are specified for flat rolled steel and should meet the properties of normalized (Time at austenitizing temperature approximately 2 min/mm of plate thickness) / stress relieved (Time at stress relieving temperature: as prescribed for Indian domestic cylinder) cylinders. Considering the drop in the normalizing, tensile properties of flat rolled products are to be mutually agreed upon between the cylinder manufacturers and steel producers for normalizes cylinders
2. Percentage elongation for products of thickness less than 3 mm, is calculated based on test pieces with a width of 20 mm and a gauge length of 80 mm
3. Percentage elongation for products of thickness 3 to 6 mm, is calculated based on test pieces with a gauge length of Lo = 5.65 S_0 (S_0 is the initial cross-sectional area of the test piece)

The LPG cylinder is of welded construction with cold or hot drawn pressure-formed cylindrical portion, hemispherical, ellipsoidal, or tori-spherical welded ends or two halves cold or hot drawn and welded circumferentially together.

Analysis of Materials of Construction

- The chemical composition of steel for the two cylinders (Oxygen and LPG) are different in carbon, Manganese, and silicon contents. This will result in different mechanical properties. It is evident that the higher carbon content of steel used in oxygen cylinders results in better mechanical properties.
- It is observed that the steel for LPG cylinders has slightly higher Sulphur and phosphorus content but is considerably lower in manganese content.
- Phosphorous strengthens low carbon steel and increases corrosion resistance. It is also useful in improving machinability. Similarly, Sulphur helps to improve machinability but has little impact on mechanical properties.
- The variation in phosphorus content (Very small quantity in oxygen cylinders – 0.015%) and sulfur content (Very small quantity in oxygen cylinders – 0.02%) seems to be acceptable from the point of using LPG cylinders for oxygen service.

Since LPG cylinders are rated for lower pressures than oxygen cylinders, it is evident that the compositions of oxygen cylinders and LPG cylinders are accordingly different. However, considering the use of LPG cylinders for low-pressure oxygen storage, the basic construction of LPG cylinders seems to be acceptable, especially during emergencies. (and subject to other procedure/approvals by relevant statutory bodies)

Pressure Rating

Oxygen cylinders have a nominal pressure rating of 137 barg for standard valve and 230-300 barg for integral valve cylinders. LPG cylinders are pressure rated at 16.5 barg vapour pressure with a test pressure of 25 barg.). A regulator of a different design than used in a standard oxygen cylinder would have to be installed on an LPG cylinder to match the delivery pressure from the lower storage pressure allowed for LPG cylinders.

Storage Capacity

Oxygen cylinders for medical use have a storage volume of 10 litres. A domestic LPG gas cylinder has a length of cylinder - 625 to 630 mm, diameter - 314.4 to 317 mm, water capacity 33.3ltr, storing 14.2 kg of LPG.

If proposed for use, existing cylinders will need to be cleaned entirely according to PESO Standard Operating Procedure No. D-21013/PBL/18-Exp dated 22-04-2020. New cylinders before first use should also be flushed and cleaned to the required standard suitable for medical oxygen supply.

Nozzle Suitability

The nozzle is screwed to the coupling that is welded on the cylinder body. LPG cylinder nozzle construction may not be suitable for medical oxygen gas, and hence the nozzle needs to be replaced with an oxygen service nozzle. Also, the end connections (threading) of oxygen nozzles must match LPG cylinder coupling. OEMs of oxygen nozzles can confirm the suitability of installation on LPG cylinders. It may be necessary to modify the threading on oxygen nozzles to match the LPG cylinder nozzle threading. Availability of nozzles for oxygen and replacement methodology, repair locations, and feasibility of quick replacement needs to be addressed before proceeding with such conversions.

Residence Time

While critical and severe patients would require high oxygen flow and be considered for mechanical ventilators, mild patients would require oxygen at roughly 0.5 ltr per minute to 2 ltr per minute. Such patients can be considered for getting supplies from these makeshift converted cylinders.

The LPG cylinder can supply oxygen for ~5 hrs to 20 hrs. As an emergency solution, it may be feasible to replace (and refill) the cylinders 2-3 times a day. It may be noted that these cylinders can be readily available everywhere, including in smaller cities in interior India. Additionally, these cylinders are easy to handle due to their relatively small weight.

When LPG cylinders are used for medical oxygen, the residence time for supply through one LPG cylinder is tabulated below -

The residence time of full cylinder with a flow rate of 0.5 ltr/min to 2 ltr/min is as follows:

Capacity	Min Res time	Max Res time
kgs	hr	hr
1 kg of Oxygen	4.9	19.6

As stated earlier, While the single-cylinder usage may be good enough for some of the patients, When the requirements of oxygen are higher, it is recommended to prepare a bank of multiple cylinders for supplying oxygen to the patient. This can be quickly done by designing a piping manifold for networking 6 to 10 cylinders in one bank.

Conversion of LPG Cylinders for Medical Oxygen

LPG cylinders are already available in large numbers based on the number of connections (approximately 28.13 crore connections as per the latest estimates). The manufacturing can be ramped up easily to meet the additional demand for use in the storage distribution of medical oxygen. The distribution network is also well organised with good penetration in remote areas.

The difference in the construction material (steel grade) between conventional oxygen cylinder and available LPG cylinder may be acceptable considering the lower storage pressure rating of LPG. The flow regulator device also must be suitably designed to operate at a lower inlet pressure of 16.5 barg of LPG cylinder and required outlet pressure for therapeutic oxygen supply.

New, unused cylinders will be preferred to avoid the possibility of contamination. In case used cylinders also

Almost all hydrocarbon-based contaminants can be removed by either aqueous-solution washing or organic solvent washing, either in the liquid or in the vapour phase. However, some pollutants become very difficult to remove by any method if an organic solvent is used first; since this solvent converts them to insoluble gums. Of course, the cleaning solution must be compatible with the intended gas service, particularly for oxidising gases, and must be removed without leaving any harmful residue.

need to be used in an emergency, complete inertization from hydrocarbons will have to be carried out by purging with nitrogen/ air and drying to render it suitable for medical oxygen administration.

The PESO guidance, as highlighted in annexure -1, can be suitably amended to include the inertization process. Other suggested conversion measures such as replacement of nozzles, regulator, colour coding, etc., can be carried out as per the PESO guidance. The ready availability of nozzles for oxygen service and quick replacement methodology needs to be further reviewed.

Necessary regulatory approval to PESO specifications and CCoE guidelines for the safety of the modified equipment will have to be taken before deployment. This alternate storage and distribution scheme may help in providing the required medical help to critical patients.

Cleaning and Inertization of Gas Cylinders

As stated in the above sections, it is essential to properly clean the CO_2 fire extinguisher and LPG cylinders before reusing them for medical oxygen service. It requires a careful inspection of the interior and exterior of the cylinder to detect the presence of corrosion products or contaminants, which must be removed for safety reasons or to avoid undesirable contamination of the contained gas. Particular attention shall be directed to assuring that purging or cleaning procedures remove all residual gas, contaminants or corrosion products and that the cleaning agents are removed and cylinders dried and sealed to prevent the entry of dirt or moisture after cleaning.

International standard ISO-11621 provides general requirements and procedures to be considered whenever a cylinder is converted from one gas service to another for permanent and liquefied gases. This guidance shall be implemented for cleaning the CO_2 fire extinguisher and LPG cylinders.

Almost all hydrocarbon-based contaminants can be removed by either aqueous-solution washing or organic solvent washing, either in the liquid or in the vapour phase. However, some pollutants become very difficult to remove by any method if an organic solvent is used first; since this solvent converts them to insoluble gums. Of course, the cleaning solution must be compatible with the intended gas service, particularly for oxidising gases, and must be removed without leaving any harmful residue.

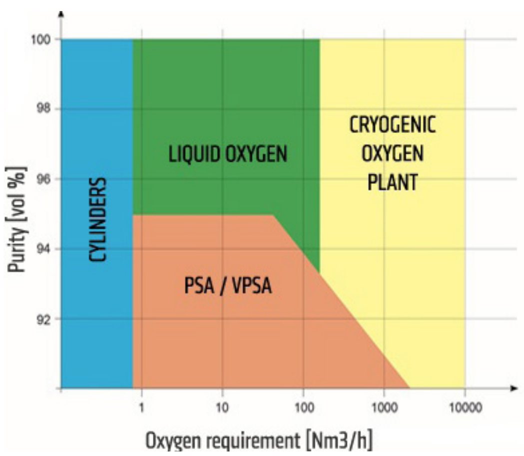
The guidance provided in ISO 11621 shall be implemented for inspection, inertization, and solvent selection to clean the internals and drying, sealing the cylinders before conversion to oxygen service.

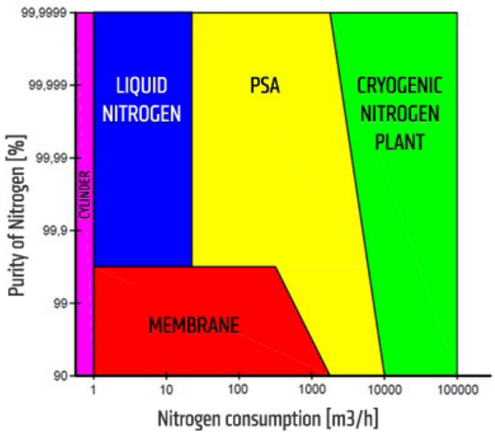
Feasibility of Converting Industrial Nitrogen Generation Units to Oxygen

Industrial nitrogen is typically produced using one of the following three technologies:

- Membrane Technology
- Air Separation Units
- Pressure Swing Adsorption (PSA) technology

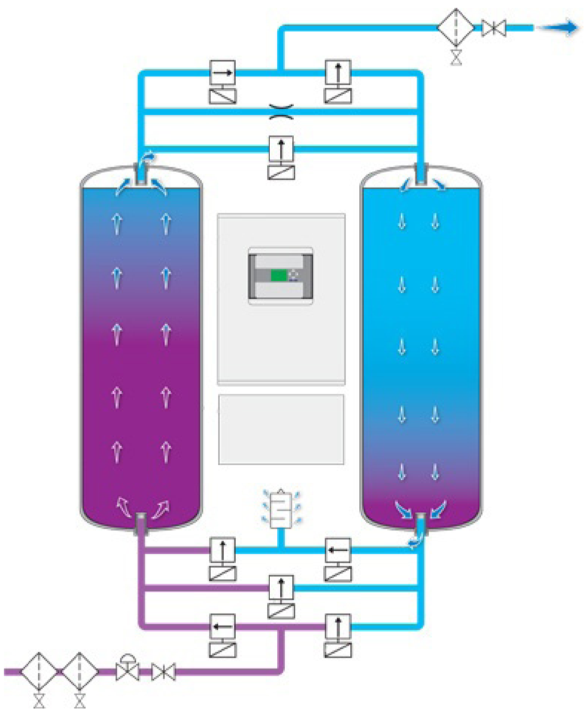
Industrial Oxygen is produced by using either Air Separation units or PSA technology.





While membrane technology is not suitable for oxygen generation, the air separation process requires cryogenic distillation and produces nitrogen and oxygen. The PSA technology used for the generation of industrial nitrogen can be considered for conversion into an oxygen generation facility. As shown from the above figures, the PSA technology is generally used for small capacities that suit typical hospitals' medical oxygen requirements. Therefore, a review is carried out to check the feasibility of converting industrial nitrogen units into oxygen making units.

Pressure Swing Adsorption Working Principle



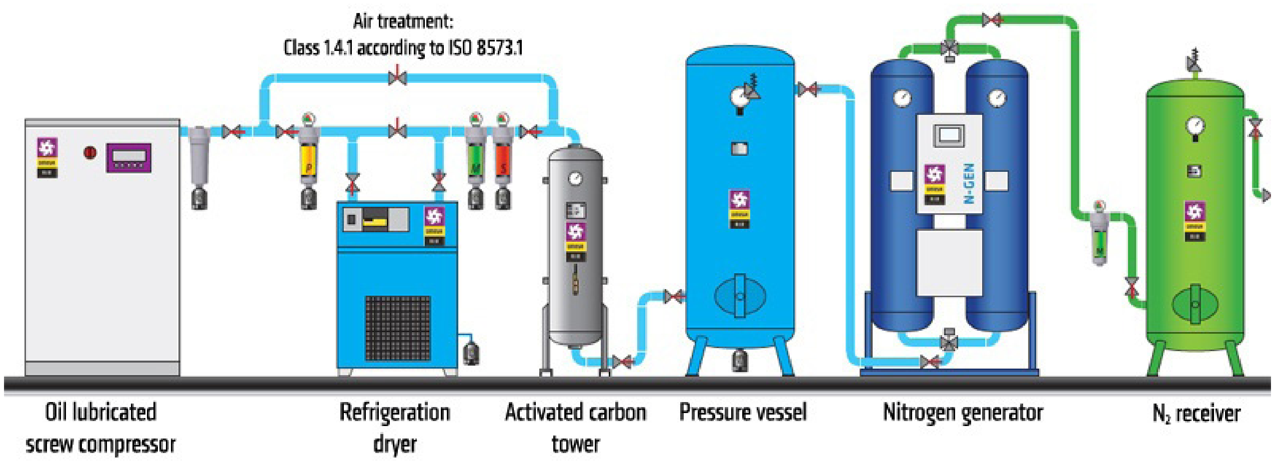
The atmospheric air is compressed and sent to one of two adsorption beds packed with an adsorbent material. The adsorbent material for nitrogen generation units is carbon sieves, while for oxygen generation units, it consists of molecular sieves made from zeolites. In nitrogen generation units, the oxygen and carbon dioxide molecules in the air diffuse into the pore structure of the adsorbent whilst the nitrogen molecules are allowed to travel through the adsorbent bed. In oxygen generation units, the nitrogen and carbon dioxide molecules in the air diffuse into the pore structure of the adsorbent whilst the oxygen molecules are allowed to travel through the adsorbent bed. The second bed is used to regenerate the adsorbed material. Automatic switching between adsorption and desorption enables the continuous production of nitrogen or oxygen.

It can be noted that the PSA technology for generating oxygen and nitrogen is similar with a difference in adsorbent material. Both the units generally operate at 6 to 8 barg pressure. Nitrogen generation units based on PSA technology are commonly employed in the industry and are widely available. Hence, the concept of converting industrial nitrogen PSA plants to generate oxygen can be explored as it would involve simply a change of adsorbent bed material. The adsorbent will need to be changed to zeolite to capture nitrogen and produce oxygen.

OEMs of PSA units need to confirm the recalibrated capacity of available units when converted from nitrogen service to oxygen service after meeting the purity requirements of medical oxygen.

The converted PSA plants can quickly produce oxygen meeting above purity level of a minimum of 90%.

A typical nitrogen PSA plant is depicted below.



A typical oxygen PSA plant would be precisely similar, with the only difference being adsorbent bed material.

Plant Capacity Limitations

As the composition of oxygen in the air is only about 21% and zeolite's adsorption capacity is different from the molecular sieves, the resultant plant capacity (and the cycle times) will need to be recalculated based on the adsorption capacity and bulk density of the zeolite. But this will be much less than the original nitrogen production capacity of the plant. Nonetheless, it is technically feasible to convert the PSA nitrogen Plant to produce oxygen. The adsorbent beds can be readily available with OEMs and can be quickly implemented.

Pressure Limitations:

Most industrial plants typically are designed for and produce nitrogen at around 7 barg pressure. Therefore, the produced oxygen will also be around similar pressure only. However, the medical oxygen cylinders are filled at a pressure of 150 bar g, which will require the installation of a booster compressor, a low-pressure oxygen storage vessel (upstream of the booster compressor), a downstream high-pressure oxygen receiver, and a cylinder filling system. The preliminary scheme is depicted in Annexure 2.

Such booster compressors and the oxygen vessels may not be available off the shelf and may require a few months of lead time for procurement and fabrication, etc. and may not be immediately possible to implement. Therefore, it would be best to shift these converted PSA units to hospital premises to help emergencies.

Feasibility of Using Nitrogen Plants for Oxygen Generation

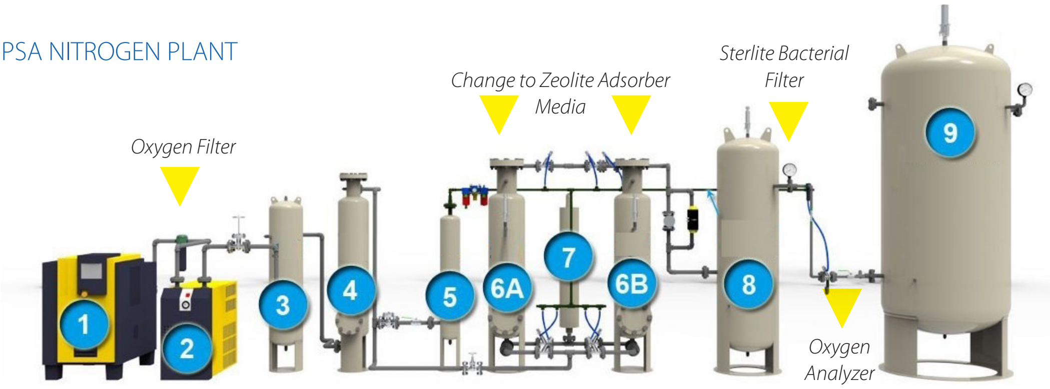
Given the urgency of the situation, one option is to physically shift such converted PSA Plants to the location of the temporary COVID19 hospital facilities. These plants are typically skid-mounted and, therefore, can be easily shifted. These plants will have to be connected to the Oxygen Piping Network of the COVID19 facility through pressure control Valves and can be quickly commissioned.

Changes to Existing Nitrogen PSA Units for Conversion to Oxygen Generation Units

PSA OXYGEN PLANT

1. Air Compression
2. Air Filtration
3. Air Drying
4. Air Buffer Tank
5. Trace Oil Particle Filter
6. Air Buffer for Pneumatic Valves
7. A Adsorbing Tower A
   B Adsorbing Tower B
8. Flue Gas Vent Silencer
9. Oxygen Surge/Buffer tank
10. Oxygen Storage Tank

PSA NITROGEN PLANT



1. Air Compression
2. Air Drying
3. Air Buffer Tank
4. Trace Oil Particle Filter
5. Air Buffer for Automatic valve
6. A. Adsorbing Tower
6. B. Adsorbing Tower B
7. Flue Gas Vent Silencer
8. Nitrogen Surge/Buffer tank
9. Nitrogen Storage Tank

The typical configuration of industrial units for generating nitrogen and oxygen through PSA technology is shown in the figure below. As discussed in earlier sections, the basic configuration of both units is similar. The significant difference being the adsorbent material which is different for nitrogen and oxygen units. When the adsorbent material (activated carbon) of the nitrogen generating units is replaced (by Zeolites), the same unit that was earlier producing nitrogen will be suitable for producing oxygen. The OEMs also confirm this point. However, when such conversion is implemented, the nameplate capacity of the converted unit will be reduced roughly to 25% of the original nitrogen generation capacity. Some of the significant steps involved in the conversion are as below in yellow highlight.

- Unit to be depressurised, Purged with air and decontaminated.
- Replace the adsorbent beds of both the vessels
- On exit pipeline, install a new oxygen analyser to check purity compliance of medical oxygen requirements
- A fine filter for any particulate matter, dust etc. to be added to suit oxygen specs
- This can be further connected to the pressure regulator to meet the supply pressure requirements of medical oxygen to patients.

Generally, three weeks is estimated by a few OEMs for complete conversion of the units. The time indicated by OEMs is on the higher side because of the OEMs internal process of Job creation, procurement of adsorbent beds and other equipment like oxygen filter, oxygen Analyser, some amount of piping change to add this additional equipment, transport to site and then site installation, recommissioning etc. Site work will require flushing/ cleaning/ purging the entire PSA Plant and making it suitable for medical Oxygen production. The estimated time of three weeks includes the time from order to medical oxygen out.

Considering the steps involved in the conversion, it seems possible to convert these units quicker than the typical three weeks indicated by some of the OEMs. However, with a national crisis and considering emergencies for the need of additional oxygen manufacturing, this three weeks' time can be crashed to one week when directly Government / Group level efforts happen.

Concluding Remarks

As discussed in the respective sections, all three options are technically feasible and duly address the changes/ modifications. It is suggested to obtain necessary statutory approvals.

CO_2 and LPG cylinder nozzle construction and end threading may not be suitable for medical oxygen gas are to be replaced with oxygen service nozzle. Another item that needs to be investigated is that oxygen is a dry gas. All medical oxygen cylinders come with a regulator, which also has a moisturiser or a humidifier. In the nozzle regulators of medical oxygen cylinders that need to be fixed to these CO_2 or LPG cylinders, a critical data that needs to be checked is the diameter of the exit nozzle. The design modification and nozzle fabrication and fixing aspects need further detailing.

These issues must be resolved upfront with OEMs of Oxygen, and suitably modified designs worked out. In addition, the logistics of fabrication and installation of the modified design and servicing of faults/ defects must be established through a network of distributors and service providers to implement these innovative solutions fruitfully. These alternate storage and distribution schemes may help provide the required medical help to patients in the early stages of the disease requiring moderate interventions.

Technically, it seems feasible to convert the CO_2 fire extinguisher cylinders and LPG cylinders into medical oxygen cylinders. The concept can be suitably detailed out for execution after approvals are obtained from concerned government agencies. However, It is important to note the following:

- Fire extinguisher cylinders are already available in large numbers and easy and quick to fabricate. They can be easily transported to the desired locations. These are technically suitable for conversion for oxygen storage, fill and transport. Oxygen nozzle fitting on CO_2 fire extinguisher cylinders needs further review and confirmation. Necessary BIS certification and approval by CCoE to store medical oxygen gas agencies must be taken before implementing such conversion.
- LPG cylinders are already available in large numbers, and additional fabrication can be taken up quickly. The high penetration of the distribution network can be advantageous for medical facilities in remote areas. The lower operating pressure will preclude the difference in construction without hampering safety for use. The cylinders must be made hydrocarbon-free, corrosion-free, entirely inert to ensure suitability for medical oxygen use. Oxygen nozzle fitting on LPG cylinders needs further review and confirmation. Necessary regulatory approval to PESO specifications and CCoE guidelines for the safety of the modified equipment will have to be taken before deployment.
- By changing the adsorbent bed material, industrial nitrogen PSA units can be quickly converted to produce oxygen. Setting up modular, skid-mounted converted PSA Plants to the location of the temporary COVID19 hospital facilities will ensure a local source of oxygen generation at remote locations. Connecting these plants to the oxygen piping network of the COVID facility through pressure control valves and can be quickly commissioned.

The Company

Delivering Aspirations, Achieving Scale

Established in 1962, Tata Consulting Engineers Limited (TCE) offers its customers invaluable expertise – a by-product of more than five decades of premier service as an integrated engineering service provider. To date, we have completed more than 10,000 assignments in over 55 countries.

Our specialised, in-house talent pool and the ability to provide holistic solutions under one-roof, makes us a force to be reckoned with, in the following engineering consulting sectors:

1. Infrastructure
2. Power
3. Resources - Mining & Metals
4. Resources - Hydrocarbons & Chemicals

TCE serves domestic as well as international markets and is known for several first-of-its-kind projects offering the following services:

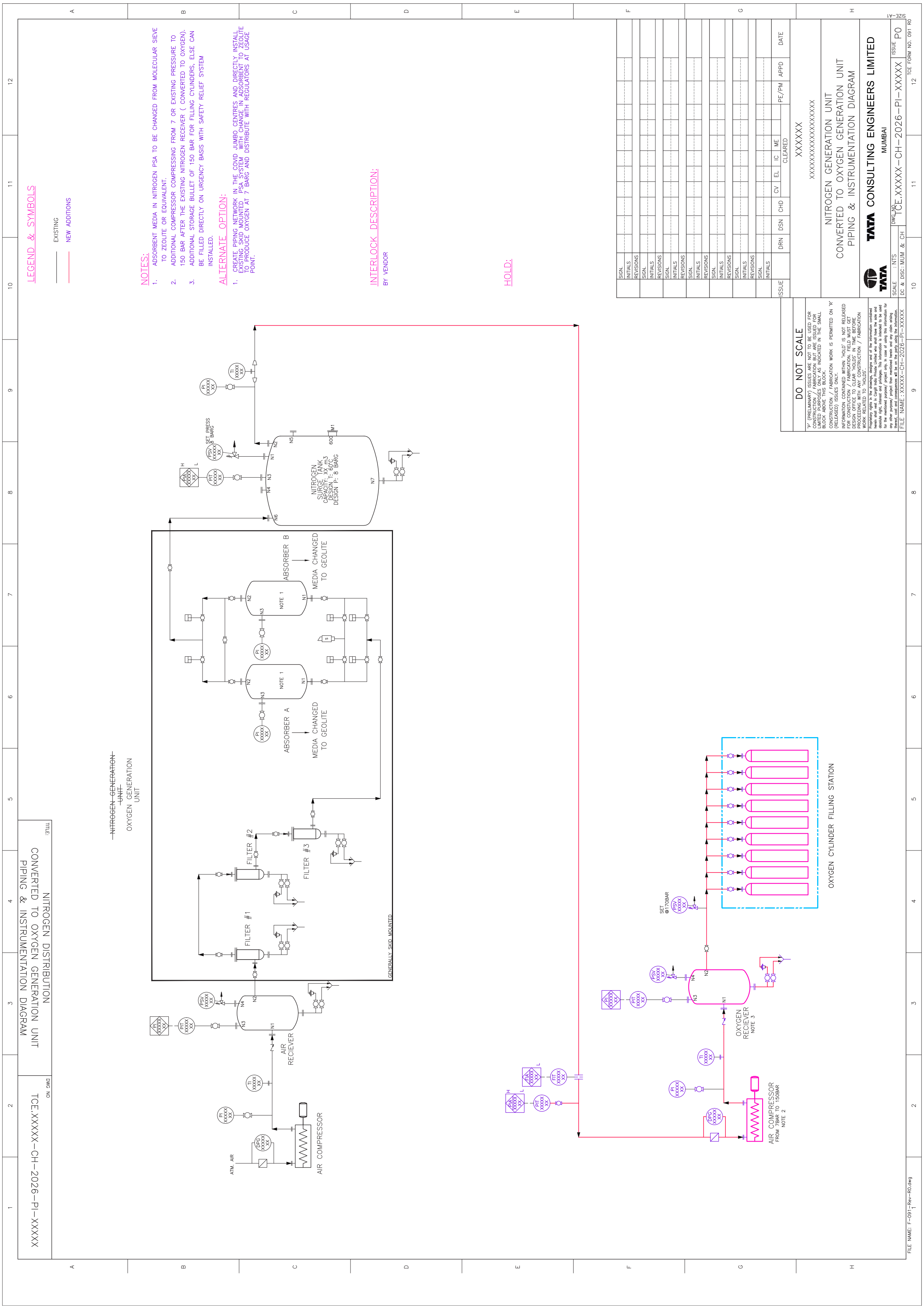
1. Design & Engineering
2. Project Management & Safety
3. Procurement Management
4. Digital & Advanced Technologies

REIMAGINE
REINVENT
GROW

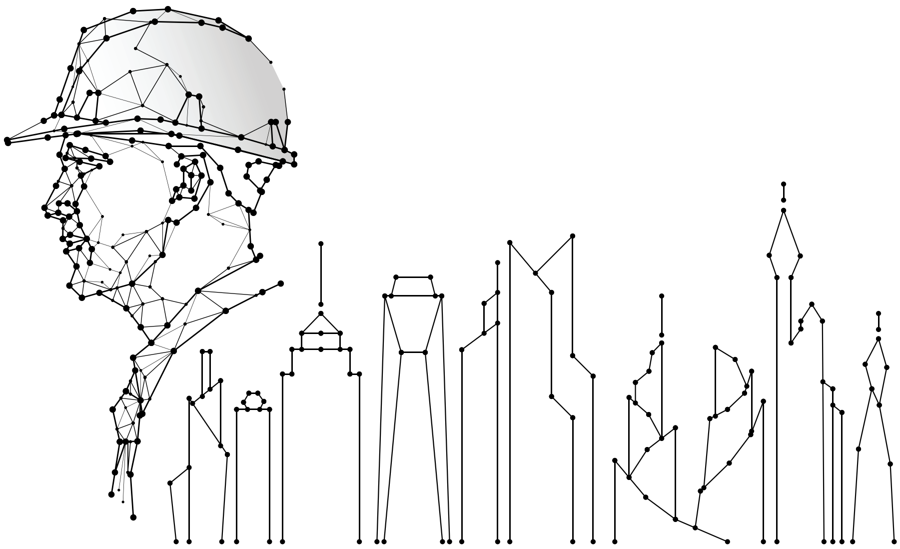
Annexure 1: PESO Guidance

1. The Cylinders shall be completely degassed, adequately cleaned from inside and outside, purged, and/or evacuated to remove any contaminations like water, oil, hydrocarbons, etc., if any, after degassing and safe removal of the valve. Refer to ISO 11621 for detailed cleaning procedures. Organic solvents like Carbon Tetra Chloride shall not be used as they are toxic.
2. Ensure that the cylinders have passed the last cylinder periodic examination/re-test as per Rule 26 of the Gas Cylinders Rules, 2016. However, the periodic testing of cylinders is extended from 5 years to 5 years 3 Months for those cylinders which are due for statutory hydro-testing on 31.03.2020 because of the ongoing COVID19 pandemic and shall be reverted to 5 years once the Government of India declares that the pandemic is over. The extension of cylinder re-test is also applicable to industrial Oxygen cylinders used in medical Oxygen service. The records of such cylinders shall be maintained.
3. Cylinders shall be fitted with appropriate valves according to the medical gas in line with IS:3224. In this case, change valve with IS 3224 No.20 (3/4 BSP RH External thread) to IS outlet No.3 (5/8 BSP, RH, internal thread) for oxygen. During the COVID19 crisis, industrial oxygen valves (without chrome plating) may be fitted and used in medical oxygen service since the outlets are identical. Where yoke-type valves are needed to be installed for small cylinders, it shall be according to IS 3745.
4. Colour-code of cylinders and warning labels shall be according to "IS 3933: Colour identification of gas cylinders and related equipment intended for medical use". This is also applicable to industrial oxygen cylinders, which are converted to medical Oxygen service.
5. These activities shall be carried at the E&F licensed premises only.
6. The records of such converted cylinders shall be maintained.

Annexure 2


LEGEND & SYMBOLS
EXISTING
NEW ADDITIONS
NOTES:
1. ADSORBENT MEDIA IN NITROGEN PSA TO BE CHANGED FROM MOLECULAR SIEVE TO ZEOLITE OR EQUIVALENT.
2. ADDITIONAL COMPRESSOR COMPRESSING FROM 7 OR EXISTING PRESSURE TO 150 BAR AFTER THE EXISTING NITROGEN RECEIVER (CONVERTED TO OXYGEN).
3. ADDITIONAL STORAGE BULLET OF 150 BAR FOR FILLING CYLINDERS, ELSE CAN BE FILLED DIRECTLY ON URGENCY BASIS WITH SAFETY RELIEF SYSTEM INSTALLED.
ALTERNATE OPTION:
INTERLOCK DESCRIPTION:
BY VENDOR
HOLD:
NITROGEN GENERATION UNIT
OXYGEN GENERATION UNIT
ABSORBER A
ABSORBER B
MEDIA CHANGED TO GEOLITE
FILTER #1
FILTER #2
FILTER #3
AIR COMPRESSOR
AIR RECIEVER
NITROGEN SURGE TANK
OXYGEN RECIEVER
OXYGEN CYLINDER FILLING STATION
GENERALLY SKID MOUNTED
DO NOT SCALE
NITROGEN GENERATION UNIT CONVERTED TO OXYGEN GENERATION UNIT PIPING & INSTRUMENTATION DIAGRAM
TATA CONSULTING ENGINEERS LIMITED
MUMBAI
TCE.XXXXX-CH-2026-PI-XXXXX

Notes:



VISION

To be an internationally respected engineering consultant offering comprehensive solutions

MISSION

Provide technically excellent and innovative solutions, for adding value for all stakeholders, and operate globally as professional consulting engineers

CORE VALUES

- Customer Satisfaction and Loyalty
- Technical excellence with professional ethics
- Responsibility to society
- Employee dignity and self-respect
- Organisational and individual growth

TATA

TATA CONSULTING ENGINEERS LIMITED

Engineering A Better Tomorrow

Corporate Office: Unit No NB 1502 & SB -1501, 15th floor, Empire Tower, Cloud City Campus, GUT NO 31, Village Elthan, Kalwa Industrial Estate, Thane Belapur Road Airoli, Navi Mumbai – 400708.

Email: tceconnect@tce.co.in | **Website:** www.tce.co.in

April 2021

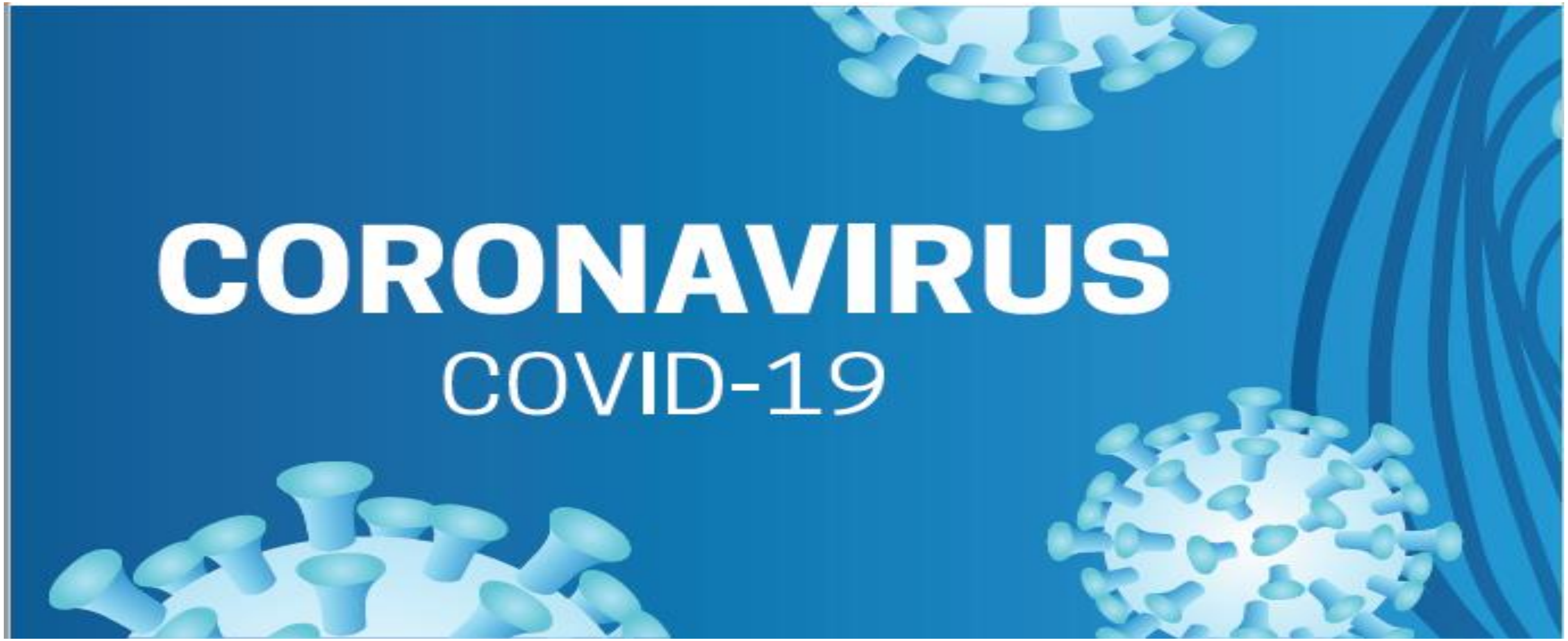
For more details, contact Atul Choudhari @ achoudhari@tce.co.in

TATA

TATA CONSULTING ENGINEERS LIMITED

ENGINEERING A BETTER TOMORROW

OVER FIVE DECADES



Emergency Options for Medical Oxygen Storage and Alternative Mode of Oxygen Generation

PRESENTATION
AGENDA

01 Medical Oxygen and Challenges

02 Explore Use of CO_2 Fire Extinguisher Cylinders

03 Explore Use of LPG Cylinders

04 Cylinder Conversion for Oxygen Service

05 Conversion of Industrial Nitrogen Generation Units for Oxygen

06 Proof of Concept - PSA Plant Conversion at IIT Bombay

Medical Oxygen

European Pharmacopoeia (Ph Eur) specification: Contains between 90.0%V/V and 96% V/V of O_2.

United States Pharmacopoeia (USP) specification: Contains not less than 90.0 % V/V and not more than 96 % O_2 V/V.

OXYGEN CYLINDER SIZE AND CAPACITY:

Size	Capacity (L)	Pressure (psi)	Tare Wt. (kg)	Valve type
B	200	1900	2.27	Pin index
D	400	1900	3.4	Pin index
E	660	1900	5.4	Pin index
F	1360	1900	14.5	Bull nose
G	3400	1900	34.5	Bull nose
H	6900	2200	53.2	Bull nose
M	3450	2200	29.0	Bull nose

Oxygen Cylinder Specification highlights IS- 7285

- Fabricated out of Mn Steel/Carbon Steel
- Valves – Brass with Chrome plating
- Working pressure – 150 barg 15 deg C
- Colour Coding as per IS 3933
- Hydraulic pressure of 250 barg High pressure rating,
- **Approved by CCoE**

Medical Oxygen - Challenges Faced

- Shortage of Liquid oxygen tankers
- Temporary Makeshift Hospitals- No Permanent Piping
- Shortage of Oxygen Cylinders that can be refilled for dedicated supply source
- Shortage of Generation Capacity
- Plans to Import 50,000 MT – Bottleneck in local transport and oxygen storage

Centralized Cryogenic Generation- Distribution is Bottleneck

Other Options - Exhausted

Inadequate In situ Generation at Hospitals

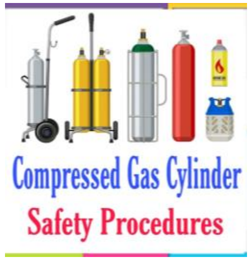
Alternate and out of box solutions for Oxygen **GENERATION** and **DISTRIBUTION** is Crucial

Alternate Methods

Use of CO_2 Fire Extinguisher Cylinders for Storage of Oxygen

Use of LPG Cylinders for storage of Oxygen

Conversion of existing PSA Nitrogen Plants for production of Oxygen



Serving The Nation Since 1898

Ministry of Health and Family Welfare
Government of India

भारत सरकार GOVERNMENT OF INDIA | वाणिज्य और उद्योग मंत्रालय MINISTRY OF COMMERCE AND INDUSTRY

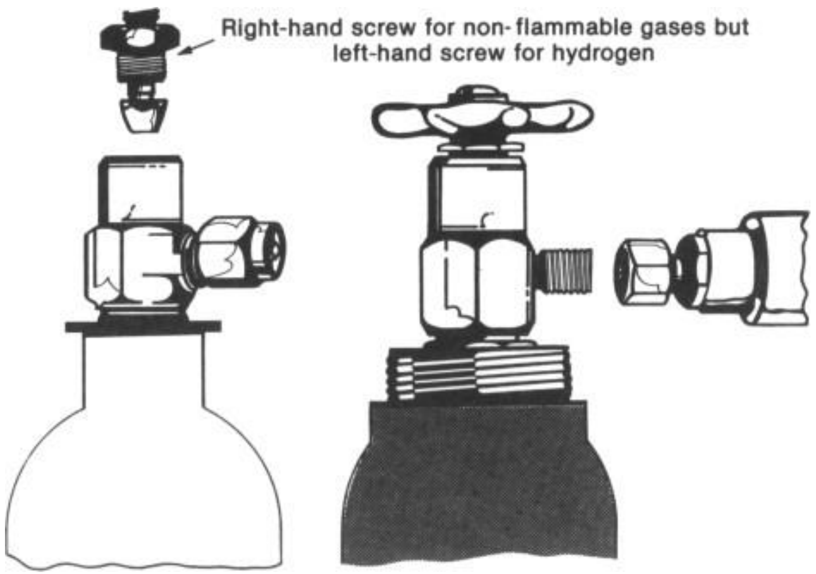
Petroleum & Explosives Safety Organization (PESO)
Department for Promotion of Industry and Internal Trade

All these methods INVOLVE Statutory, Legal and other APPROVALS. They must be done with proper involvement of Government authorities. Proper cleaning and COLOUR coding of CYLINDERS is required for SAFETY reasons. A governance mechanism involving government officials, PESO, Controller of Explosives, Fire Department, Medical Department (Min. of Health) and administrative authorities is required for related compliances and approvals.

CO_2 Fire Extinguisher Cylinders for Storage of Oxygen

CO_2 Fire extinguisher available in 2kg, 3kg and 4.5kg

Capacity (kg)	2	3	4.5
Average Discharge Time (Sec)	9	9	10
Height (mm)	580	545	705
Diameter (mm)	108	140	140
Empty Weight (kg)	6.2	9.9	12.4
Filled Weight (kg)	8.2	12.9	16.7
Operating Temperature (Deg. C.)	-30 to +60	-30 to +60	-30 to +60
Service Pressure (barg)	169	169	169
Test Pressure (barg)	250	250	250



Nozzle suitability

- CO_2 fire extinguisher cylinders are suitable for medical oxygen w.r.t construction and IS compliance
- Medical oxygen cylinders stores the oxygen at ~150 barg. **CO_2 fire extinguisher cylinders** are suitable up to **169 barg** and are tested at **250barg**
- Mechanical integrity, operating pressure, test pressure and design pressures → **CO_2 fire extinguishers qualify for the usage as Medical Oxygen cylinders**

Plenty of Fire extinguisher are already available across – both under new production, or under usage at many locations, offices, Theatres, malls, etc.

Nozzle need to be replaced with oxygen service nozzle; modify the threading on oxygen nozzles to match the CO_2 extinguisher nozzle – Else in case a CYLINDER BANK is being used – no changes needed. It is recommended to use CYLINDER BANK approach as opposed to individual Cylinders for both safety and time since it will not involve any nozzle changes

CO_2 Fire Extinguisher Cylinders for Storage of Oxygen

Residence Time

CO_2 Extinguisher Capacity (kg)	Min. Residence Time (Hrs)	Max. Residence Time (Hrs)
2	6.7	26.7
3	10.6	42.2
4.5	13.7	54.6

- For higher oxygen requirements (10ltr/min) **a bank of multiple converted cylinders** is recommended during emergency

For low flow, one bank can serve to **4-5 patients** and **10** banks can serve a hospital of **50 patients**

Implementation measures

1. BIS certification and approval by CCoE to store medical must be taken
2. Nozzle design suitability to be reviewed and modified if necessary
3. PESO guidelines to be strictly followed w.r.t inerting and cleaning of the cylinders

Website : http://peso.gov.in
Email: explosives@explosives.gov.in
दूरभाष/ Telephone : 0712-2510248
फ़ैक्स/ FAX : 2510577

कार्यालयीन उद्देश्य के सभी पत्रादि "मुख्य विस्फोटक नियंत्रक" के पदनाम से भेजे जाएं उनके व्यक्तिगत नाम से नहीं।
All communications intended for this Office should be addressed to the 'Chief Controller of Explosives' and NOT to him by name.

भारत सरकार
GOVERNMENT OF INDIA
पेट्रोलियम तथा विस्फोटक सुरक्षा संगठन
Petroleum and Explosives Safety Organisation
(पूर्व नाम – विस्फोटक विभाग)
(Formerly- Department of Explosives)
"ए-ब्लाक ú, पाँचवा तल, केन्द्रीय कार्यालय परिसरú,
"A" Block, 5th Floor, CGO Complex,
सेमिनरी हिल्स, नागपूर - 440 006 (महा)
Seminary Hills, Nagpur- 440006

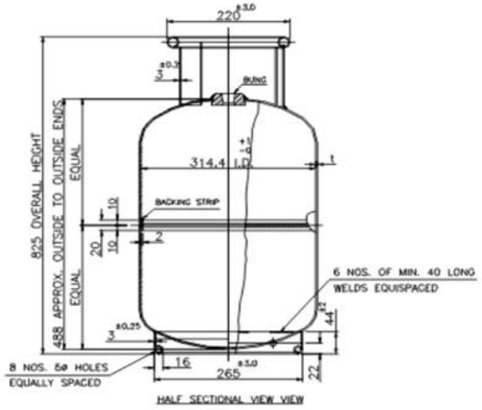
संख्या: D-21013/PBL/18-Exp   दिनांक /Nagpur, dated : 22/04/2020

CIRCULAR

Sub: Standard Operating Procedures (SOP) for conversion of Industrial Oxygen Cylinders and Inert Gas Cylinders (Nitrogen, Argon & Helium only) to Medical Oxygen Cylinders in the wake of COVID-19 pandemic- reg.

PESO Guidance Can Be Suitably Used For Conversion

LPG Cylinders for Storage of Medical Oxygen

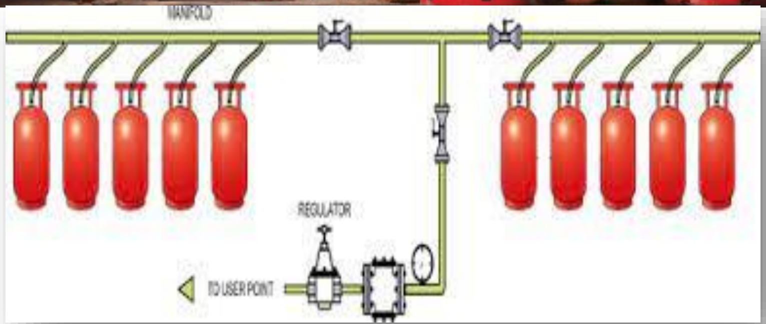


- LPG cylinders are widely available (~28.13Cr connections)
- New / unused cylinder is preferred to avoid possibility of contamination
- Used cylinders during emergency – Inertization (solvent-based cleaning), Purging with Nitrogen/air and drying is necessary

Low Pressure Storage – Lower Residence Time.

Capacity (kg)	Min Res time (hr)	Max Res time (hr)
1 kg of Oxygen	4.9	19.6

Basic Materials Of Construction are Suitable for Oxygen Service



- For requirement of higher oxygen, a bank of 50 cylinders may be used.

Conversion Procedure

- Cleaning And Inertization
- Inspection
- Corrosion Checks
- Nozzle Replacement
- Hydrotest, Drying
- Painting
- Certification and Approvals

INTERNATIONAL STANDARD

ISO 11621

First edition 1997-04-15

Gas cylinders — Procedures for change of gas service

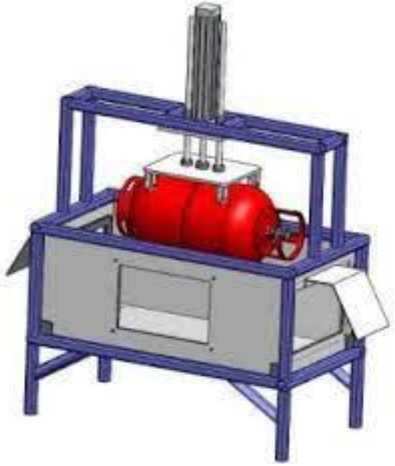
Exterior Cleaning

Equipment for internal inspection of LPG cylinders

STATUTORY APPROVALS TO BE OBTAINED –

(PESO, CCOE, Etc)

Painting

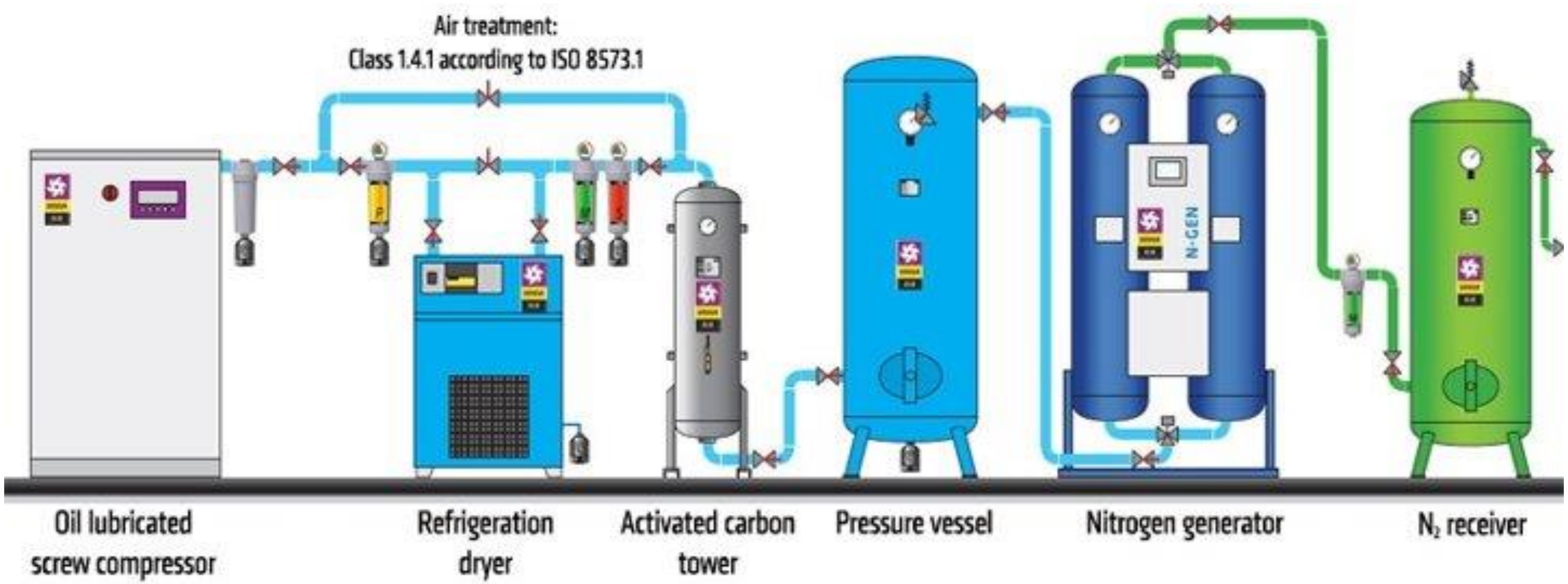


Testing

Nozzle Replacement

Conversion of Industrial Nitrogen Generation Units for Oxygen Generation

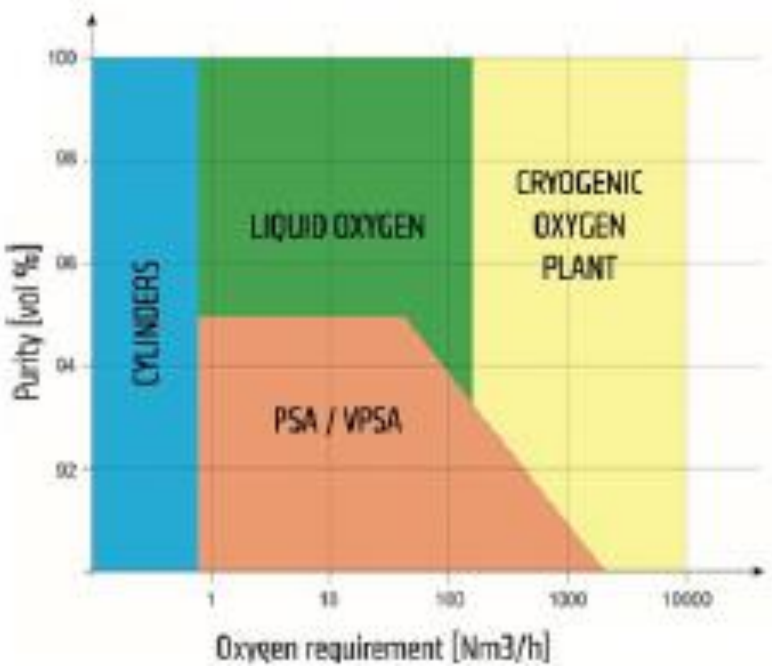
Pressure Swing Adsorption (PSA) technology

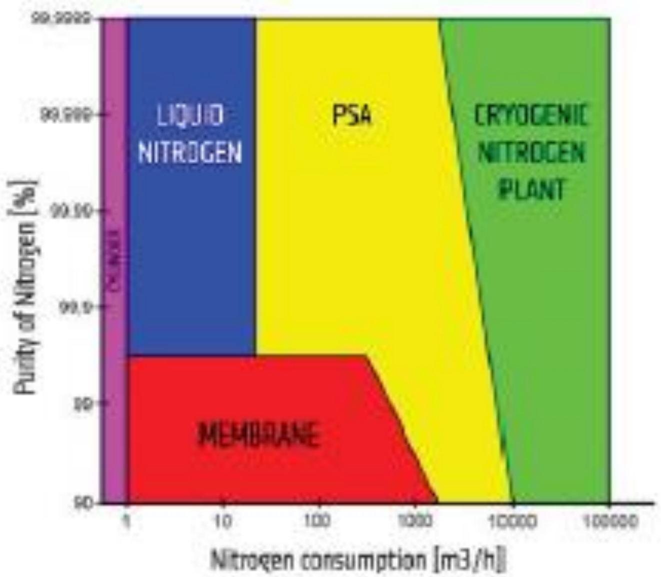


Conversion of Industrial Nitrogen Generation Units for Oxygen

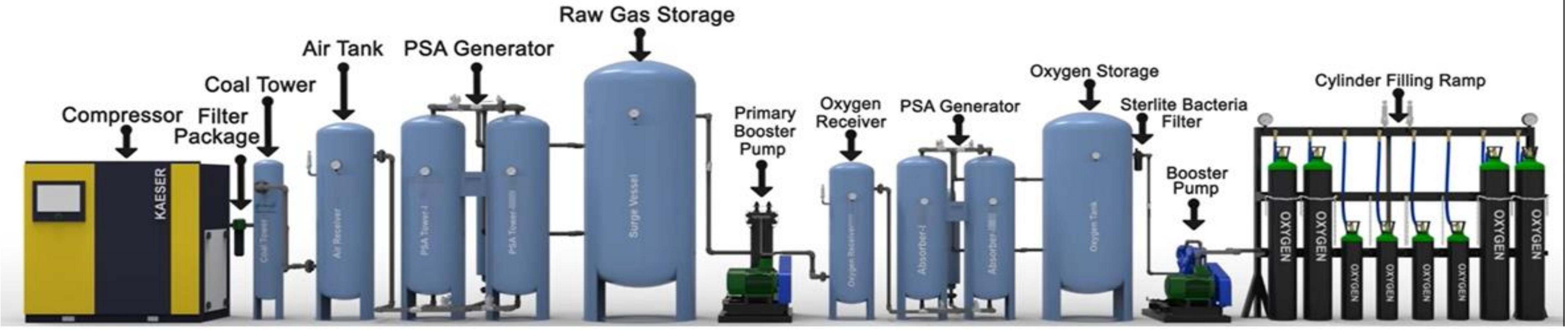
Industrial Nitrogen and Industrial Oxygen are produced by

- Air Separation Units
- pressure swing Adsorption (PSA) technology



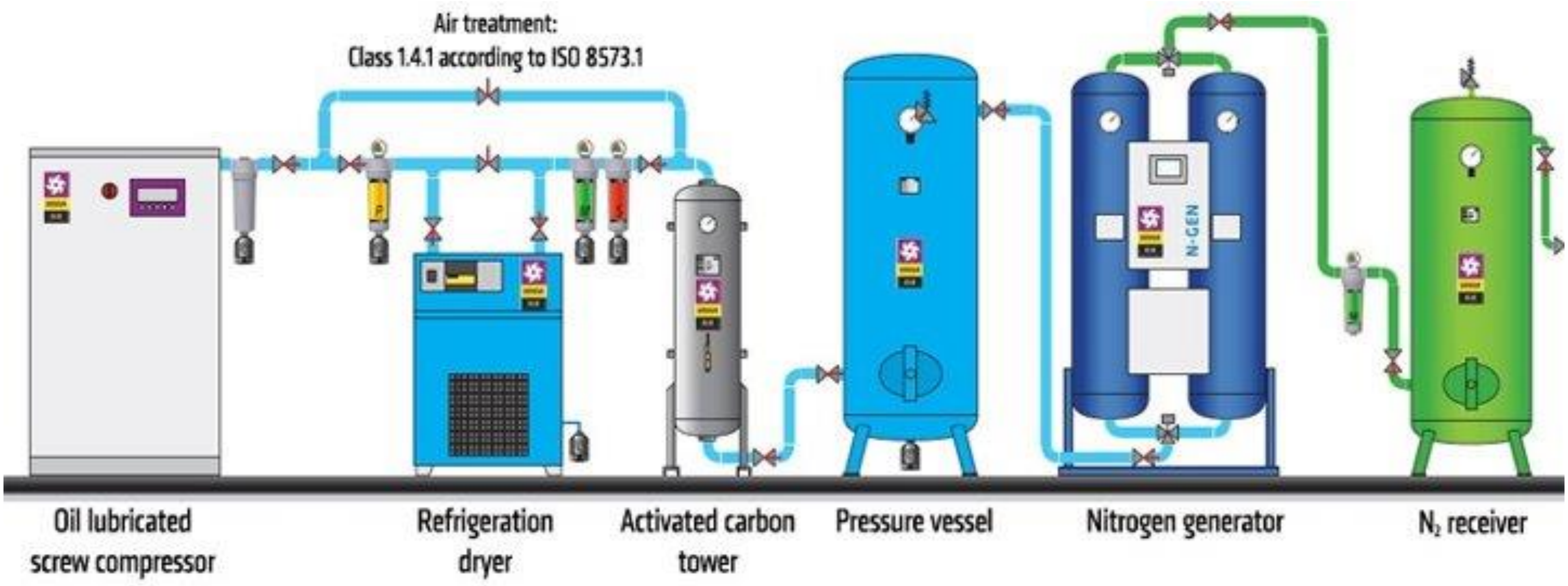


PSA OXYGEN PLANTS



Feasibility of Conversion of Industrial Nitrogen Generation Units for Oxygen

Pressure Swing Adsorption (PSA) technology



PSA OXYGEN PLANTS

https://youtu.be/LxaoBoOAFAk

99% Pure Oxygen Generators
Oxygen plant based on pressure swing Adsorption (PSA) Technology for Continuous process application like Metal Cutting,Oxygen Enrichment etc.

99% Pure Oxygen Generator with Cylinder Filling
Oxygen Plant based on pressure swing adsorption (PSA) Technology used for charging cylinders/bottles up to high pressure of 2900 PSI.

PSA NITROGEN PLANTS

https://youtu.be/l0KDdiI916E

PSA Based Nitrogen Plant

Nitrogen plant based on pressure swing Adsorption (PSA) Technology for Continuous process application like Food Packing, Metal Cutting, Inerting, etc.

PSA Based Nitrogen Plant with Cylinder Filling

Nitrogen Plant based on pressure swing adsorption (PSA) Technology used for charging cylinders/bottles up to high pressure of 3200 PSI.

MOLECULAR SIEVE

Carbon **Molecular Sieve** used in the **PSA Nitrogen** generation, the **Nitrogen** generation by Pressure Swing Adsorption (**PSA**) process is a technology used to separate **nitrogen** from a mixture of gases under pressure according to the special selective adsorption characteristics of the Carbon **Molecular Sieves** (CMS).

PSA plant employs **Zeolite** molecular sieves to separate the **oxygen** from the air. **Oxygen** with high purity is delivered whereas the nitrogen adsorbed by the molecular sieves is sent back into the air through the exhaust pipe. Pressure swing adsorption (**PSA**) process comprises of two vessels filled with molecular sieves and activated alumina.

Adsorber Media (ARKEMA, BASF, ZEOX, UOP etc) – each have different propertied and these must be studied before ordering
(1 NM3/hr of Oxygen requires approx. 30-35 KG of ZEOLITE media)

1. ARKEMA *:* Products - Siliporite® Airsiev - Arkema Group (cecachemicals.com)
2. ZEOX : Medical Oxygen Generation | ZEOX Applications | Zeochem
3. BASF : https://catalysts.basf.com/files/literature-library/92015BASF_Molecular_Sieve_Brochure_USL_190411_110814.pdf
4. UOP: UOP Molsiv Adsorbent

EXAMPLE OXYGEN NEW PSA OXYGEN GENERATOR Setup – Standard Modular Skids

Interested in this product?

Get Best Quote

PSA Onsite Oxygen Generator

Rs 2.35 Cr / Plant Get Latest Price

Automation Grade	Automatic
Design	Standard
Brand/Make	Airox
Capacity	Filling Capacity 275 Cylinder / day (D-Type)
Pressure	45-65 psig
Make	Airox
Purity	93+-3%
Cylinders Filling In A Day	275
Flow Rate	2500-2800 SCFH (1,917-1,321 LPM / 65.72-73.61 Nm3/hr)
I Deal In	New Only
Model Name/Number	AS-Q
Is It Leak Proof	Leak Proof
Country of Origin	Made in India

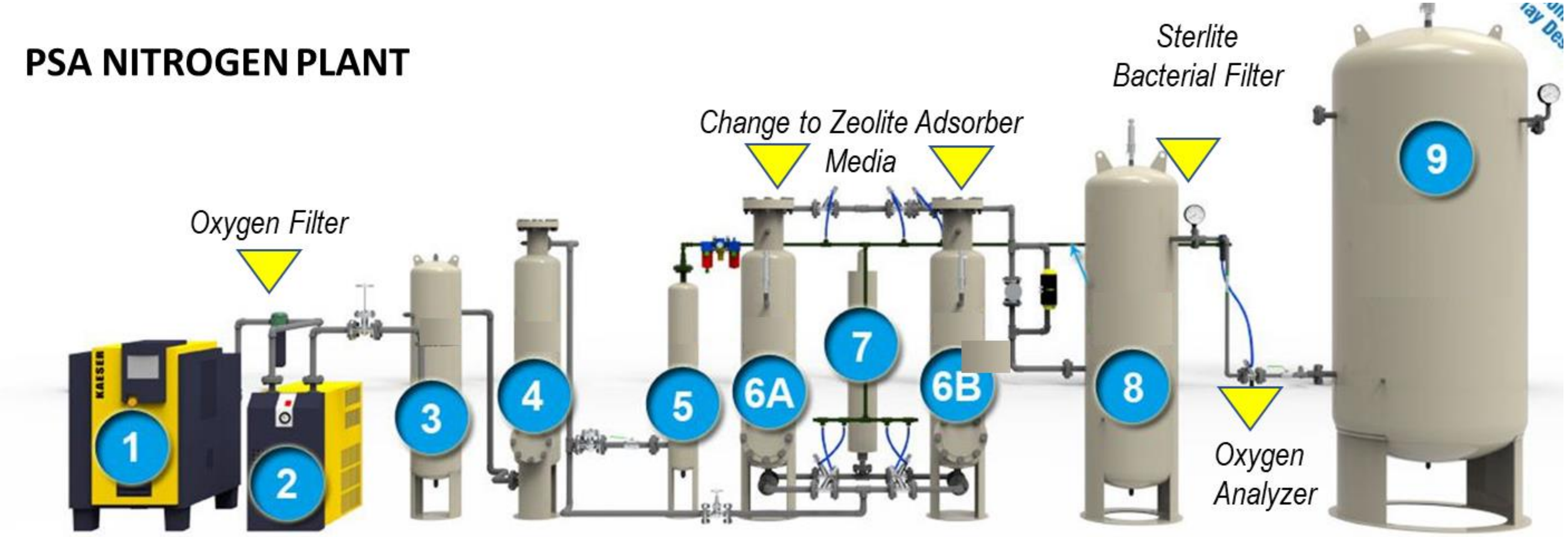
It is OBVIOUS that IF ONE can buy a NEW PSA OXYGEN Unit – That is preferred over PSA Nitrogen Unit Conversion to produce OXYGEN

1. 1500 liters/min can provide 100-150 ***Critical*** patients needing 10-15 lit/min Oxygen
2. 1500 liters/min can provide 200-300 ***serious*** patients needing max 5 lit/min Oxygen
3. 1500 liters/min can provide 300-500 ***moderate*** patients needing 0.5-5 lit/min Oxygen

Meets a 100-500 bed COVID Hospital requirement

COMPARISON

1. Air Compression
2. Air Filtration
3.Air Drying
4.Air Buffer Tank
5. Trace Oil Particle Filter
6. Air Buffer for Pneumatic Valves
7.A Adsorbing Tower A **B** Adsorbing Tower B
8. Flue Gas Vent Silencer
9. Oxygen Surge/Buffer tank
10. Oxygen Storage Tank



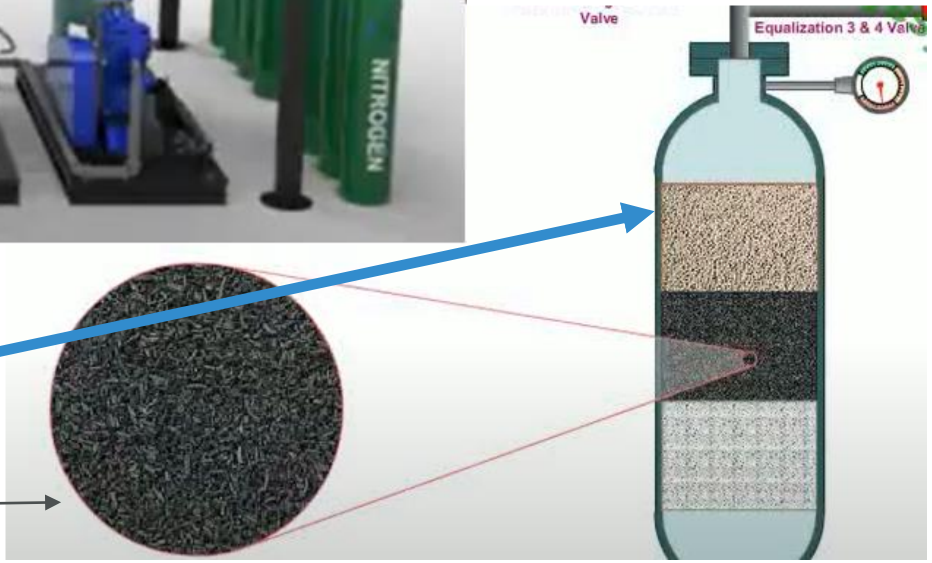
1. Air Compression
2. Air Drying
3. Air Buffer Tank
4. Trace Oil Particle Filter
5. Air Buffer for Automatic valve
6.A. Adsorbing Tower
6 ***B.*** Adsorbing Tower B
7.Flue Gas Vent Silencer
8.Nitrogen Surge/Buffer tank
9.Nitrogen Storage Tank

Conversion Points

PSA Nitrogen Plant Conversion to OXYGEN

STEPS

1. Change Complete Adsorber with ZEOLITE OR Change Only the MOLECULAR SEIVE to ZEOLITE type from CARBON
2. Add Bacterial FILTER at the END
3. If existing Nitrogen Plant
    1. **WITH** Cylinder filling – then use for Oxygen Cylinder filling
    2. **WITHOUT** Cylinder filling – **then SHIFT the plan to HOSPITAL and provide continuous Oxygen feed via Oxygen Line**
4. **Few valves and flow rate adjustments to PLC panel also needed – OEM can help on this front**



ADSORBER TOWERS (2)

MOLECULAR SIEVE

EXAMPLE of SKID mounted PSA Nitrogen Plant which can be converted to OXYGEN

STEPS

1. Change Adsorber with ZEOLITE OR Change Only the SEIVE
2. Add Bacterial FILTER at the END
3. If existing Nitrogen Plant
   1. **WITH** Cylinder filling – then use for Oxygen Cylinder filling
   2. **WITHOUT** Cylinder filling – **then SHIFT the plant to HOSPITAL and provide continuous Oxygen feed via Oxygen Line**
4. **Few valves and flow rate adjustments to PLC panel also needed – OEM can help on this front**

Conversion Process

PSA Nitrogen to PSA Oxygen Conversion Timeline: Between 1 - 3 weeks - Which can be further shortened with focussed efforts by Government officials and other bodies.

- Up to Three week timeline because as per vendor interviewed : Internal process of Job creation, procurement of ZMS and other equipment like Oxygen Filter, Oxygen Analyser, some amount of piping change to add these additional equipment, transport to site, site installation, recommissioning etc. Site work will require flushing / cleaning/ purging of entire PSA Plant and making it suitable to medical Oxygen production. Three-week timeline is from order to Medical Oxygen Out – But this can be reduced to less than 5 days with better governance, control and direct government intervention.

Conversion KIT: To convert nitrogen plant to oxygen plant

- Things to be changed: Adsorber Media (ARKEMA, BASF, ZEOX, UOP etc) – each have different propertied and these must be studied before ordering ***(1 NM3/hr of Oxygen requires approx. 30-35 KG of ZEOLITE media)***
    - ARKEMA *:* Products - Siliporite® Airsiev - Arkema Group (cecachemicals.com)
    - ZEOX : Medical Oxygen Generation | ZEOX Applications | Zeochem
    - BASF : https://catalysts.basf.com/files/literature-library/92015BASF_Molecular_Sieve_Brochure_USL_190411_110814.pdf
    - UOP: UOP Molsiv Adsorbent
- Things to be added: Oxygen Filter, Oxygen Analyser, Some Piping Changes, Pressure Control Valve to provide Oxygen at Controlled Pressure.
- Bulk of the cost is the cost of Zeolite, Oxygen Filter, Oxygen Analyser, Transportation and Site work.

Feasibility of Converting PSA Technology Based Nitrogen Plants to Oxygen Plants

1. The Technology applied to produce both Nitrogen and Oxygen based Pressure Swing Adsorption Principle, is more or less the same.
2. Compressed Air at approximate 7.5 Bar g pressure is the feed gas to produce both Nitrogen and Oxygen,.
3. However, the Medium used for separation is different – Carbon Molecular Sieves (CMS) is used for Nitrogen, whereas Zeolite Molecular Sieves (ZMS) is used for Oxygen.
4. Since atmospheric air has almost 79% of Nitrogen, it is possible to get purity up to 99.99% (N2 plus other inert gases) by PSA Technology, as CMS has a high selectivity to adsorb Oxygen
5. Since Oxygen is less than 21% in atmospheric air, and ZMS has selectivity to only Nitrogen, but cannot adsorb Argon, so along with Oxygen, Argon also gets concentrated, thereby giving a mixture of approximately 93% Oxygen, 4.5% Argon, and balance Nitrogen with others inert gases.
6. For producing 1 Unit of 99.5% Nitrogen, we use around 4 units of Compressed Air for producing 1 Unit of Oxygen, we use around 16 units of Compressed Air to get 93% Oxygen.
7. Approximately 7 kgs of CMS is required to produce 1 Unit of 99.5% Nitrogen, whereas 30 kgs of ZMS is used to produce 1 Unit of 93% Oxygen.
8. So, if we use the same plants that are built for Nitrogen, we can get roughly 25% Equivalent of Oxygen. For example, if we have a 100 NM3/hr Nitrogen plant, and replace the CMS with ZMS in the same Adsorbers, we will get 25 NM3/hr of Oxygen.
9. We will have to replace 1-2 valves in the Desorption lines to adjust the flow rates.
10. We will also need to change the PLC Program for operation of the valves.
11. The Oxygen analyser used also needs to be replaced, so in effect it we will need to replace the Control panel.
12. The Flow meter will also have to be replaced with suitable range flow meter.
13. We also need to add a Sterile Filter at the outlet of the Oxygen plant to ensure sterile gas flowing from the plant.

Feasibility of Converting PSA Technology Based Nitrogen Plants to Oxygen Plants

To Build an Oxygen plant from scratch, it will take us approximately 30-45 days, but such a Retrofitting Job can be done within 10-15 days, subject to the following

1. Ready availability of ZMS
2. Availability of Control panel (we can make one in 4-5 days)
3. On Site manpower of 3-4 people to remove CMS, completely dedust the adsorbers, and fill the ZMS. (this operation will take 2-3 days max)
4. Commissioning of Oxygen plant (roughly 2-3 days)

For Commissioning an Oxygen Plant following need to be considered

1. Area required will based on the Size of Nitrogen plant available. For example, a Nitrogen plant of 100 Nm3, converted to Oxygen of approx. 25 Nm3, required a space of approx.3 m x 5 m and additional space for Compressor and Oxygen tank.
2. This plant once commissioned, should be connected to the same Manifold that the Cylinder Bank is connected to, and Oxygen is delivered through the same Oxygen distribution line.
3. In case of emergencies of power cuts, a suitable DG set is advised to keep the plant running.

Complement	N_2 PSA	To Convert to O_2 PSA
Air Compressor	Existing	Available Flow and pressure to be confirmed for maximum usage for O2 production
Molecular Sieves	CMS	To be changed to ZMS. Volume of adsorber bed to determine quantity 0.65 as a factor of the adsorber volume
Air Treatment for Inlet air Quality	Remove – Particulate, Moisture and Oil	Remove – Particulate, Moisture and Oil
Pressure Equalisation Line	May or may not be in line	To be checked and adapted as per the O_2 Gen Needed To be Added if not existing
Purging		Valve + Needle Valves as needed based on line size. Line size need to higher to handle higher exhaust flow
Exhaust		Valve size / Orifice to be adapted as per the O_2 flow rate delivery
Flow meter	N2 Calibrated	To be replaced to O2 calibrated
Analyser	Low Purity Calibrated (typical range 0 to 25% O_2)	To be changed for O2 Purity range of 0% - 100% O_2
PLC	Programmed for N_2 Cycles	Programme change to O_2 Cycles
PHV		To be calibrated to required pressure
Gas Purification Sterile filter	Usually 0.1 micron	Need to Add additional filtration system to remove residual odours, particulate matter and pathogens

Setting up Of Medical Oxygen Facility:

For setting up of medical oxygen facility, one needs to obtain approvals mainly from following two government bodies.

1.Permission from Local Pollution Control Board:

a) The applicant and operator of the medical oxygen facility must have an 'Establishment Registration License' from labour department of respective state government.

b) Brief Project Report shall be submitted to local pollution control board authorities for obtaining a license for producing medical oxygen.

c) Project report shall include (but not limited to:) - what are the raw materials used, Quantity per day/Month, Name plate capacity, etc. Any kind of hazardous material/or any other chemical used in the process must be highlighted. The report shall contain process description and Process brief of the manufacturing technology.

2.Approval from PESO:

Similar to any other chemical facility, engineering drawings such as plant Layouts, Area classification, etc shall be submitted for PESO approval.

No approvals are required for commissioning .

3.Certification:

a) No more certification is required for medical oxygen generation facility as govt has recently moved medical oxygen facilities into white category of manufacturing. White category is least polluting industrial sector.

b) As of now, no certification is required for product purity but hospitals might require and demand it.

c) Central pollution control board classifies industries in four categories such as Red, Orange, Green and White. {example Red for Chemical and explosives and more polluting sectors).

d) Union Environment Ministry introduced a 'White' category - a colour code that meant 36 industry sectors may need no green clearance at all. {https://www.indiatoday.in/india/story/36-industries-white-category-central-pollution-control-board-967995-2017-03-28}

4.Other Requirements: It is suggested to consult 'Liasioning dept' of the organization to confirm requirement of any other documents . This may include NOC from collector or district authority.

Memorandum of Understanding on Teaming

Between

INDIAN INSTITUTE OF TECHNOLOGY BOMBAY

and

SPANTECH ENGINEERS

and

TATA CONSULTING ENGINEERS LIMITED

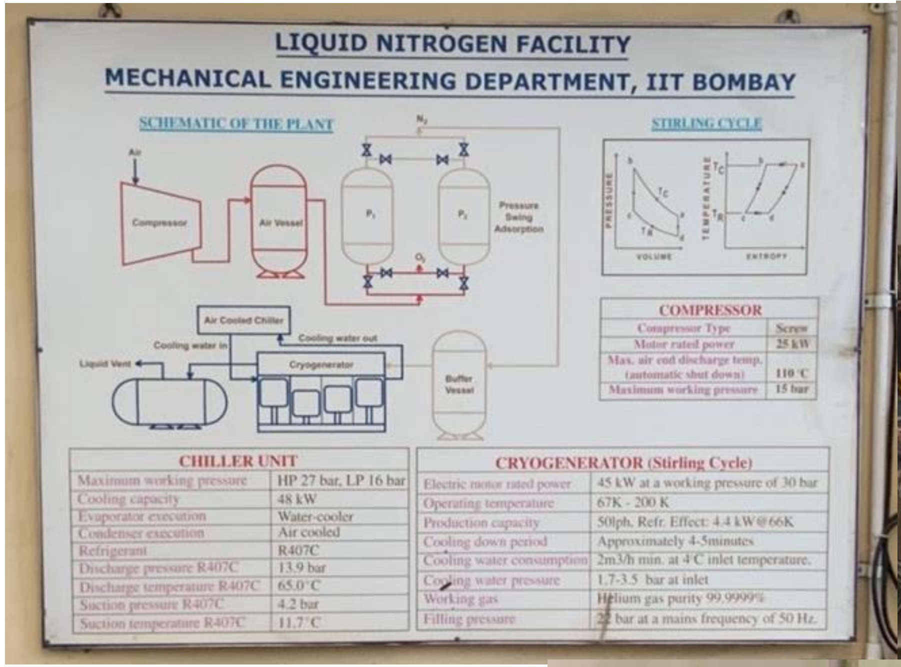
PSA Nitrogen Plant conversion to PSA Oxygen Plant

DEMO Plant at IIT Bombay

Contact:

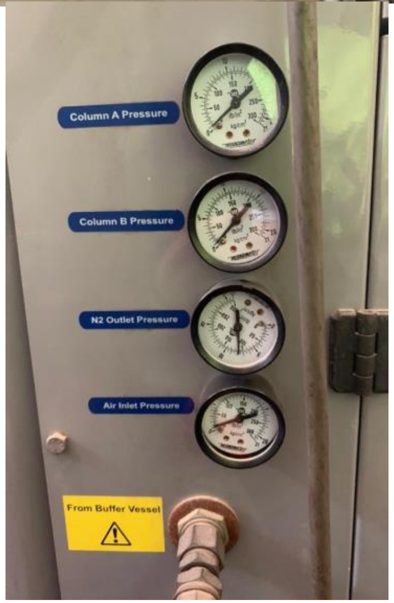
Prof Milind Atrey

(dean.rnd@iitb. ac.in)



Proof Of Concept

Conversion of PSA Nitrogen to PSA Oxygen @ IIT Bombay Lab



Prof Milind Atrey
Dean (R&D) IIT Bombay

Prof Subhasis Chaudhuri
Director of IIT Bombay

PSA Nitrogen Plant conversion to PSA Oxygen Plant

Director IIT Bombay
Dean (R&D)

DEMO Plant at IIT Bombay

Contact:
Prof Milind Atrey
(dean.rnd@iitb. ac.in)

Prof Milind Atrey
Dean (R&D) IIT Bombay

Mr. Amit Sharma
MD Tata Consulting Engineers

PSA Nitrogen Plant conversion to PSA Oxygen Plant

Director IIT Bombay
Dean (R&D)

DEMO Plant at IIT Bombay

Contact:
Prof Milind Atrey
(dean.rnd@iitb. ac.in)

IIT BOMBAY Release

IIT Bombay demonstrates conversion of Nitrogen generator to Oxygen generator: A simple and fast solution for the current oxygen crisis -- requesting implementation bodies to set it up at different locations (wherever there is an existing nitrogen plant or air compressor) in the need of the day.

In view of the national emergency in India with respect to pandemic and Oxygen production, Prof Milind Atrey, Dean (R&D), who also specialises in Cryogenic Engineering along with Tata Consulting Engineers Limited (TCE), took up a pilot project to evaluate the conversion of PSA (Pressure Swing Adsorption) Nitrogen Unit to PSA oxygen unit by fine-tuning the existing Nitrogen Plant setup and changing the molecular sieves from Carbon to Zeolite. Such Nitrogen plants, which take air from the atmosphere as raw material, are available across India in various industrial plants. Therefore, each of them has the potential of being converted to an oxygen generator to tide over the current emergency.

At IIT Bombay, a PSA Nitrogen plant in the Refrigeration and Cryogenics Laboratory was identified for conversion to validate the proof of concept. To undertake this study on an urgent basis, an MOU was signed between IIT-Bombay, Tata Consulting Engineers and Spantech Engineers to finalise a SOP that may be leveraged across the country.

Spantech Engineers, Mumbai, who deal with PSA Nitrogen & Oxygen plant production, agreed to partner with IITB and TCE on this pilot project and installed the required plant components as a skid at IIT Bombay for evaluation using IIT Bombay's infrastructure at the IITB Nitrogen facility at the Refrigeration and Cryogenics lab. This setup for the experiment was developed within three days, and the initial tests have shown promising results. Oxygen production could be achieved at 3.5 atm pressure (much higher rate possible by replacing the parts with higher ratings) with a purity level of 93-96 %. This gaseous oxygen can be utilised for COVID related needs across existing hospitals and upcoming COVID specific facilities by providing a continuous supply of oxygen.

Prof Milind Atrey acknowledges and thanks Mr Amit Sharma, Managing Director, Tata Consulting Engineers, along with Mr Rajendra Tahiliani, Promotor Spantech Engineers and alum IITB (1970), Mr Raj Mohan, MD Spantech Engineers and their passionate team members for their collaboration and partnership on this project. We encourage and request various government authorities, NGOs, and private companies to contact Prof Milind Atrey (dean.rnd@ iitb. ac.in), IIT Bombay, and Tata Consulting Engineers to know more about this project and its rapid adoption across the country. Let us work together to see that there is enough oxygen for all. I am told that the plant can be set up within 48 hours when components are available.

https://www.moneycontrol.com/news/business/economy/iit-bombay-pilots-technology-to-convert-nitrogen-into-oxygen-6830381.html

PRESS RELEASE 29 April 2021 by IIT Bombay

The HINDU

IIT-Bombay finds innovative way to generate oxygen

MoneyControl

IIT Bombay pilots technology to convert nitrogen plant into oxygen generator

MyNation

Oxygen crisis: IIT Bombay converts Nitrogen Unit to PSA Oxygen Unit

Outlook

COVID-19: IIT Bombay finds innovative way to generate oxygen

TimesNow

IIT Bombay: With aim to help COVID patients, team works to convert Nitrogen plants to Oxygen Generators

THANK YOU

For Further Details –

Refer to Whitepaper- (Click here),

Atul Choudhari

Chief Technology Officer

Tata Consulting Engineers

Email: tceconnect@tce.co.in

achoudhari@tce.co.in