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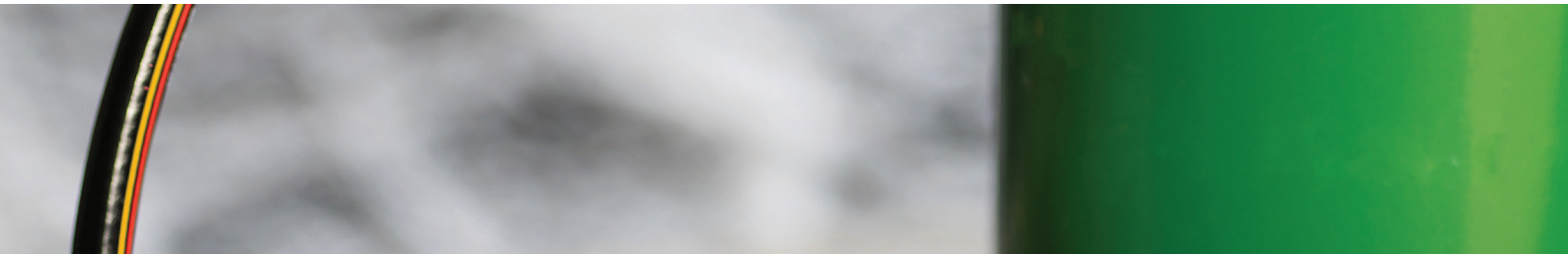
ENGINEERING A BETTER TOMORROW SINCE 1962

OXYGEN STORAGE AND DISTRIBUTION

through LPG Cylinder Bank



IMPORTANT NOTE:

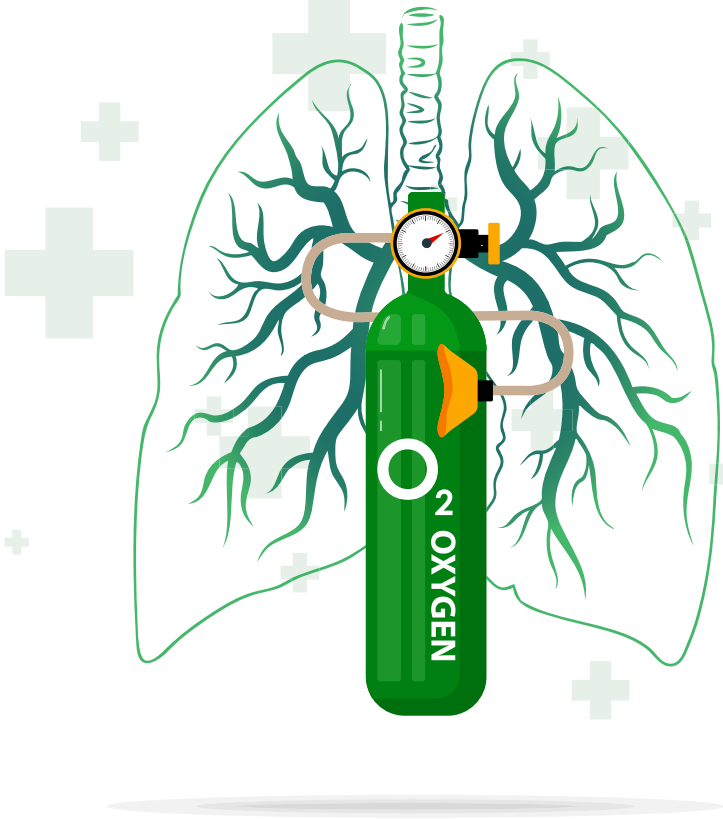
This paper provides technical concept and feasibility of using LPG Cylinders for medical oxygen usage.

Implementation of the concept provided in this paper shall involve further Statutory, Legal and other approvals. They must be done with proper involvement of Government authorities. Adequate cleaning and colour coding of the cylinders are required for safety reasons. A governance mechanism involving government officials, PESO, Controller of Explosives, Fire Department, Medical Department (Min. of Health) and administrative authorities are also required for related compliances and approvals.

The conversion MUST be implemented ONLY after approvals of Statutory authorities are obtained.

BACKGROUND

Hospitals treating COVID-19 patients requiring oxygen support in India have a severe shortage of medical oxygen during the second wave of the pandemic. While industrial-grade liquid oxygen is being diverted from the steel plants and refineries, the transportation and distribution challenges need to be overcome to ensure medical oxygen reaches the patient's bed. Particularly in makeshift hospital facilities especially installed to fight the pandemic as they do not have a piping infrastructure of oxygen. Though the oxygen is made available from various sources, including imports, oxygen cylinder shortage is of grave concern and one that needs to address ways and means to counter this issue.



The cylinders are the last mile connectivity between oxygen production facilities and the hospitals' patient beds. Various alternative means for storing medical oxygen are being explored. One such alternative way of overcoming oxygen cylinder shortage, particularly in rural India, is converting domestic LPG cylinders to store medical oxygen and supply to the patient bed and minimise the dependency on the oxygen cylinders.

The suitability of domestic LPG cylinders for storing medical oxygen is discussed in "Preliminary Assessment Report on Emergency Options for Medical Oxygen Storage & Alternative Mode of Oxygen Generation", published by Tata Consulting Engineers in April 2021.

LPG CYLINDERS AS STORAGE FOR MEDICAL OXYGEN

LPG cylinders are available across the country through its well-connected and robust supply chain network, even in India's remotest parts. As an alternative solution during emergencies, LPG cylinders can be utilised for medical oxygen after obtaining necessary approvals from statutory authorities.

It must be remembered that LPG cylinders are rated to store much lower pressure, limited by the vapour pressure of LPG as compared to conventional medical oxygen cylinders. The vapour pressure of LPG is determined at 16.9 bar(g) and suitable for operating pressures between 15.5 to 16.5 bar(g). LPG cylinders are hydro tested at 25bar(g). The lower pressures of LPG cylinders restrict lesser oxygen storage resulting in lower residence time before the cylinder gets empty. However, this need not be of any concern for its suitability as a storage means for medical oxygen.

The usefulness of the LPG cylinder concerning construction materials is also reviewed and ensured that it is safe to store oxygen at lower pressures. Apart from operating pressure and/or materials suitability, it is essential to note that LPG is a highly flammable fluid. Hence, it is not recommended for filling oxygen directly without proper cleaning and drying.

It is mandatory that all LPG cylinders need to be made free of hydrocarbon and corrosion elements by purging and cleaning and ensuring that not even traces of contaminants are present before filling with oxygen. However, it is recommended to use new cylinders to avoid issues related to internal corrosion. The cylinders should be adequately cleaned, inertized, and hydro tested before utilising them for oxygen services. Suitable particulate filters and sterile filters shall be installed in the oxygen supply line from the converted LPG cylinders.

CLEANING AND INERTIZATION OF GAS CYLINDERS

It is extremely important to properly clean the LPG cylinders before utilising them for medical oxygen service. Cylinder internal and external surfaces need to be scrutinised for detection of corrosion or presence of contaminants.

These surfaces need to be decontaminated by proper cleaning methods to ensure patient safety by avoiding undesirable contamination. Proper care needs to be taken while performing purging and cleaning activities for guaranteeing complete removal of any residual gas, contaminants and/or corrosion products. Before filling with oxygen, It is vital to ensure that even traces of cleaning agents are removed and cylinders are adequately dried and sealed to prevent ingress of dirt or moisture post-cleaning.

Requirements and procedures during the conversion of the cylinder for storing different gas other than the gas for which the cylinder is designed shall be followed as per International standard ISO-11621. These guidelines shall be followed while cleaning the LPG cylinders.

Washing the cylinder internal and external surfaces by aqueous solution or by organic solvent can ensure the removal of hydrocarbon-based contaminants in the liquid or vapour phases. The cleaning solution must be compatible with oxygen service, especially with oxidising gases. It must be cleaned without leaving behind any residue that is harmful to the handlers of the cylinders and the patients inhaling oxygen from converted LPG cylinders.

The guidelines provided in ISO 11621 shall be strictly followed while inertizing, selecting cleaning solvents, inspecting internal surfaces, drying and sealing the cylinders immediately after cleaning but before the conversion for oxygen storage.

PESO GUIDELINES *(CURRENTLY DOES NOT COVER LPG SERVICE)*

Inservice LPG cylinders proposed for oxygen storage shall undergo a detailed procedure for complete cleaning and drying following PESO Standard Operating Procedure No. D-21013/PBL/18-Exp issued on 22-04-2020. Please note that this PESO guidance does not include LPG cylinders; but the guidelines provided should be suitably used for conversion of LPG cylinders in Oxygen service. New cylinders that have not been filled with LPG but identified for the first fill of oxygen should also be flushed and cleaned following PESO guidelines issued for conversion of other non flammable service gas cylinders (such as nitrogen) into medical oxygen services and certified for storing medical oxygen. The following clauses are reproduced from the guidelines:

I. The Cylinders shall be thoroughly 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. (Though not covered in PESO guidance, refer to ISO 11621 for detailed cleaning procedures. Organic solvents like Carbon Tetra Chloride shall not be used as they are toxic.)

II. Ensure that the cylinders have passed the last cylinder periodic examination/ retest per Rule 26 of the Gas Cylinders Rules, 2016. However, the routine testing of cylinders is extended from 5 years to 5 years 3 Months for those cylinders due for statutory hydro-testing on 31.03.2020 because of the ongoing COVID-19 pandemic reverted to 5 years once the Government of India declares that the pandemic is over. The extension of cylinder retest is also applicable to industrial Oxygen cylinders used in medical Oxygen service. The records of such cylinders shall be maintained.

III. 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 COVID-19 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.

IV. 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.

V. These activities shall be carried at the E&F licensed premises only.

VI. The records of such converted cylinders shall be maintained.

INSTALLATION OF CYLINDER BANK FOR MAKESHIFT COVID-19 HOSPITALS

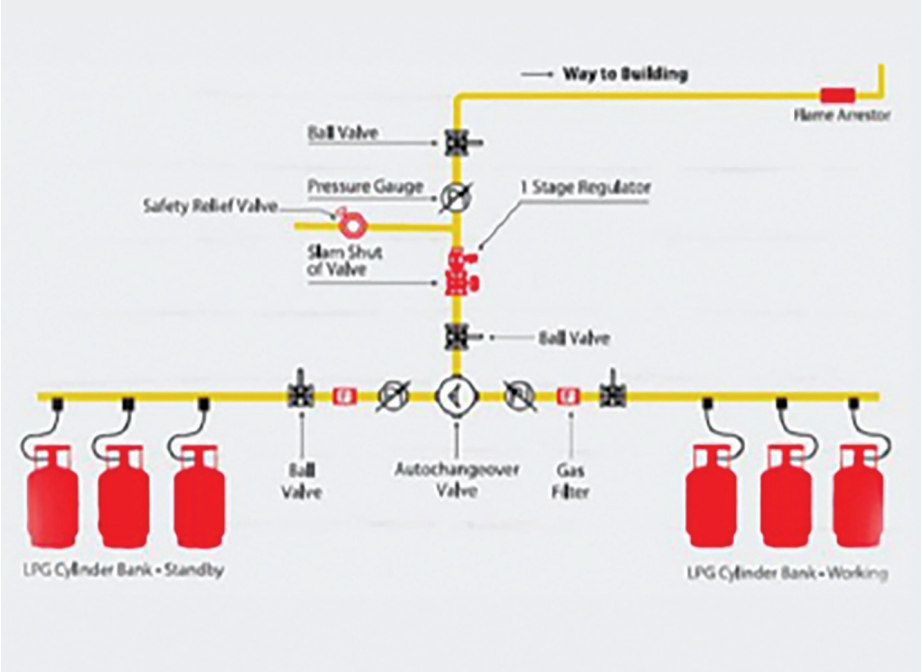
Once the LPG Cylinders are thoroughly intertzied and after ensuring the LPG cylinders are safe for filling medical grade oxygen, the cylinder bank consisting of 10 to 50 cylinders can be installed with all the necessary manifolds, adaptors, pigtails, non-return and isolation valves, filters such as activated carbon filter, fine filter and sterile filters, automatic changeover valves cum regulators and piping network along with flow meters, pressure gauges etc. for distributing oxygen from cylinders to patient bed. Technical specifications of the critical components of the cylinder banks are discussed in the subsequent paragraphs.

TECHNICAL SPECIFICATION OF CRITICAL COMPONENTS

Cylinder Bank

A cylinder bank shall have at least two manifold sets connected with several cylinders, say between 10 to 50 on each manifold. The number of cylinders to be connected on each manifold shall be worked out based on the total Oxygen demand for the hospitals considering the number of beds in wards, ICU, operation theatres etc. Each bank is installed with two sets of cylinders, one set of the bank is in supply or active mode supplying oxygen to the patients, and the other is in standby or reserve mode. The manifold is made of 25 to 50NB diameter seamless stainless-steel or copper pipe, depending on the oxygen flow rate. The length of the manifold depends on the number of cylinders connected. Manifold is welded with threaded nipples for connecting cylinder to the manifold. Each cylinder is connected to the manifold through an adaptor, a pigtail braided hose and a non-return valve. In place of the pressure regulators fitted on a domestic LPG cylinder, an adaptor is fitted onto the cylinder valve, and there is no pressure reduction across the adaptor. The gas will flow out from the cylinder on turning the adaptor ON. The pressure through the adaptor is equal to the cylinder operating pressure.

Pigtail is a flexible wire-braided rubber or plastic hose compatible with medical-grade oxygen service and provided with brass nuts on both ends. One end of the pigtail is connected to the adaptor, and the non-return valve is connected to the other end. In case of any damage to the pigtail, it can be easily replaced with the new one with the help of the screwed ends. A non-return valve between the cylinder pigtail and manifold nipple stops the gas supply from the cylinder to the manifold in case of a damaged pigtail, faulty adaptor, or loose connections from cylinder to cylinder manifold. Non-return valve will ensure continuous gas supply to the manifold even if any cylinder connection develops adaptor defect or pigtail damage. Once proper connections between the cylinders and manifold are ensured, the adaptor on each cylinder is opened. Gas flow shall start from cylinders to the manifold & the connecting piping network to the patient beds get oxygen supply of sufficient flow to meet the demand of a hospital.



Cylinder Manifold

A manifold is a pipe header connected to the cylinders bank, and oxygen is continuously supplied from cylinders. Manifold, along with the piping network, also works as a gas reservoir from which patients continuously withdraw oxygen. Manifold has two branches that are connected to the cylinder bank in supply mode, and in standby or reserve cylinder bank. Sizes of manifold and branches are designated based on the number of cylinders connected. For example, a manifold of dimension 2 X 50 indicates two branches and each branch is connected with 50 cylinders. The maximum operating pressure of the manifold is 20 bar(g).

Manifold is fabricated out of seamless pipe of diameter 25NB, 40NB or 50 NB depending on the flow rate requirement of the hospital, conforming to ASTM A-312 TP304 Stainless steel or copper. Nipples equal to the number of cylinders connected to the manifold are either welded or screwed on the manifold at regular distances. The distance between the nipples welded on the manifolds is 350mm for cylinders up to 19 kg when the cylinders are connected in series and 200mm when connected to the manifold in a staggered way.

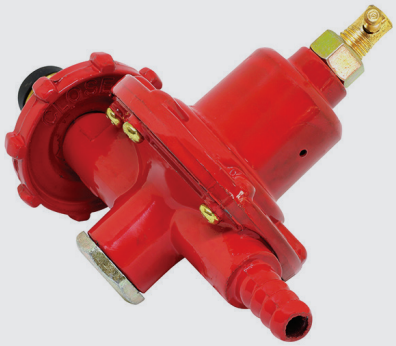
The manifold and the pipe network can be painted white as per the ISO system to indicate that it is reserved for oxygen. One end of the manifold is closed by welding a forged or extruded end cap of stainless steel or by screwing the copper end cap. The distance between the closed end of the manifold and the centre line of the first nipple shall measure a minimum of 75 mm & the distance between the last nipple on the manifold pipe header shall be 150 mm.

An isolation valve installed on the manifold is also included in this distance. The manifolds preferably shall be fabricated and hydro-tested at the factory under a controlled environment.

The manifold and piping network installed at the hospital shall be hydro tested at a pressure of 20 bar(g) for 30 minutes. All nipples on the manifolds shall be properly closed before the commencement of the hydro test. Reduction in pressure during the hydro testing arising out of possible leakages shall be identified and repaired before retesting.

Adaptor

An adaptor is fitted directly onto the cylinder valve and works like an on-off valve. The other end of the adaptor is connected to the pigtail. It looks like a regulator but does not reduce the pressure. On turning, the adaptor ON, gas in the cylinder starts flowing out. The operating range of the gas pressure of an adaptor is 20 bar(g).



The adaptor body is made of pressure die-cast zinc alloy. Free cutting brass bars can be used for brass parts of an adaptor. Nitrile rubbers in line with technical specifications provided in IS 9798 shall be followed for O-rings. Parallel male threads provided on the inlet of the adaptor conforms to Systems International threads. The angle of the threads is 60 degrees & the pitch is 1.814 mm. (Refer IS:8737). Left-hand male taper threads conforming to Male European Cylinder Valve shall be provided at the adaptor and match internal pigtail threads.

The adaptor is tested with hydraulic pressure of 25.4 bar(g) and pneumatic pressure of 0.5 bar(g) & 22 bar(g) for checking the presence of leakages, if any, after machining. Adaptors shall be designed for a gas flow rate proportional to that arrived for each cylinder based on the total consumption and number of cylinders in a cylinder bank at 20 bar(g) pressure. The adaptor shall perform satisfactorily in the temperature range of -20 0C to + 50 0C when tested under Annexure F of IS:9798.

Flexible Braided Cylinder Pigtail

A pigtail is a flexible hose connecting the cylinders with the manifold. They are made from braided plastic tubes with brass nuts fitted on the ends. The adaptor is connected to one end of the pigtail, while a non-return valve is screwed on the other end. The gas flows to the manifold through the pigtail at a pressure equal to that of cylinder pressure. The standard operating pressure of a pigtail is 20.0 bar(g). It is easier / quicker to replace a pigtail with a new one when damaged without affecting the total gas flow.

The rubber of the pigtail is synthetic & acryl nitrate butadiene rubber and shall not release any contaminants when contacted with oxygen. The brass nuts shall be either forged or extruded. Alternatively, free cutting brass can also be used for the nuts. The nuts shall be machined as per the requirements of IS 8737. Left-hand female threads conforming to FECV (Female European Cylinder Valve) are provided to match the threads provided on the adaptor outlet and NRV inlet.

The bare tubes are hydro tested at a pressure of 42 bar(g). The finished pigtail shall be pneumatically tested at a pressure of 22 bar(g). The burst pressure of the assembly shall not be less than 44 bar(g). A crushing force of 102 bar(g) is applied for 5 mins on the middle of the tube over a length of 25 mm for 30 minutes. The tube shall not show signs of any permanent deformation or collapse. The tube shall not be leaking when an internal pressure of 22 bar(g).is applied.

During the type tests on the pigtails, there shall not be a change in weight above 5% and a volume change above 10% even after immersing the tube for 72 hours in Pentane. The hardness of the rubber shall be 60 IRHD ± 5. The rubber shall undergo the accelerated ageing test as per IS 3400 (Part 4). The hardness of the rubber shall not reduce by more than 10 IRHD, elongation shall be within ± 25%, and tensile strength variation shall be within +10% and –30% after the ageing test. On applying a clamping pressure of 5 bar(g), the material shall not get damaged or press away or flow away.

Non-Return Valve (NRV)

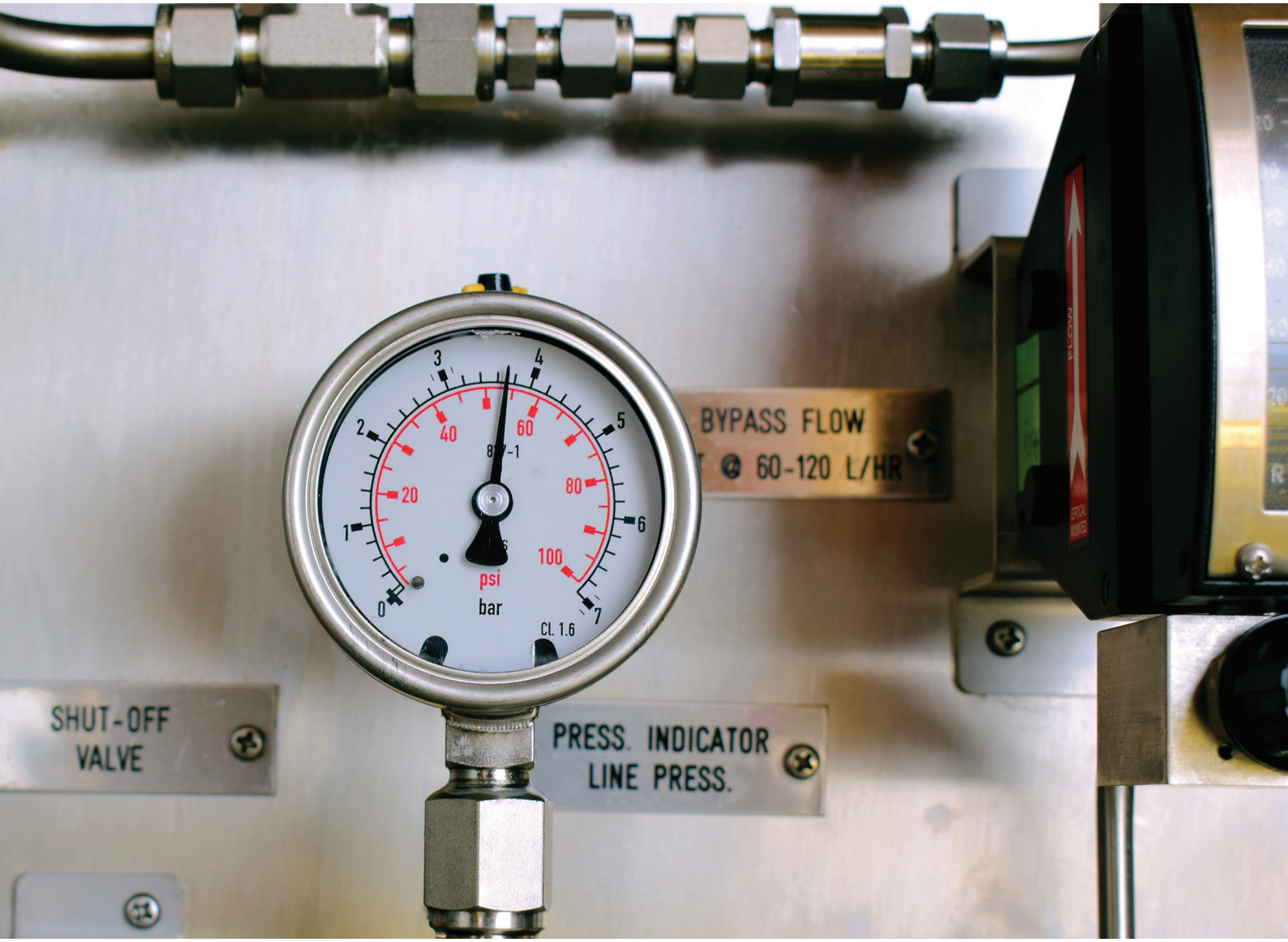
NRV is installed between pigtail and threaded nipple on the manifold.

In case of any damage or leak developed in the pigtail or loose connection of the adaptor on the cylinder, NRV closes the gas supply from the cylinder to the manifold. NRV also restricts the gas flowing from the manifold to the damaged pigtail, ensuring uninterrupted supply in the manifold from remaining cylinders except for the one whose adaptor or pigtail is defective till the time the same is repaired/replaced. The operating pressure range in NRV is 20.0 bar(g). The non-return valve is pneumatically tested at a pressure of 22 bar(g) for ensuring the proper functioning of the valve assembly.

Pressure Gauge, Manifold Isolation Valve

Manifolds are fitted with pressure gauge for measuring and indicating piping network pressure before the regulator. In other way, the pressure gauge indicates pressure in the cylinders connected to the manifold. Isolation valves are installed on each manifold's branch soon after the pressure gauge to isolate the cylinder bank when the same is being replaced.

The maximum operating pressure is 20.0 bar(g). The pressure gauge shall have a 4" dial and suitable for measuring pressure range of 0 to 50 bar(g). The calibrated pressure gauge shall be used for testing the pressure gauge for the specified pressure range.



Isolation Valve Fitted on Pressure Gauge

Isolation valves are installed below the pressure gauges so that the gas flow can be stopped to the pressure gauge when the gauge is being replaced. Under regular operation, the isolation valves are open to measure the gas pressure in the system. When a pressure gauge is damaged, the isolation valve of the pressure gauge is closed so that the new gauge can replace the defective/damaged pressure gauge.

The vale body is either forged or made from free cutting brass. The tensile strength of the body material shall be 40 MPa minimum & elongation of 21%. The minimum Izod impact strength shall be 2.2 kg.m as per IS 1598. The valve shall be designed and manufactured to work satisfactorily in the temperature range of (-)20 0C and (+)65 0C

The complete valve assembly is pneumatically tested at a pressure of 0.5bar(g) and at 22 bar(g) for meeting the functional requirement.

Manifold Isolation Ball Valve

Upstream of the pressure gauge, a ball valve is installed on each branch of the manifold for isolation purpose. The isolation valve is normally in open condition for the active or working cylinder bank and closed for the reserve or standby bank. The gas supply from that branch to the manifold will be stopped when the isolation valve is closed.

The manifold isolation valves are designed for cylinder maximum working pressure.

The isolation valves are sized based on the flow rate and diameter of the branches of the manifold. They can be 25 NB or 40 NB. These valves are made from bronze, or stainless steel wetted parts, PTFE seats and gland washers. The lever and spindle have a dual lock system for quarter-turn operation.

The valves are hydro tested at a 30 bar(g) pressure and pneumatically tested at a pressure of 22 bar(g). The non-metallic components such as rubber, PTFE and other moulded parts are selected to withstand severe climatic conditions.

Filtration (ACF, Fine Filter and Sterile Filter)

Activated Carbon Filter, Fine Filters and sterile filters shall be installed upstream of the automatic changeover valve and adjustable regulator for removing any particulate and biological impurities from the pipe network and clean oxygen shall be delivered to patients. Fine filter with 0.1 microns with efficiency exceeding 99.9% and sterile filtration down to 0.01microm with efficiency 99.99%.

Automatic Changeover Valve with Adjustable Regulator

The system shall be provided with an auto changeover device that includes a valve and a regulator connected to both the cylinder manifold branches. This assembly can also be termed a first-stage regulator and reduces the pressure from 20 bar(g) in the cylinder to 0.5 bar(g). When the active or working cylinder bank is used up, the regulator automatically changes over from the empty cylinder bank to the full or reserve bank ensuring continuous oxygen supply to the patients.

The outlet pressure from the regulator valve shall be adjustable between 0.5 bar(g) to 1 bar(g). The flow rate shall be as per the requirement of the hospital. The body & cover of the regulator shall be manufactured out of die-cast zinc alloy, and the diaphragm & valve pad shall be from synthetic rubber. The automatic changeover/regulator shall conform to the requirements of IS:9798 with suitable changes in the pressure, which is more in this case than the domestic LPG regulators covered in IS:9798.

Main pipeline isolation valve and pressure gauge

This isolation valve is installed at the start of the distribution pipeline after the regulator. If this valve is closed, the supply of gas to the hospital can be stopped. Before this isolation valve, a pressure gauge is installed, indicating gas pressure in the distribution pipeline after the first stage regulator.

Isolation Ball Valves at Patient Bed

Near each patient bed, an isolation valve is installed. If this valve is closed, the gas supply to that patient bed is stopped. These valves are in an open condition as long as the bed is occupied by the patient requiring oxygen. The size of the valve can be 15 NB (½"). Both the inlet and outlet end connections have ½" BSP female threads, which are screwed onto the male threads on the distribution pipeline.

Gas Meter

The gas meter can be installed after the first stage regulator, which measures the quantity of gas consumed by the patients. The gas meter shall conform to BS 4161 Part 5. The maximum operating pressure is 1.5 bar(g). The working pressure range is 0.50 to 1.0bar (g). The max gas flow rate is depending on the total oxygen requirement of the hospital.

Pipes of varying diameters

Oxygen is distributed from cylinder bank to patient bed through a pipe of different diameters depending on the total requirement for the hospital and the arrangement/location of Operation theatres (OT), ICUs and general wards that require the life-saving gas. All the pipes and fittings shall be either of stainless steel or copper.

- 40 NB/50 NB nominal bore pipe (1½" / 2")
- 40 NB/50 NB nominal bore pipe runs from the outlet of the First Stage Regulator to various locations. This is the main distribution header, and the branches are connected to this header depending on the requirements of various wards / OT/ICUs.
- 15 NB pipe (½")
- This pipeline runs from the header to various consumers lie OT, ICUs as well as wards.

Pressure testing of pipeline

Piping network up to first stage regulator is hydraulically tested at a pressure of 30 bar(g) for 30 minutes. The maximum working pressure in the pipe network in this section is 20 bar(g). Piping after 1st stage regulator is Pneumatically tested at 2 bar(g) for 30 minutes. The oxygen pressure in this section is about 1.0 bar(g).

Statutory Approvals

Once the cylinder bank / manifold system is in place at hospitals, necessary approvals shall be obtained by PESO for LPG cylinder conversion to medical oxygen storage, State pollution control board approvals needed for starting the plant and local fire officer on the facility layout and safety aspects for oxygen cylinder storage.

BRIEF SPECIFICATIONS OF MAJOR PARTS OF THE CYLINDER BANKS

Sr. No.	Item Description	Specification	Name of Suppliers
1.	LPG Cylinders	Domestic LPG Cylinder of 14.2 kg storage	HPCL/BPCL/IOCL
2.	Manifold till regulator	50 NB or 40 NB & 25NB or 15NB conforming to ASTM A-312 TP304 or copper	United/Greentech
3.	Adaptor	• Body - Pressure die-cast zinc alloy. Brass parts - Free cutting brass bar. • Rubber components - Nitrile rubber conforming to IS 9798.	United, SKN, Vanaz, Nova Comet, Medas Gas
4.	Flexible Wire-Braided Cylinder Pigtail	• Rubber tube - Synthetic & acryl nitrate butadiene rubber compatible with oxygen. • Brass nuts - Forged or extruded	Markwell, United
5.	Non-Return Valve (NRV)	• Body – Bronze, Disc – Bronze • Test Pressure – 30bar(g)	SKN, United, leader
6.	Pressure Gauge with isolation valves	Dial – 4", Pressure Range - 0 to 50 bar(g)	Donfoss, Alot,
7.	Manifold Isolation Ball Valve	Body – Cast Steel	Audco, Leader, Hawa
8.	Automatic Changeover Valve with Adjustable Regulator	• Outlet pressure - 0.5 - to 1 bar(g). Flow rate – As per oxygen requirement of the hospital. • Body & cover - Die-cast zinc alloy. • Diaphragm & valve pad - synthetic nitrile rubber conforming to IS:9798	United, SKN, Vanaz, Nova Comet, Medas Gas
9.	ACF, Fine filter & Sterile Filter	304 stainless steel construction, 0.01-micron filtration, Organisms, oil, dirt with efficiency in access of 99.99%	Walker, Parker, Raxor
10.	Gas Meter	• Conform to BS 4161 Part 5. • Max. working pressure - 1.5 bar(g). • Working pressure range is 0.5 to 1.0 bar(g). • Gas flow rate – As per hospital requirement	Raychem RPG / ITRON

References:

1. Technical specification for LPG Gas Pipeline Product - LPG Gas Pipe Line (greentechengineers.com)
2. cdn.iimkashipur.ac.in
3. ISO 11621 – Gas Cylinders – Procedure for Change of Gas service
4. bis.org.in/sf/med/0710.pdf
5. "Preliminary Assessment Report on Emergency Options for Medical Oxygen Storage & Alternative Mode of Oxygen Generation" published by Tata Consulting Engineers https://www.tce.co.in/wp-content/uploads/2021/04/Meeting-Oxygen-Demand-Tata-Consulting-Engineers-Response.pdf

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For questions, please contact

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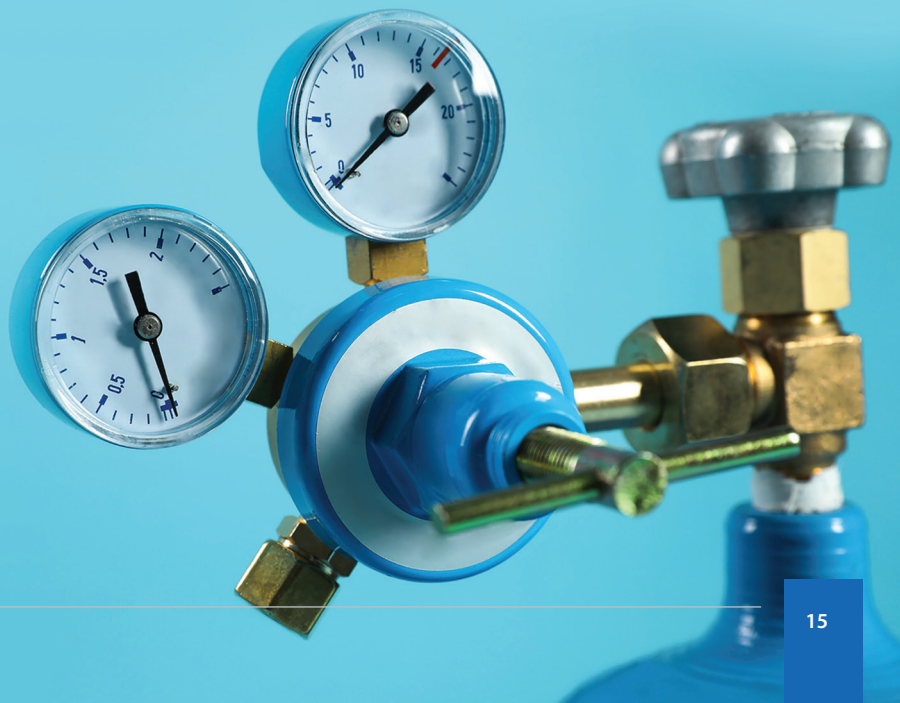

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