Federal Ministry of Health
Ethiopia

Medical Gas(O2) Management System

MGMS Training document

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Chapter 1. Introduction

Oxygen has potential risks if is not administered safely and appropriately. Underuse of oxygen is dangerous as it exposes critically ill patients to the risk of hypoxic organ damage. However, overuse of oxygen can also be harmful, especially for vulnerable patients such as premature infants and those with chronic obstructive pulmonary disease

AmedicalGasManagementSystemissupposedto deliveryall requiredmedicalgasescontinually andsecurelyin therequiredquantity(flow), pressureandquality.

1.1.How long could you live without?

Food	***2 weeks***
Drink	***3 days***
Breathing	***3 minutes***

Without Oxygen?

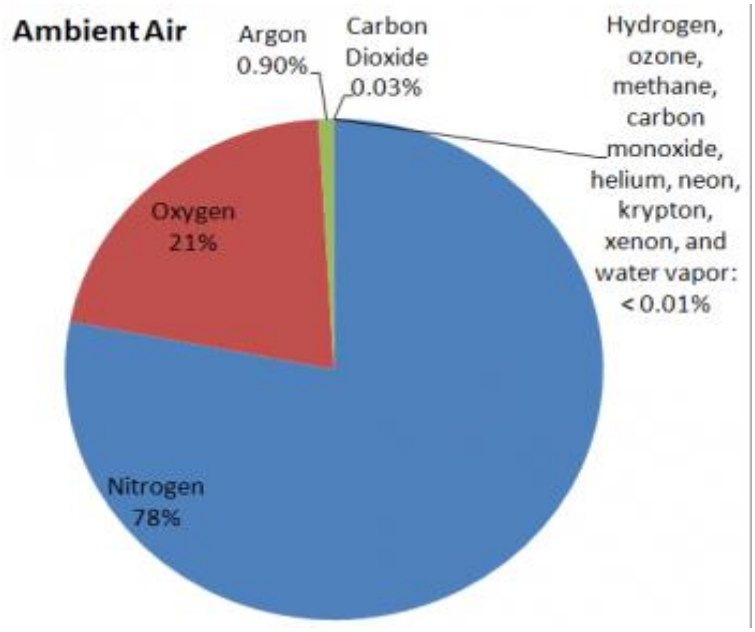
Oxygen	***2 breaths***

Atmospheric Air elements

Type of Gas (Symbol)	% Percentage
Oxygen (O2)	20.95
Nitrogen (N)	78.09
Argon (A)	0.93
Others …Dust, Water….	0.002

Is medical O_2 different than the other O_2 sources?

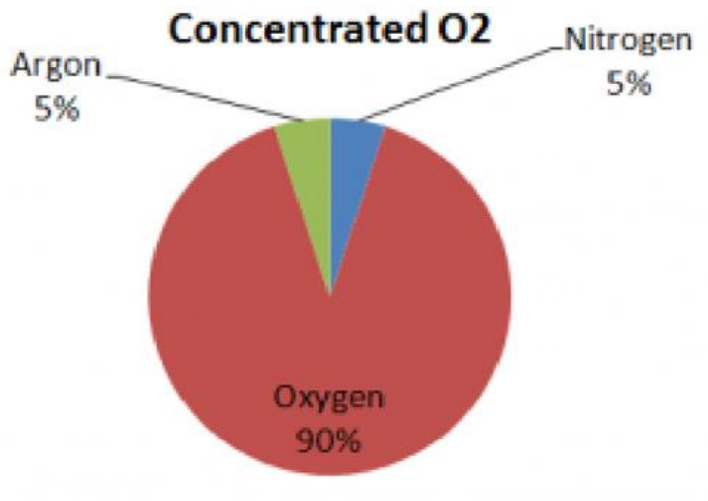
Ambient air consists of many gasses, but of that mix, only 19% of it is oxygen.



Many applications will require a higher percentage than the 19%. That's where Concentrated Oxygen fills the need. Concentrated Oxygen refers to oxygen which is a minimum of 90% pure with moisture removed to a -100 deg F dew-point. It can be produced from an oxygen concentrator or delivered in a pressurized cylinder bottle.
There are a few methods used to produce the concentrated oxygen;

Pressure Swing Adsorption (PSA)
This system operates on a similar principle to the heat less desiccant dryer in that air is pressure fed to a molecular sieve. The selected media will be pressurized to then adsorb nitrogen, moisture, hydrocarbons, and CO_2, leaving oxygen to flow through. When the pressure is reduced, the vapor, nitrogen, and other gases are dispersed and removed by the purged gas. The product gas contains about 90-95% O_2 and a few percent each of nitrogen and argon. (Most small oxygen concentrators use the PSA method.)

Other methods of on-site oxygen generation include vacuum swing adsorption and cryogenic treatment which will not be addressed.



All concentrated oxygen is really the same and needs to be generated from oil-free compressors/liquefiers because any oil (of whatever nature) is highly flammable in 100% oxygen. **The difference** between the four various oxygen grades, (Aviation, Medical, Welding and Research) is not in the quality of the oxygen but rather, the custody chain of the tanks. **Here's the issue:** If a welding tank is used, but it's a rotated or swapped out tank, you will not know if the tank has been left open allowing contaminants to enter the tank. To then use that tank for medical applications would not be good, as impurities could be expelled from the tank.

A solution is: Buy a new oxygen tank, tag it in some manner, and when you get it filled/refilled, demand your personal tank back. You will then establish a chain of custody. The oxygen can be considered medical grade because you started with a clean tank having no contaminants. Because oxygen is considered to be a prescription drug, the FDA is enforcing the chain of custody for the protection of the patients who need bottled oxygen. Companies that fill/refill Medical bottles need to be registered with the FDA and will need to comply with cGMP parts 210 & 211. Currently, the cGMP regulations require the company that fills the cylinders to either own the cylinders or to have written permission of the owners of the oxygen cylinders. Proper pre-fill inspections, labeling, and testing are also required.

If you are using an oxygen concentrator and that machine is being properly inspected and maintained, such as replacing the air compressor air filter(s), and periodically checking its oxygen output purity with an oxygen meter[1]:

That machine will be producing the same grade of oxygen as bottled oxygen.

If you are switching oxygen bottles as I listed above, then you are susceptible to impure oxygen due to the contaminants entering the tank. If you want purer oxygen, maintain the chain of custody!

1.2. The purpose of this manual

This manual is intended to be a guide for the medical gas equipment user to carry out basic maintenance tasks. As the majority of equipment problems are either simple or user-related it is the aim that the better care and regular maintenance enabled by this manual will have a significant positive effect on the delivery of healthcare across the nation (Ethiopia). The tasks are limited to simple first-line maintenance, that is: tasks that can be done by the user of the equipment tasks that take place at the point of equipment use tasks that do not require the opening of the main body of the equipment This manual is not intended as a complete maintenance guide that is the role of a biomedical engineer/ technician. Neither is it intended to be a guide to the actual use of equipment it is assumed that the user is trained in the correct operation of the equipment. Users are asked to note that while every care has been taken to make the contents as clear and accurate as possible, neither the authors, the Ministry of Health, RHB Biomedical Team can take responsibility for the results of actions taken as a consequence of using this manual.

1.3. The format of this manual

The text of the manual is in English and is designed for on-line access as well as hardcopy prints. General topics on maintenance management and principle of operation are covered inthis document.

The section comprises: a brief description of the function and working of the equipment a line drawing of the equipment; The checklists are on separate pages so they can be copied and laminated for display near the equipment. The choice of which equipment to include was guided by the 2013FMHACA List of Medical Equipment with minimum specification document. Equipment specified for health institutions up to the primary hospital was included, on the basis that this will cover the vast majority of simple equipment may not include. More advanced equipment will naturally require more advanced maintenance support. This manual does not include laboratory equipment, since the recent excellent World Health Organization publication Maintenance Manual for Laboratory Equipment covers these in great detail. In Ethiopia, EPHI is responsible for this specific device. Similarly, cold chain equipment will cover comprehensively by next version of Maintenance of Cold Chain Equipment.

[1] http://www.ozonesolutions.com/products/Ozone-Rental-Products/Oxygen-Meter-Rental_Accurate_Oxygen_Tester

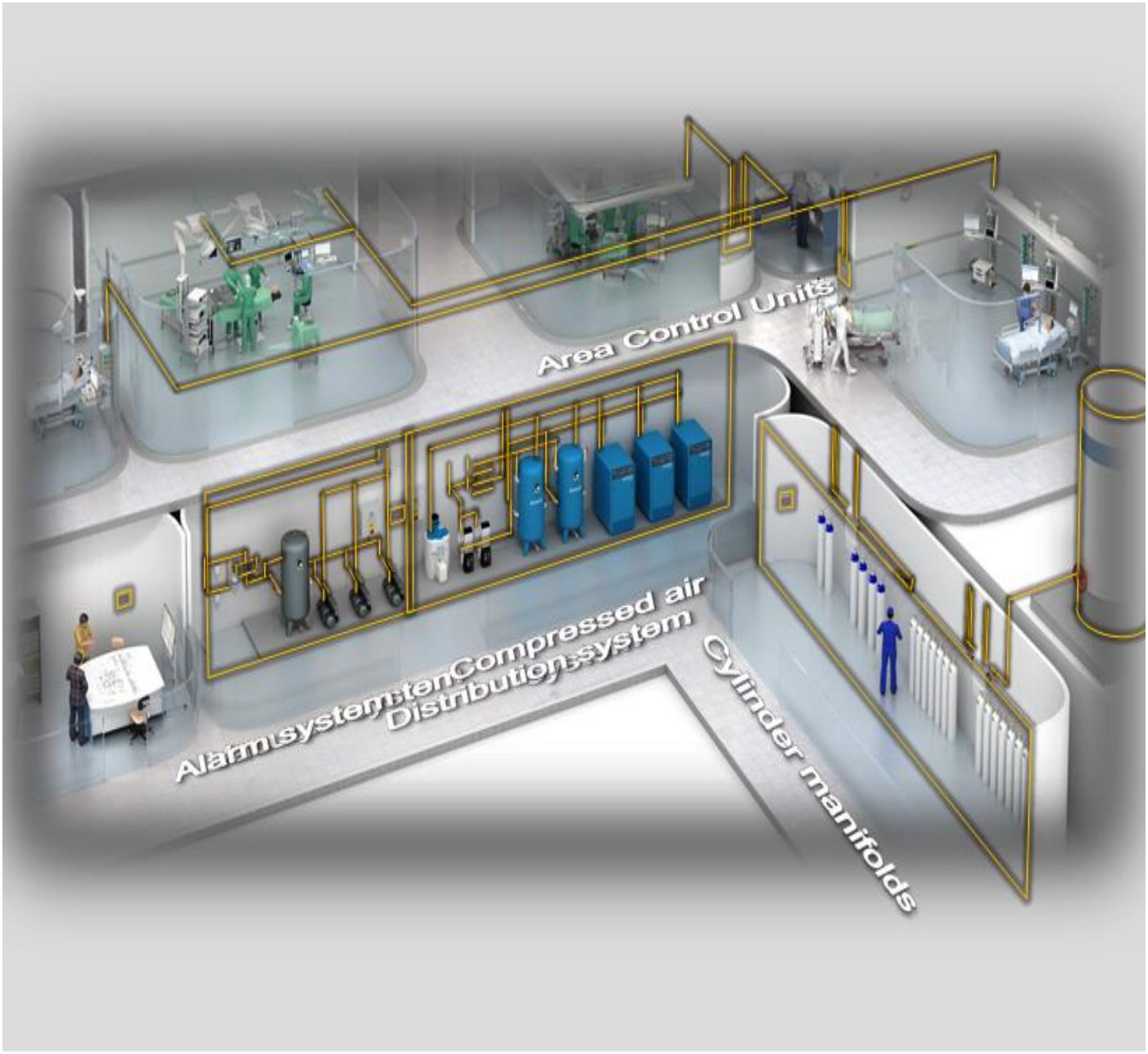


Fig. 1. Overviewofa medicalgassupplysystem

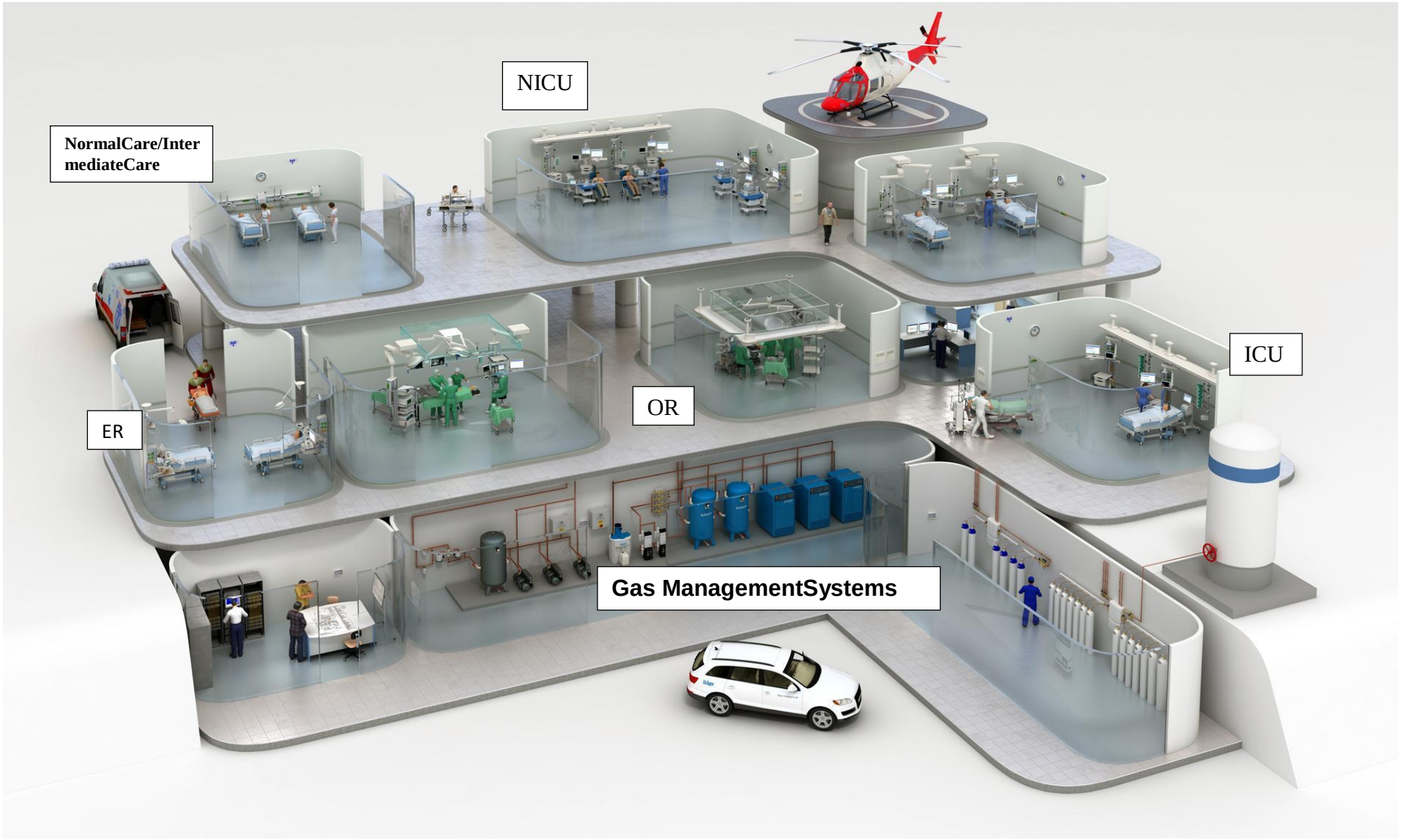


Fig. 2. Over all clinical service and medical supply system in Hospital

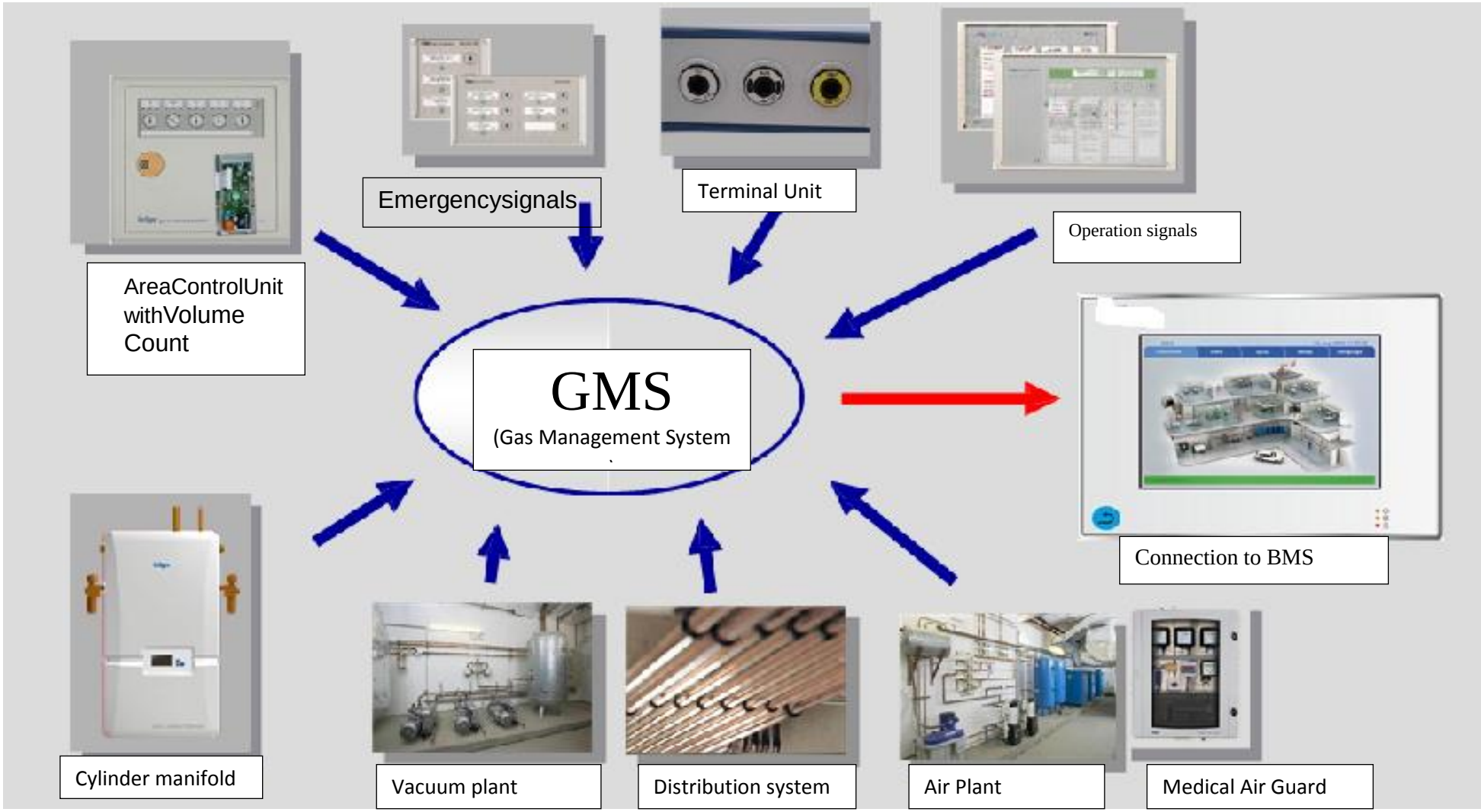
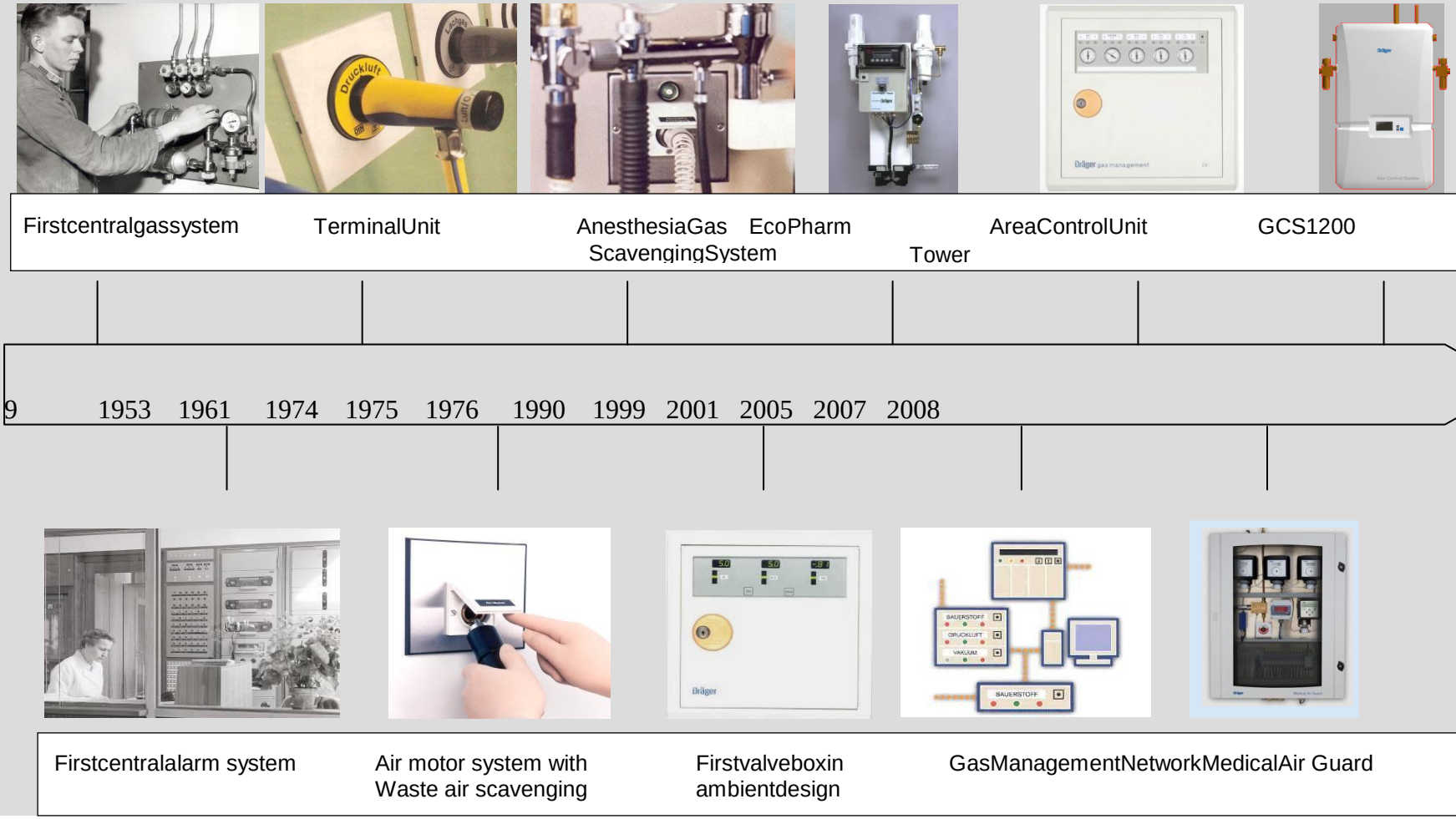


Fig. 3 GasManagementSystems

fig. 4. Basic Technical development



GLOSSARY

For purposes of this guideline, the following definitions apply:

- Compressed medical gas (CMG)--Any liquefied or vaporized gas alone or in combination with other gases which is a drug as defined by FMHACA
  Calibration gases and lung diffusion mixtures should classed as medical devices.
- Container--A metal container designed to contain either liquefied or vaporized CMG.
- Cryogenic vessel--A metal container designed to contain liquefied CMG at extremely low temperatures.
- Cylinder--A metal container designed to contain CMG at a high pressure.
- Dead ring test--Also called the "hammer test." A test used to determine the soundness of a cylinder by striking the side of the cylinder. If a clear bell-like sound results, the cylinder is considered satisfactory. If a dull sound results, the cylinder is not considered suitable for filling with a high pressure CMG (not applicable to aluminum cylinders).
- Home Respiratory Company (HRC)--Any firm that fills, transfills, or distributes compressed medical gases intended for use by patients at their residence.
- Manifold--Equipment or apparatus designed to fill one or more CMG containers at a time.
- Odor test--A test performed by opening a CMG cylinder valve to allow the CMG to flow into a cupped hand. The gas is then organoleptically examined by smelling for foreign gases. This test is not done on cylinders containing anesthetic gases or carbon dioxide.

How is the quality of a gas management system defined or ensured?

- - Components?
- - Standard?
- - …

Chapter. 2. Pharmaceutical and Medical Gases Information

Pharmaceutical and medical gases are fluids manufactured specifically for the medical, pharmaceutical manufacturing and biotechnology industries. They are frequently used to synthesize, sterilize, or insulate processes or products which contribute to human health. Pharmaceutical gases are also inhaled by patients in a technique known as gas therapy.

Fig 2.1. Medical gas cylinders

Pharmaceutical and Medical Gases Operation

Gases used for human healthcare are strictly controlled by both legislation and industrial standards so as to not impair human physiology. Gases of this nature may be manufactured as pure gases or as compounds, but are always filtered to the highest quality possible. The application of each individual gas determines its production and distribution. Medical-grade gases are used in the following applications:

- In the **production** of pharmaceutical merchandise and medicines. They may be used in the synthesis of these items, to sterilize such items, to test the item's packaging, or to insulate them from undesirable environmental effects such as oxidation.
- As an **analytical agent**, to calibrate medical devices or to diagnose a patient by exposing cultures or a biopsy to the gas and examining the reaction.
- As a **therapy**, in which the gas is prescribed as an anesthetic, drug delivery agent, or remedy for an occurring illness.
- As an **atmosphere** in environments in which air composition must be regulated.
- As a **pneumatic power source** for surgical and dental tools.

Medical Gases

In regard to fire risk, Medical compressed gases are classified as:

1. Non- flammable (do not burn)
   Nitrogen (N), Helium (He), Carbon dioxide (CO_2)
2. Composition (non-flammable but supportive of combustion, oxidizing)
   Air, O_2, He/O_2, CO_2/O_2, Nitric oxide (NO), Nitrous Oxide (N_2O),
3. Flammable (burns readily, potentially explosive)

Medical Gases

In regard to Application, Medical gases are classified as:

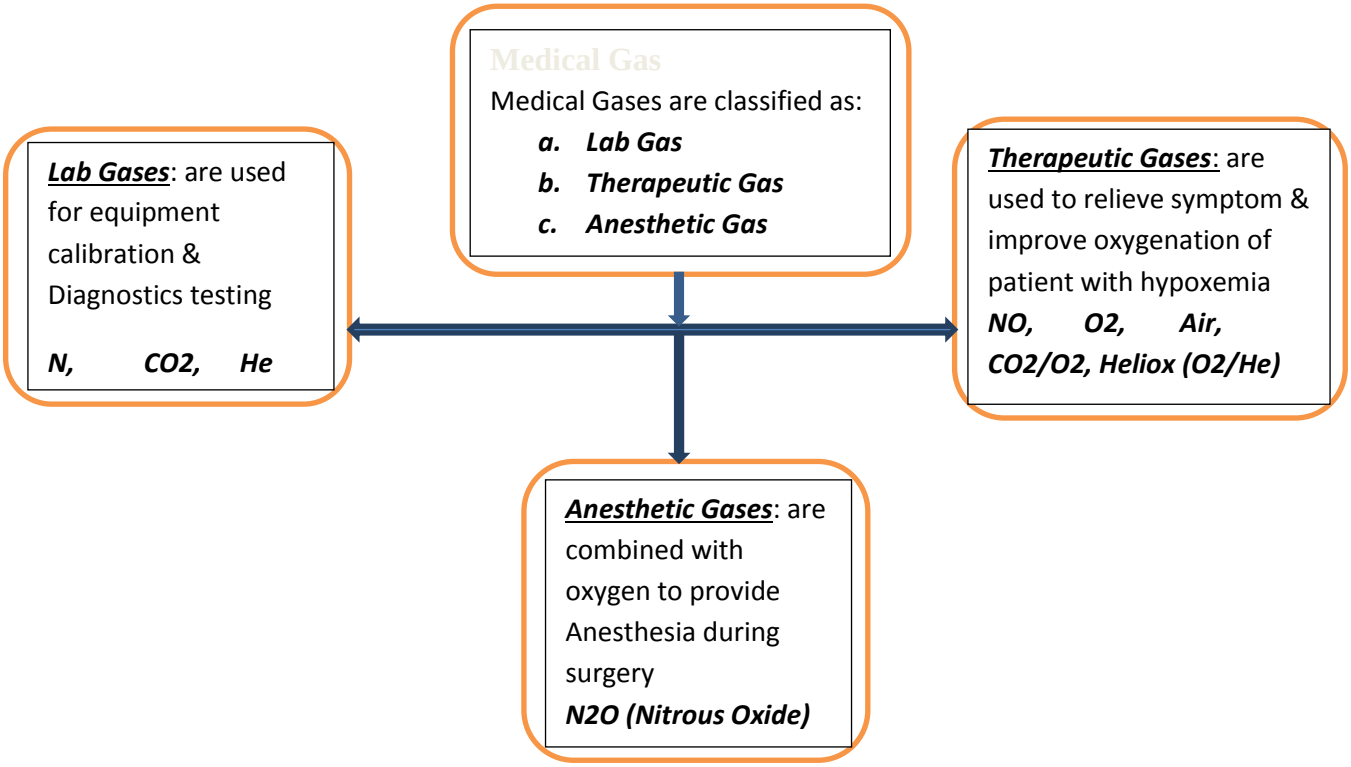
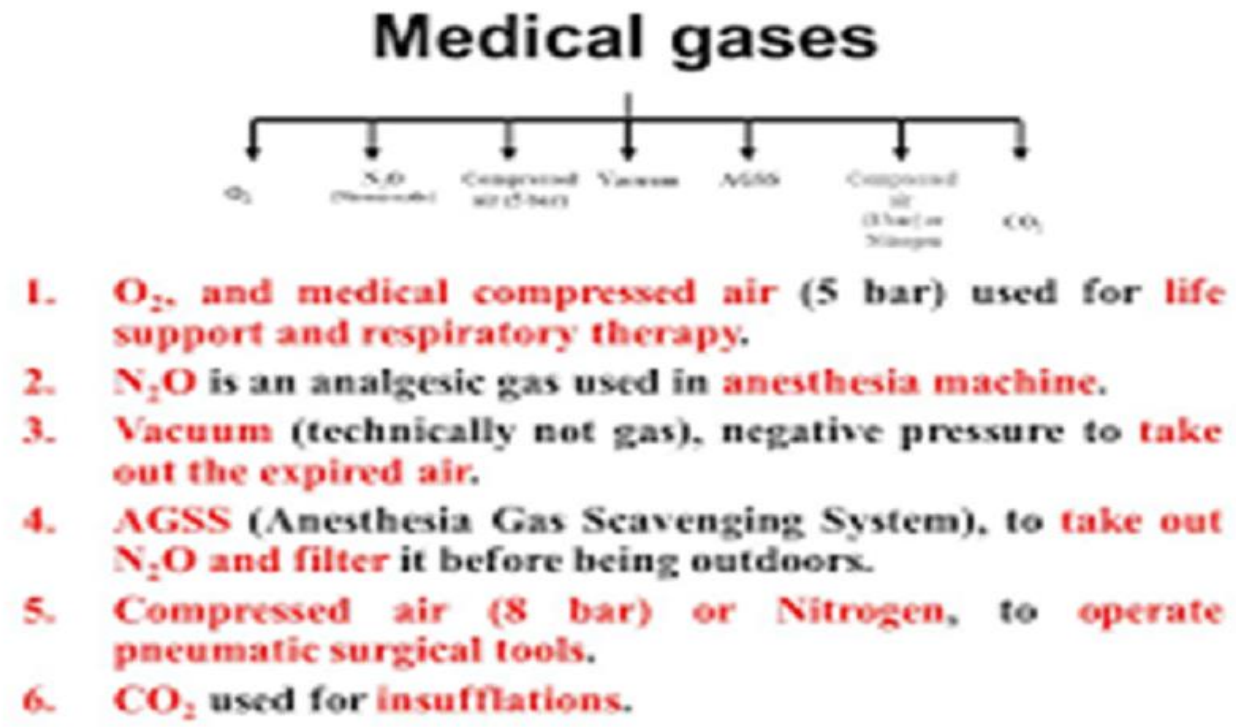


Fig 2.2. Medical Gas category based on application



Delivery

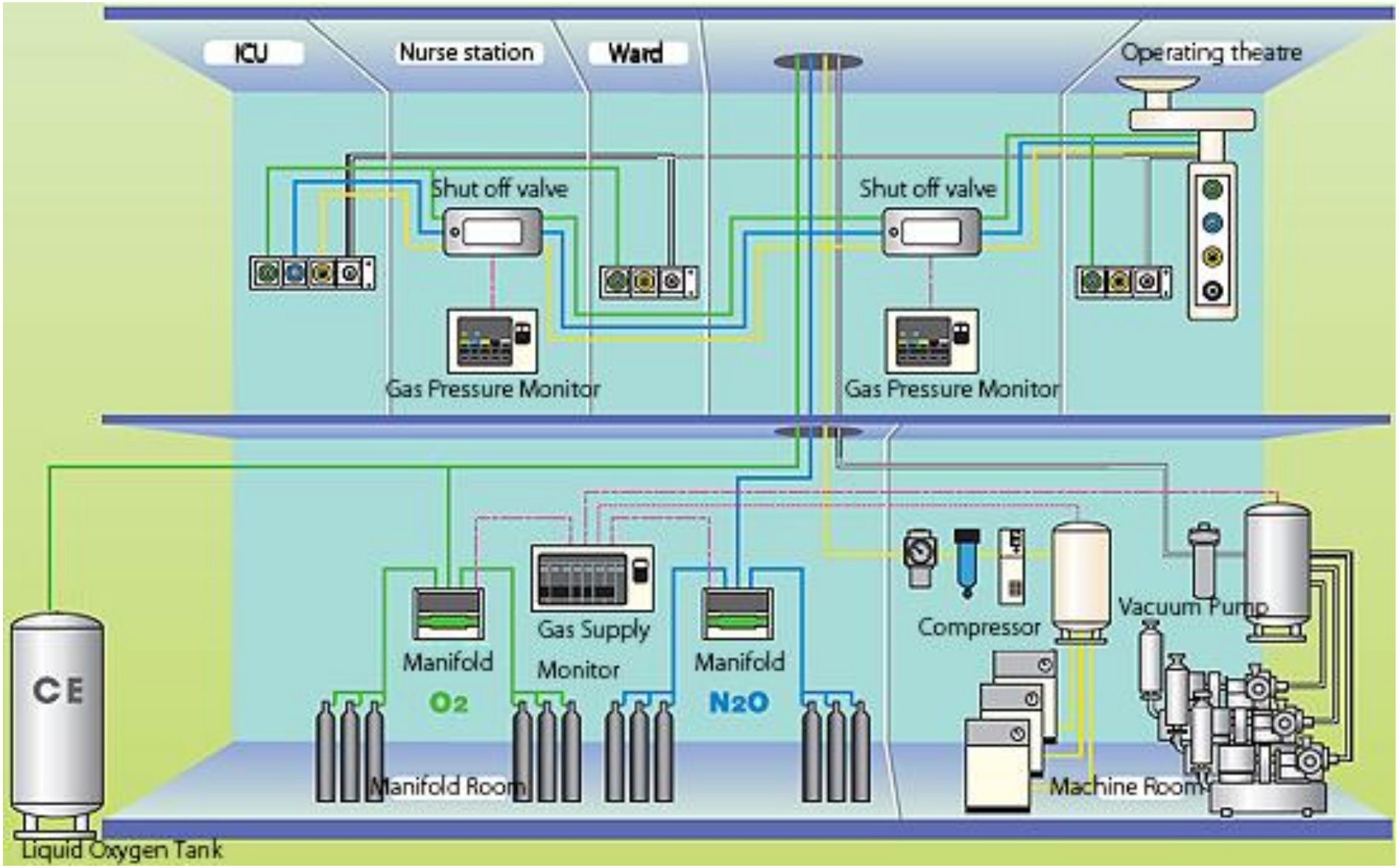
Medical gases are provided by licensed manufacturers who meet the quality controls which have been established by a jurisdiction's prescription drug regulating agency. Medical gases must be extremely pure, with at least 99.995 percent of the gas congruent to how it is identified. With the exception of medical-grade oxygen, all medical gases are delivered in compressed gas cylinders constructed of aluminum, stainless steel, or some other noncorrosive and nonreactive metal.

Fig 2.3.

Facility Distribution

Since medical gases are used in healthcare facilities, pipelines are routed from a cylinder storage location, through a gas manifold, and to the rest of the facility wherever access to medical gases is critical to patient care. Pipelines are devoted to a particular type of gas, and these systems will also include a medical vacuum and waste anesthesia exhaust system. Lines are accessible by outlets located around the facility. The proper installation and maintenance of these gas lines is critical to patient care. Many professionals contribute to this system, including anesthesiologists, pharmacists, nurses, engineers, maintenance personnel, and gas suppliers.

Accompanying these pipeline systems are various alarms, gauges, and testing instruments to ensure that the pipeline maintains pressure and flow. Occasionally, pipelines may need to be serviced to maintain service.



[Image credit: Air Water Safety Service Inc.]

Applications

Gas Therapy

Within medical facilities, gases are introduced to a patient's airway most often by the use of a medical ventilator and/or continuous-flow anesthesia machine. After these machines have been attached to the pipeline outlet, the gas delivered to the machine is vaporized into the correct ratio and administered to the patient via a mask which delivers the gas to the patient's mouth and nose, or by a nasal set which inserts the gas right into the patient's nasal passageway. Other means of introducing the gas to the patient's lungs include tracheostomy tubes, laryngeal masks, and endotracheal tubes. Various gauges and testing equipment guarantee the proper flow and ration of the medical gas being administered to the patient. Backup systems, including reserve gas storage and components for manual ventilation, can be found within these life-support devices.

Production and Atmosphere

Medical gases are occasionally valued for their ability to expel other gaseous fluids from a container or environment. Most often, nitrogen or carbon dioxide is introduced to a pharmaceutical product to reduce oxygen and humidity within the packaging environment, both of which greatly contribute to the decay and ineffectiveness of the drug. Furthermore, gases may be used to suspend cells and tissues in a cryogenic state after freezing, as is the case with nitrogen.

Analysis

Most often, gases are used to search for leaks in fluid handling equipment. Blood samples are often examined for their ability to carry oxygen and carbon dioxide, and the devices used to measure these samples require a known constant for calibration. Cell cultures may be incubated in certain atmospheres to determine diagnoses.

Pneumatic Power

Some medical hand tools, especially those used by dentists and dental hygienists, utilize medical air as the power source for the instrument. In these regards, the air must be absolutely pure and medical-grade gases are required.

Types of Pharmaceutical and Medical Gases

The following gases and gas compounds are frequently used in the healthcare industries. Gases manufactured for medical use may be identified by the acronym "USP," which represents that they adheres to the United States Pharmacopeia Convention. Most of the following gases have system pressures of about 50 to 55 psi to enhance breathability.

Medical Air[2]

Unlike the other piped medical gases which are typically delivered to hospitals in cylinders, medical air is most often manufactured on-site. This is accomplished by pulling outside air into a medical air compressor which is connected to the piping system feeding the facility. Rarely, due to poor quality ambient air, medical air can be produced from blending compressed cylinder nitrogen and oxygen. Due to the large volume of air that most hospitals consume, on-site production is usually the most practical and economical method of supply. There is a down side, however, in that the equipment

[2]by Ervin Moss, M.D. and Thomas Nagle, M.B.A

required to produce medical air suitable for patient use is quite complex and as such must be carefully installed and maintained to ensure that the risk of contamination or breakdown is kept to a minimum.

Most anesthesiologists are unaware of the complexity of the systems used to produce the medical air that they use. As medical air is considered by United States Pharmacopoeia to be a manufactured drug, anesthesiologists should be aware of the quality of the medical air produced in their facility and delivered to their patients. This article is meant to provide a basic understanding of a typical medical air system, including the purpose and operation of the key components. A familiarity with these basics should be sufficient to allow anesthesiologists to make inquires concerning the quality of the medical air delivered to their patients.

Medical air is used for a variety of patient applications. Many patients sensitive to oxygen toxicity are delivered air to lower their exposure to oxygen. Many of these patients have extremely delicate respiratory systems or processes which rely on a pure, accurate concentration of medical air. Some examples of patients dependent on a reliable, quality air supply would be neonates and those patients suffering from adult respiratory depression syndrome. Medical air is also used during anesthesia as a substitute for nitrous oxide to reduce the high concentration of oxygen exposure. While the source of medical air may be a manifold with a bank of compressed air cylinders, most hospitals use a compressor system. This article will refer to installations with air compressors. An illustration of a typical medical air plant is provided for your reference throughout this article's discussion. To better understand the medical air system, we will follow the path of the air as it flows through the key components, from the source to the patient.

Start at the Source

The logical place to start learning about the medical air system is the intake pipe of the compressor. The intake is usually located on the facility's roof. The intake location can have a major impact on the quality of the medical air produced. The location, design, and components of the air intake are described in National Fire Protection Association (NFPA) codes. NFPA 99, Standard for Health Care Facilities, recommendations for the design of medical gas systems are followed throughout the United States and will be referenced frequently in this article. However, you should be aware that local codes can supersede NFPA codes. NFPA 99 Sec. 4-3.1.9.2 states that the air intake shall be located outdoors above roof level, a minimum distance of 10 feet (3m) from any door, window, other intakes, or opening in the building, and a minimum distance of 20 feet above the ground. Intakes shall be turned down and screened or otherwise protected against entry of vermin or water with screening that shall be fabricated or composed of a non-corrosive material, such as stainless steel or other suitable materials. The NFPA allows flexibility when the roofs are staggered in height and suggests that factors such as the size of roofs, distance to nearest doors and windows, and the presence of other roof equipment can influence the final location. The intake need not always be higher than the highest roof.

In the case where there is more than one compressor system in the hospital, it is permissible to join pipes from separate compressors to one intake pipe which must be properly sized. However, the design must allow each compressor intake to be closed off by check valve, blind flange, or tube cap when a compressor is removed from service. This is meant to prevent mechanical room air from being drawn into the system from the open pipe.

The intake shall be labeled as the source of medical air. There has been a case where the medical air intake was located in the facilities heating ventilation air conditioning (HVAC) system. The coils on

an HVAC system were being washed with an acidic solution for cleaning and maintenance. This resulted in fumes being unknowingly drawn into the medical air system and to the patients.

Air quality varies from region to region and even with proximity of your facility. For example, the air on the roof of a hospital located within a large city will not be as pure as air at a rural hospital. Yet, a rural facility's air can be polluted by its proximity to a major highway, or the air intake placed too close to the medical vacuum system exhaust outlet. The latter is not an uncommon source of bacterial pollution where the gases from vacuum systems, literally of sewer quality, can be sucked into its medical air intake pipe. In older facilities the air intake may have been properly located and initially certified, but, there are cases where an intake became improperly located as the environment around the intake changed through facility expansion. Such has been the case with the addition of helicopter pads, parking lots, and truck loading docks where exhausts rich in carbon monoxide and engine pollutants were thus introduced in the manufacture of medical air.

The infamous "tweety bird" at the APSF scientific exhibit "Look Beyond the Walls" is an example of gross particulate contamination of a medical air supply. In this case, a bird was aspirated into the medical air compressor of a hospital and had occluded the system. The foul odor resulting from the decaying bird was a patient complaint that brought our committee member, Mr. Fred Evans, to service the system. Foul odor of any kind in a medical air system must be investigated. If the bird entered the system through an unscreened roof intake, the hospital was in violation of NFPA code. However, the entry was most likely through a break in the intake pipe which ran along a warehouse roof in course from the roof intake to the compressor. The break in pipeline continuity was a contractor error.

Interestingly, NFPA permits the intake to be within the building when the air source is equal or better than outside air, as filtered for use in operating rooms ventilating systems. It must be available twenty-four hours a day, seven days a week and periodically checked for purity. It is a good practice to test both the inside and outside air to occasionally determine if the inside air is of equal or better quality. Unless removed through the use of scrubbers or special filtration, any undesirable gases found in the atmosphere where the intake pipe is located will be compressed and delivered through the medical air system. Examples of this were covered at the beginning of the article.

Air Compressor and Its System

1. Inlet Filter/Muffler:

The air compressor process takes eight cubic feet of ambient air and compresses it into one cubic foot of compressed air. As a result, containments such as particulate matter, pollen, water, carbon monoxide, and breakdown materials of internal combustion engines or other containments are concentrated. Therefore, it is necessary to have methods in the manufacturing process to eliminate contaminates. The inlet filter/muffler should be located in the inlet side of the air compressor and can be part of some factory compressor packages. It is not uncommon for some systems to lack this filter since NFPA does not recognize it as a standard. Its primary function is to filter gross particulate from the ambient air aspirated through the screened intake usually located on the roof. It also acts as muffler for the air compressor to reduce noise pollution.

2. Air Compressor:

The air, usually from the atmosphere, is compressed by multiplexed medical air compressors, the "heart" of the medical air system. Two or more compressors (usually two) must be used for the support of medical air. Triplex and quadraplex systems are also available for facilities requiring greater demand. Simplex system components are not acceptable by NFPA 99. The duplication of much of the medical air systems provides a backup system if one unit breaks down or is in need of repair. The multiplexing provided by alternating units extends the life of the units and provides backup during demand overload. NFPA 99 requires that each unit separately must be capable of maintaining the supply of air at peak demand (NFPA 99 Sec. 4-3.9.1.2). Each compressor should be provided with an isolation valve, a pressure relief valve, and a check valve in its discharge line. Each compressor should be isolated from the system for servicing through an isolation (shut-off) valve in its discharge line. As stated in NFPA 99 Sec. 4-3.1.9.1, "The medical air compressors shall be designed to prevent the introduction of contaminants or liquid into the pipeline by: (a) Elimination of oil anywhere in the compressor, or (b) Separation of the oil-containing section by an open area to atmosphere, which allows continuous visual inspection of the interconnecting shaft."There have been cases where non-medical grade compressors have been installed in hospitals which can create oils, water, and toxic oil breakdown products to mix with the medical air.

The medical air system is intended to produce gas used exclusively for breathable air delivered to patients through devices such as: flowmeters, blenders, anesthesia machines, and critical care ventilators. This would also include instruments that exhaust into the pharynx such as dental tools and pneumatically powered surgical tools. Medical air should not be used for non-medical applications such as powering pneumatic operated doors, engineering, or maintenance needs. As stated in NFPA 99, "As a compressed air supply source, a medical air compressor should not be used to supply air for other purposes because such use could increase service interruptions, reduced service life, and introduce additional opportunities for contamination."

3. Aftercoolers (if required):

In larger air plants, aftercoolers may be desirable. Through the compression process air is heated and warmer air holds more moisture. Aftercoolers are used to reduce the temperature of the air after the compression process; this results in the precipitation of water. This water is then drained off. Aftercoolers should be duplexed so that one unit can handle 100% of the load. They should have water traps with automatic drains for water removal and isolation valves for servicing without the need to shut down the system. Although aftercoolers remove gross amounts of water they are not a substitute for dryers (see below).

4. Receiver:

The receiver is a large cylindrically shaped reservoir which stores a reserve volume of compressed air for usage. The receiver allows the efficient on/off operation of the compressors. Receivers are usually composed of iron and can be a source for rust particulate. Even though iron receivers meet NFPA standards, this material is subject to oxidation and flaking when introduced to moisture. Stainless steel receivers are available and should be installed during new construction, repair, or expansion despite the minimum NFPA standard. The receiver should be equipped with a pressure relief valve, site glass, pressure gauge, and a water trap with an automatic drain. The receiver should also be provided with a three valve bypass to allow servicing.

5. Air Dryers:

Dryers are an essential part of the system used to remove the water produced in the manufacturing process by the compression of ambient air which may be rich with humidity. Air dryers are usually of the refrigerant or desiccant type technology. Refrigerant dryers are an air-to-air refrigerant heat exchanger, a mechanical condensate separator, and an automatic drain trap. While desiccant dryers use an adsorption process to remove water, desiccant particulate can contaminate medical air if not properly maintained or filtered. The dryers should be duplexed so that only one dryer is used at one given time. Hence, each dryer should be capable of handling 100% of the load. They should also use bypass valves for isolation during servicing. Desiccant dryers are approximately 50% more expensive than refrigerant dryers.

6. Final Line Filters:

Important components of the medical air system are final line filters used to prevent introduction of particulate, oil, and odors from the medical air supply. Some contaminants may be introduced as hydrocarbons from leaking oil seals, spill-over from overloaded filters, rust flaking from a receiver, etc. NFPA 99 states, "Each of the filters shall be sized for 100% of the system peak calculated demand at design conditions and be rated for a minimum of 98% efficiency at 1 micron. These filters shall be equipped with a continuous visual indicator showing the status of the filter element life." The need for visual indication was added by NFPA in 1993. The filters shall also be duplexed for isolation and shut down for servicing without completely shutting down the system. NFPA 99 recommends quarterly inspection of the filters. Some manufacturers provided filtration capabilities down to a .1 micron level. In environments with high concentrations of carbon monoxide special scrubbers may be introduced at this location to remove this or other pollutants.

7. **Final Line Regulators:**

Final line regulators should provide operating pressure for medical air throughout the facility at 50 to 55 psig. Whereas, the air compressor plant generates operating pressures of 80 to 100 psig. to facilitate the efficiency of the dryers. The regulators should be duplexed with isolation valves to allow servicing without the need to shut down the system. In Air Quality Monitoring as of the 1993 edition, NFPA 99 requires new construction to have continuous monitoring with central alarm capabilities for dew point and carbon monoxide contaminants downstream of the dryers and upstream of the piping system. These requirements have been largely driven by the water and elevated levels of carbon monoxide found in some medical gas systems.

8. **Shut-off Valves:**

The source shut-off valve should be located to permit the entire source of supply to be isolated from the piping system. This valve is located at the air compressor and its accessories downstream of the final line regulators. All shut-off valves should be quarter turn, specially cleaned, ball valves suitable for medical gas applications. The main supply shut-off valve should be located downstream of the source valve and outside of the enclosure, source room, or where the main line source first enters the building. The purpose of this valve is to shut off the supply in case of emergency or if the source valve is inaccessible. Each riser distributing gases to the above floors should have a shut-off valve adjacent to the riser connection. Each lateral branch or zone shall be provided with a shut-off valve which controls the flow of gases to the patient rooms on that branch. The branch/zone valve should allow the control of gases to that specific area and not effect the gas flow anywhere else in the system. Pressure gauges should be provided downstream of each lateral branch shut-off valve. NFPA 99 also states: "Anesthetizing locations and other vital life-support and critical areas, such as postanesthesia recovery, intensive care units, and coronary care units, shall be supplied directly from the riser without intervening valves...""A shut-off valve shall be located outside each anesthetizing location in each medical gas line, so located as to readily be accessible at all times for use in an emergency." It is important that all shut-off valves be labeled with a caution, the name of the gas, and the location(s) which the valve controls. There have been numerous incidents of medical gases being shut off due to poor labeling (if any) of the valve and the locations which it supplies.

9. **Alarms:**

An automatic pressure switch shall be located downstream of the main supply line shut-off valve. A visual and audible alarm should indicate a rise or fall of the main line pressure above or below the nominal line pressure. The alarm should be located where it is continuously monitored throughout the facility's time of operation. NFPA 99 states, "Area alarms shall be provided for anesthetizing locations and critical care areas. Warning signals shall be provided for all medical gas piping systems supplying these areas..." The area alarm in the anesthetizing location is intended to monitor all locations on a single branch, not each individual operating room.

10. **Piping:**

Piping which is used for the system downstream of the source shut-off valve shall be composed of copper. NFPA states: "Piping shall be hard-drawn seamless medical gas tube Type K or L (ASTM B819), and bear one of the following markings: OXY, MED, OXY/MED, ACR/OXY, or ACR/MED." Medical air pipes are to be of the same material and quality as oxygen pipes.

The type of material used with the compressors and with the piping system shall be non-corrosive. Copper and brass are most commonly used. The pipe bringing air from the outside intake to the compressor should be non-corrosive since it is exposed to moisture and atmospheric contaminants. Although the NFPA does not spell out the intake pipe's specific composition, as it does for the compressor and the pipeline downstream, the intake pipe should not be iron. It is not uncommon to find the plumbing contractors engaged to install medical piping to treat the piping as ordinary water or sewer plumbing. Galvanized steel is also unacceptable since the zinc plating could flake off under the pressure and flow of gases.

A recent (1995) major hospital inspection was found to have iron piping between the medical air compressor, dryers, receiver, and aftercoolers. The system had been certified as meeting NFPA codes seven years earlier. The correction of such design errors can be expensive. It is far more reasonable for the anesthesiologists to be aware of basic construction codes and have a say in proper installation from the beginning. Iron and galvanized pipe may oxidize, resulting in particulate matter flaking off from the pressure and flow, and will result in being carried downstream where it may interfere with the flow of gases or proper operation of station outlets, ventilators, blenders, anesthesia systems, or other pieces of secondary equipment.

11. Station Patient/Outlets:

Station outlets consist of primary and secondary check valves which allow secondary pieces of equipment to be attached to the medical gas line. Station outlets should be used only for the delivery of gases intended for medical use. The outlet shall also be designed as being gas specific by using size or keyed dissimilar connections specific for each individual gas. Each outlet shall be labeled with the name or chemical symbol and the specific color coding for the gas supplied.

More on Contaminants and Particulates:

Water is the most common contaminant found in medical air lines and is perhaps the most insidious of the contaminants found. It can also cause some of the most costly damage to secondary equipment. Water, unlike particulate, can pass through particulate filters and make its way into anesthesia machines, ventilators, other commonly used secondary equipment, and the patient as well. Jerry Lavene, Manager of the Anesthesia Vaporizer Repair Center from Ohmeda, states "The most common contaminant we find in vaporizers during their disassemble for remanufacture is moisture. Moisture or the combined effects of moisture with the anesthetic agent can create issues within the internal mechanisms of the vaporizer." Some critical care ventilators saturated with water were non-repairable and had to be scraped by one facility. The anesthesia machines required a complete overhaul to restore them to usable condition. The presence of water can also provide the medium for bacterial growth. Water located in medical air lines which are subjected to low temperatures can freeze and occlude gas flow. Water can also facilitate the oxidation of the copper piping inside the medical air line.

Water may be introduced through a variety of ways. Inadequate removal of water through undersized, saturated, or the lack of appropriate air dryers is common. Water may be introduced through malfunctioning liquid ring air compressor components. Failure of automatic drains in aftercoolers, receivers, dryers, or other components of the medical air plant is an area of frequent fault allowing unwanted water into the system.

Oils can be introduced through a non-medical grade air compressor being installed. This may occur through improper equipment specification or purchasing. Medical grade compressors have been known to fail and introduce oil into the system. Some medical air compressors are now available which use a totally oil-less compressor technology to prevent this possibility. Don't assume the air compressor being used for your facility is suitable for medical grade air. The possibility of oil contamination has resulted in hydrocarbon monitoring requirements.

Construction debris such as sand, solder, flux, dirt, vermin, and so on have been found in medical air lines due to poor techniques in the construction process. These particulates can be introduced downstream of the filtration system located at the medical air plant. This can be avoided through proper design, installation procedures and techniques, and final testing (certification) of the new system or addition. There are processes available to remove these contaminants found in existing systems. Medical air is an important life sustaining gas commonly used in our facilities. Anesthesiologists should be aware of those responsible for overseeing the medical air system and their qualifications. During construction they should be aware of design and installation specifications. Preventative maintenance programs should be in place and the results of as many as 17 tests performed at required intervals should be reviewed and evaluated

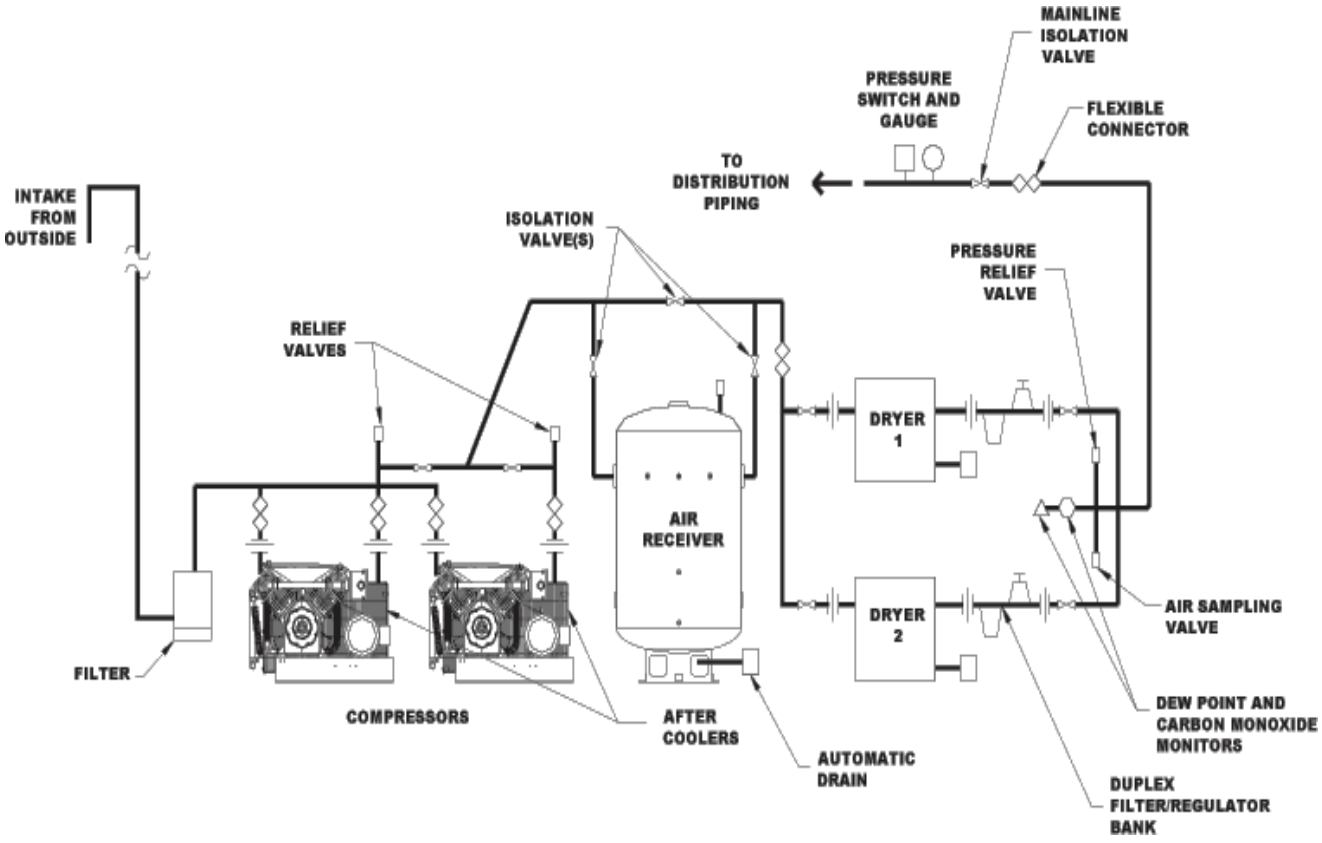
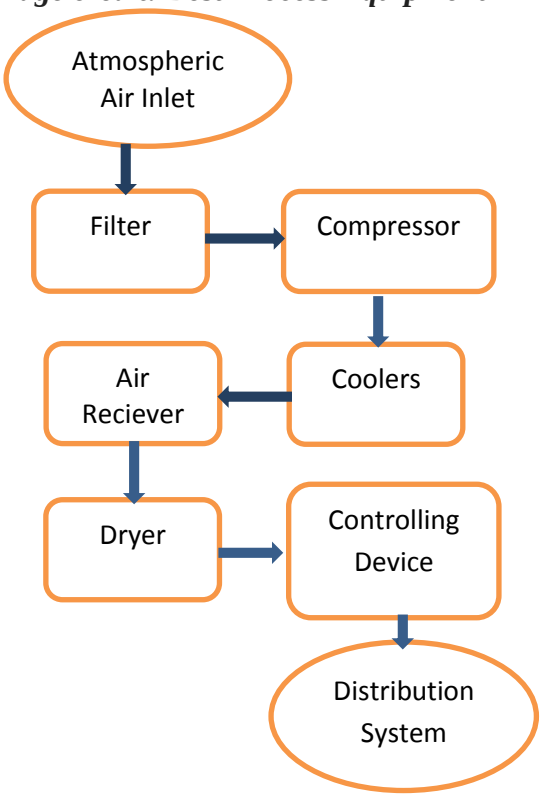


Image credit: Best Process Equipment



Oxygen (O_2)

Oxygen is essential to the life functions of animals and plants. In humans, oxygen is carried to tissue by hemoglobin in red blood cells, where it assists in the metabolism of the chemical bonds from nutrients. Oxygen therapy is used in several applications: to supplement the breathing of patients whose respiratory system has become comprised from ailments such as chronic obstructive pulmonary disease, bronchitis, or emphysema; to treat patients who need resuscitation or who are suffering from hemorrhage, shock, convulsions or other trauma; to administer atomized, liquid medication into the lungs; or as a treatment itself, due to pure oxygen's vasoconstrictive properties.

Medical oxygen used in hospitals or other large healthcare facilities is frequently provided by a vacuum-insulated evaporator. In this instance, liquid oxygen is supplied to the facility and kept at a temperature which assures a liquid state. This reserve is drawn from and the oxygen is fractionally distilled to turn it back into a gas. For patients who need access to O_2 at home, gas cylinders or oxygen concentrators are available and provide medical oxygen at lower volumes. Medical oxygen is frequently represented by green or white labels, and exceptional care must be taken around pure oxygen due to its high combustibility. Furthermore, it cannot come into contact with hydrocarbon materials.

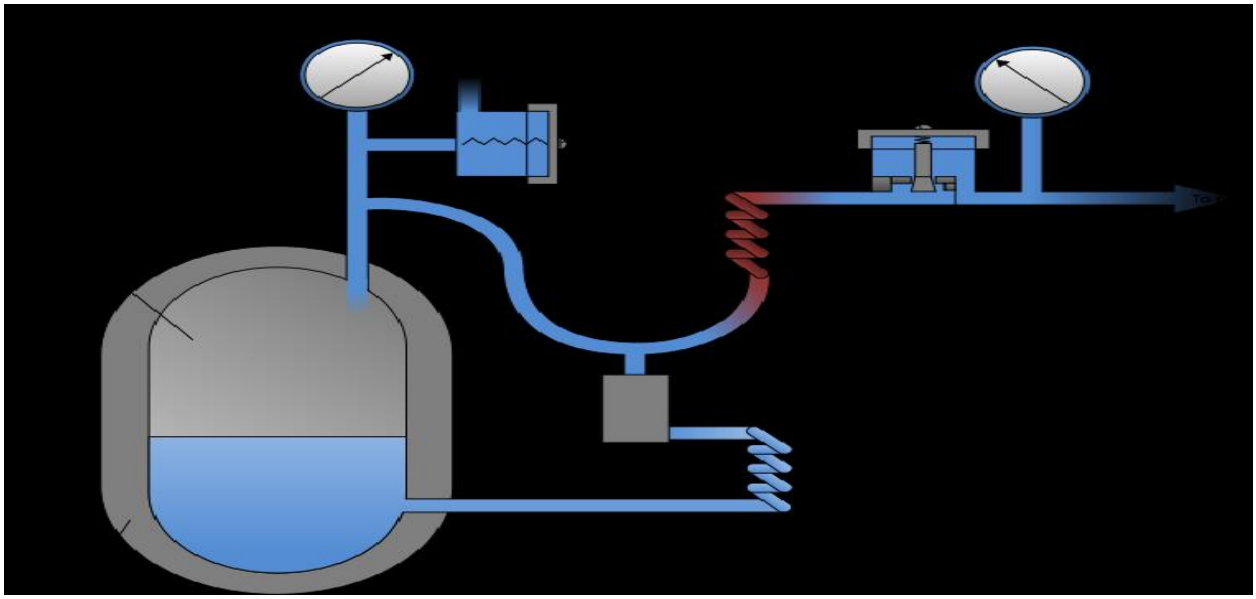


Image credit: Wikipedia

Carbon Dioxide (CO_2)

Since carbon dioxide is a waste byproduct of human respiration, its pharmaceutical uses are limited to: as a gas for noninvasive surgery, to inflate and stabilize body cavities for increased visibility and to increase blood flow to the brain; to remedy bronchial spasms; to stimulate respiration, since the need to release CO_2 is greater than the need to inhale O_2; and for clinical and physiological examinations. Carbon dioxide is administered to the patient via face mask. Carbon dioxide is also used as an atmosphere for organs which are artificial or awaiting transplant, and as a tracer gas for pharmaceutical package testing.

Carbon dioxide is supplied to facilities via compressed gas cylinders, where it remains as a pressurized liquid until extracted. Health facilities use grey labels to indicate carbon dioxide.

Image credit: Rx Resource

Nitrogen (N)

Nitrogen's inert characteristics make it a versatile gas in pharmaceutical applications. It is regularly used as a pressurizing agent. Tanks, pipelines, hoses, vessels, and other process equipment can be

tested for leaks with nitrogen gas. It can also be used to dispense or transfer nearly any type of fluid from storage tanks or reservoirs. Its use as an asphyxiant makes it suitable for purging volumes of other corrosive or volatile gases. It is used as a blanketing agent when packaging pharmaceutical medications. Liquid nitrogen is also used to instantly freeze biological samples, such as agricultural, flora, and fauna specimens, as well as human blood, sperm, embryos, and bone marrow, without degrading specimen integrity. It is also used in dermatology to treat cutaneous micro-trauma. Finally, nitrogen may be elected to power pneumatically-controlled surgical and dental handtools.

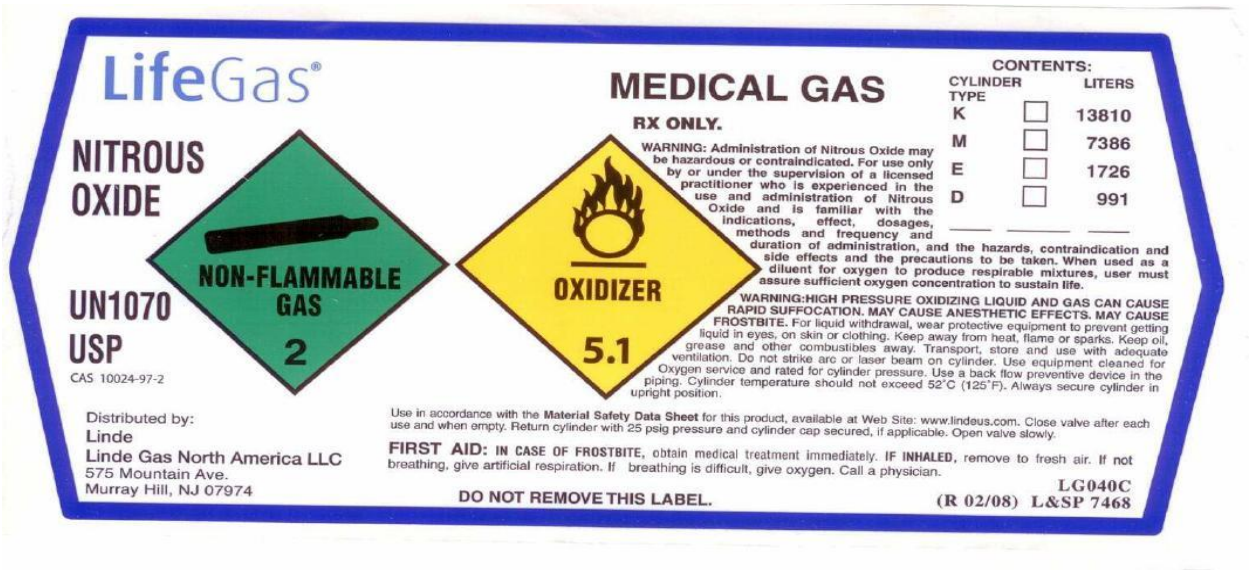
Nitrogen is typically packaged in gas cylinders as a pressurized liquid, but nitrogen generators are available. Black labels indicate nitrogen pipelines and tanks. Nitrogen pressures can reach 174 psi.

Medical nitrogen cylinder; medical nitrogen generator
Images credits: Med Gas Supplies; Medical Expo

Nitrous Oxide (N_2O)

Nitrous oxide is valued for its contributions as a weak general anesthetic, where it is prescribed to patients via facemask in a ratio with oxygen. At least 21% of the gas mixture must be oxygen. It is used as an anesthetic in surgery and dental applications. N_2O also helps alleviate anxiety in patients. Nitrous oxide is commonly referred to by its nickname "laughing gas" because of its intoxicating effects, and when used as an analgesic it is usually a precursor to other intravenous or oral painkillers. It is considered an alternative therapy for narcotic addiction.

Nitrous oxide is manufactured by the thermal decomposition of ammonium nitrate. The N_2O byproduct is filtered to eliminate impurities and refrigerated to induce liquefaction. It will remain as a liquid at room temperature in a pressurized cylinder, which is how it is distributed. Labels for nitrous oxide are light blue in color.



Nitric Oxide (NO)

Nitric oxide is a powerful vasodilator, essential signaling molecule, and also a free radical. Since it dilates blood vessels, it is commonly prescribed to patients who suffer from circulation or heart ailments; however, it is prescribed as nitroglycerin and amyl nitrate pills which are metabolized into NO. In fact, the only instance for a NO gas prescription, which needs to be implemented in equal parts with oxygen, is for neonatal patients who suffer from pulmonary hypertension or post-meconium aspiration.

There is no standardized label color for nitric oxide systems; the only designation is that it remains separate from established colors. Nonetheless, nitric oxide lines and cylinders are frequently labeled with teal and black labels.

Images credits: Ceretec Inc.; ASTM

Helium (He)

Helium is most commonly used in respiratory therapies. Its low density makes it easy to respire and it is provided as an oxygen/helium mixture, most commonly in a 21%/79% or 30%/70% ratio, known as heliox. Its low temperature, when compressed, cools metal components used in magnetic resonance imaging (MRI) machines. It is also used in some cryogenic applications.

Helium is manufactured from the liquefaction of natural gas. It is provided to customers in compressed cylinders which are outfitted with brown or brown and green color-coded indicators.

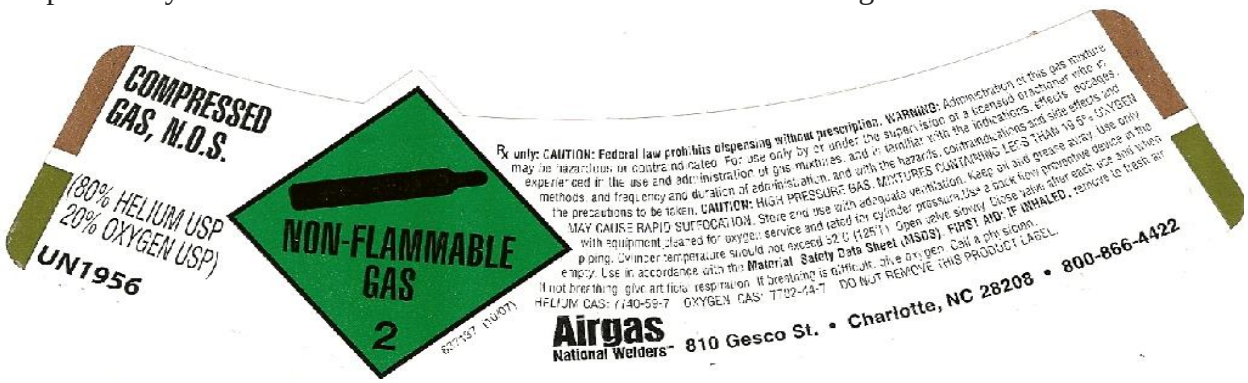


Image credit: National Institute of Health

Xenon (Xe)

Medical-quality xenon is used for hyperpolarized magnetic resonance imaging (HPMRI) and xenon-enhanced computed tomography. Xenon is beginning to replace nitrous oxide as an anesthetic because it does not inebriate patients and reduces the potential for nausea. Recent studies have indicated that xenon can protect neurological and cardiovascular systems from oxygen deprivation and overstimulation during bypass surgeries. Xenon is also useful for medical imaging applications as it can be used to visualize cavities, airways, and soft tissue.

Xenon is relatively expensive for USP-grade gas and until recently was used sparingly; new harvesting techniques have improved its economic viability. Since xenon is largely inert, bright green labels typically indicate xenon supplies, but no set color code has been established.

Images credits: Sparks; Daily Globe and Mail

Argon (Ar)

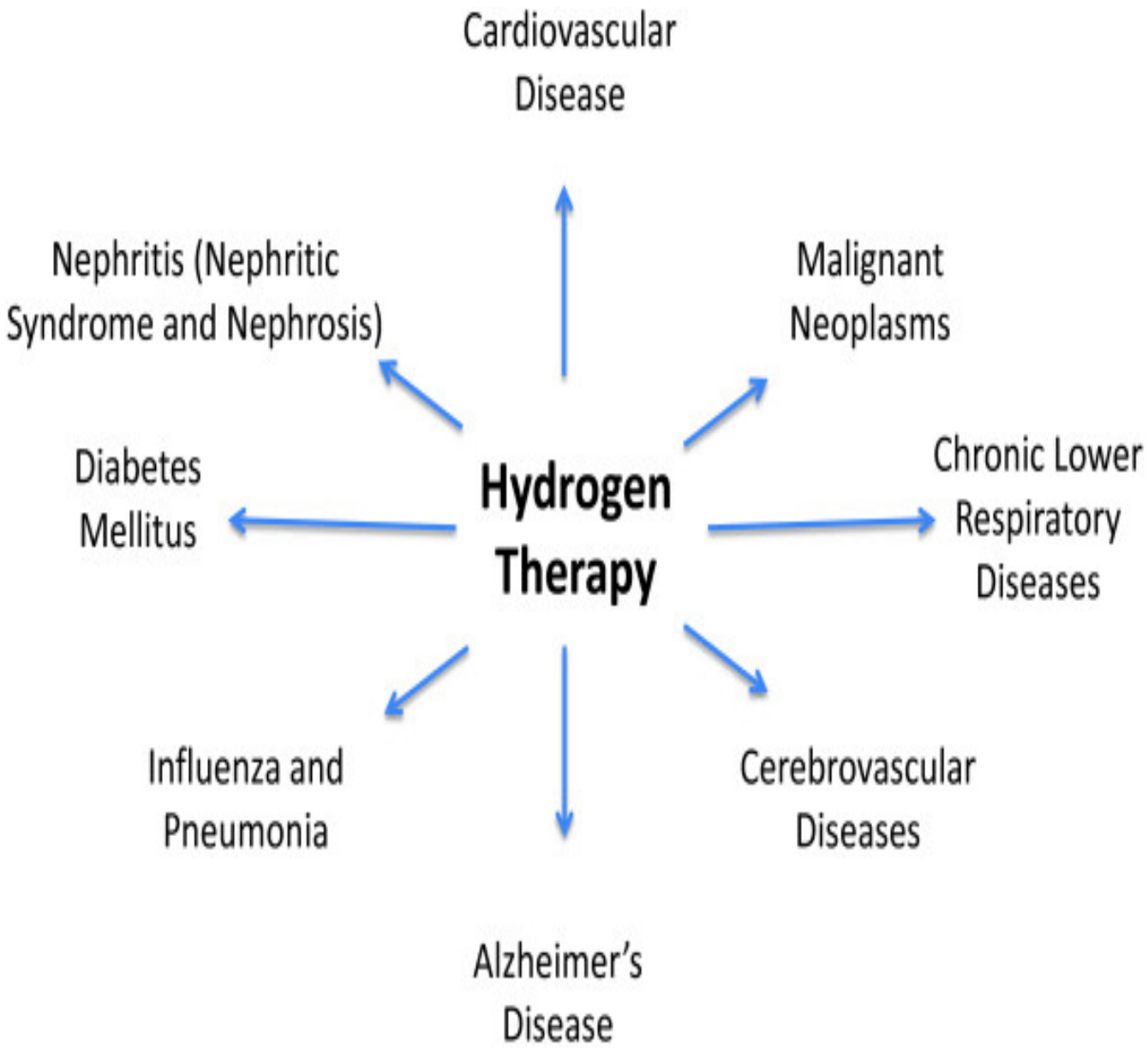
Argon gas has limited employment in the medical and biotechnology sector. It is occasionally used in pharmaceutical packaging to retard or prevent the oxidation of prescription drugs where nitrogen may conflict. Blue argon lasers--ion lasers which utilize argon as the lazing medium--are used to weld arteries, destroy tumors, and correct eye defects. An argon and oxygen mix, known as argox, may be

used to deplete excessive amounts of nitrogen in the bloodstream. Like most other medical gases, argon is supplied to the end user via cylinders which will have dark green labels.

Image credit: Dreamstime

Hydrogen (H)

Recent studies indicate hydrogen gas has an emerging role in gas therapies. Minute amounts of inhaled hydrogen gas are shown to have antioxidant, anti-inflammatory, and anti-apoptotic protective effects on biological tissues. Hydrogen cylinders are indicated with red labels, but hydrogen gas used as a remedy is not widespread.



Ailments which can benefit from H gas therapy
Image credit: Dixon et al. via Medical Gas Research

Hydrogen gas [4]

It is a bioactive molecule that has a diversity of effects, including anti-apoptotic, anti-inflammatory and anti-oxidative properties; these overlap with the process of neuroprogression in major psychiatric disorders. Specifically, both bipolar disorder and schizophrenia are associated with increased oxidative and inflammatory stress. Moreover, lithium which is commonly administered for treating bipolar disorder has effects on oxidative stress and apoptotic pathways, as do valproate and some atypical antipsychotics for treating schizophrenia. Molecular hydrogen has been studied pre-clinically in animal models for the treatment of some medical conditions including hypoxia and neurodegenerative disorders, and there are intriguing clinical findings in neurological disorders including Parkinson's disease. Therefore, it is hypothesized that administration of hydrogen molecule may have potential as a novel therapy for bipolar disorder, schizophrenia, and other concurrent disorders characterized by oxidative, inflammatory and apoptotic dysregulation[1].

International Medical gas Color Codes(Chart)

The accompanying diagram indicates the color codes for medical gases based on which standard is adhered.

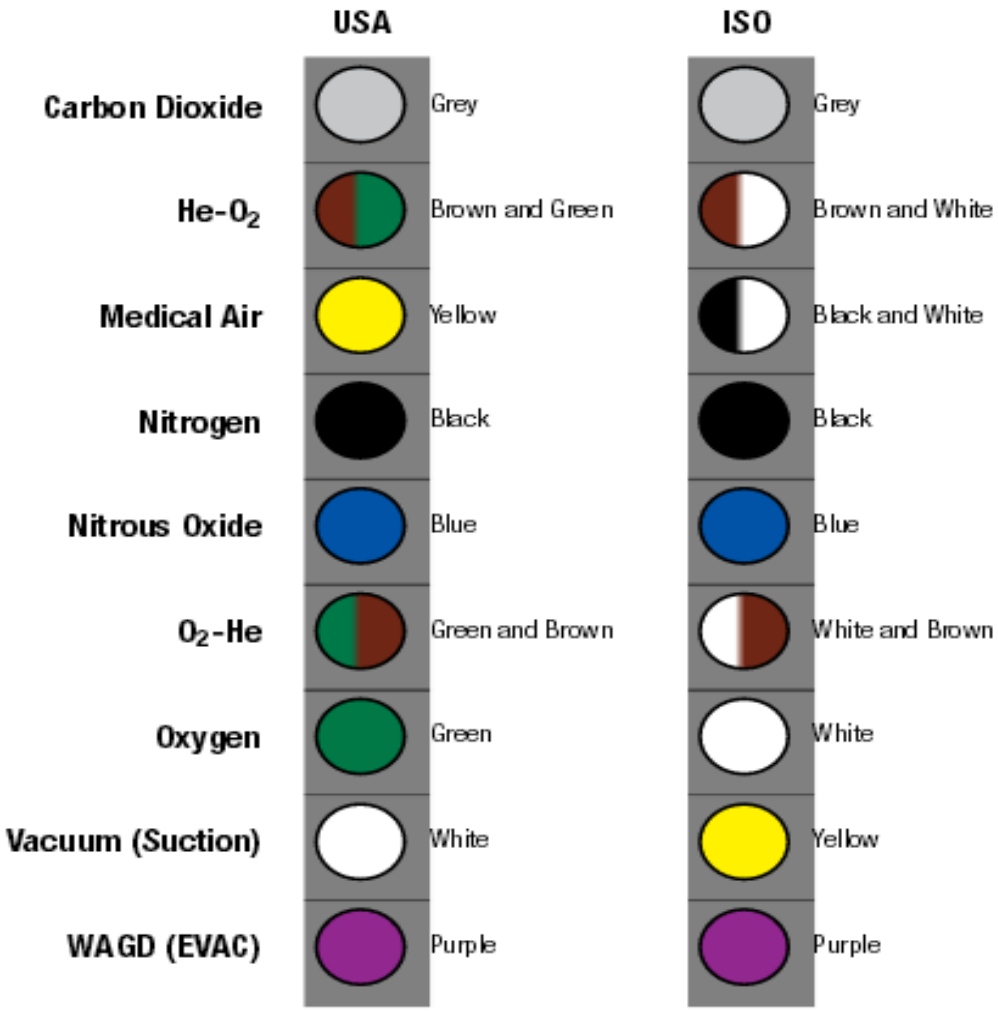


Image credit: Ohio Medical

Image: Patient side Medical Gas terminal point

Left Intentionally

Terminology:

Airflow is Air will flow from an area of higher pressure to one of lower pressure; during inspiration, the pressure in the alveoli must be less than the pressure at the mouth for air to flow in, and during expiration, the reverse is true. Air flow may be laminar, turbulent or transitional, depending on the velocity of flow and on the diameter and configuration of the tube.

Airway is the anatomical structures through which air passes on its way to or from the alveoli; the nasopharynx and oropharynx, the larynx, the trachea, bronchi, and bronchioles.

AirwayResistance is driving pressure divided by flow (P/V); or, the opposition to motion caused by the forces of friction, which is a function of flow rate, airway caliber, nature of gas breathed, and type of flow (laminar vs. turbulent).

Alveolar Pressure is the pressure within the alveoli is conventionally given in cm H20, with reference to an atmospheric pressure of zero. Thus, a negative alveolar pressure indicates that the pressure is lower than atmospheric; a positive alveolar pressure indicates that the pressure is above atmospheric.

Alveoli are the air sacs that act as the primary gas exchange units of the lung.

Asthma is a condition characterized by increased tone of the smooth muscle surrounding the bronchi and by bronchial inflammation and excess mucous secretion. An individual with acute asthma will present with an obstructive profile on respiratory function tests.

Atmospheric Pressure is ambient air pressure, averages 760 mm Hg at sea level. In pulmonary calculations, atmospheric pressure is taken as the reference value, 0 cm H20. Pressures higher than atmospheric pressure then are positive; those lower than atmospheric pressure are negative.

Body Plethysmograph is a large airtight box used for measuring lung volumes; the subject sits in the box where pressure and volume changes are measured by Boyle's Law during respiratory efforts.

Boyle's Law is the principle that at constant temperature the volume of a gas varies inversely as the absolute pressure applied to the gas.

$$P1V1=P2V2;$$

Bronchitis is a clinical condition marked by airway inflammation and excess mucus secretion, manifested by couth and sputum production. It may cause narrowing of the airways and increase their resistance; this results in an obstructive ventilatory defect.

Chest Wall is the anatomical structures that border the parietal pleura, including the ribs with intercostal muscles, and diaphragm; when the muscles of the chest wall are relaxed, the chest wall acts in an elastic fashion comparable to the lung, responding passively to the pressure differences around it.

Compliance is Volume change per unit of pressure change across an elastic structure.

Compliance Curve is the pressure-volume curve for the lung or relaxed chest wall; plotting volume as a function of pressure inside minus pressure outside. The slope of this curve is the compliance.

Dead Space is the portion of each breath that does not participate in gas exchange. Anatomic dead space is the volume of the conducting airways; physiologic dead space also includesthe contribution of alveoli that are well-ventilated but poorly perfused.

Diaphragm is a thin, dome-shaped sheet of muscle that inserts into the lower ribs; it is the most important muscle of inspirationÑwhen it contracts, it lowers pleural pressure.

Distending Pressure is the inside pressure minus the outside pressure of an elastic structure; for the lung, this is also referred to as the transpulmonary pressure or the recoil pressure of the lung.

Elastance is the reciprocal of compliance; a measure of the change in pressure achieved per unit change in volume, or stiffness.

Elastic Recoil of the Chest Wall is Pleural pressure minus pressure at the body surface (Ppl-Pbs).

Elastic Recoil of the Lung is Alveolar pressure minus pleural pressure (Palv-Ppl).

Emphysema is a condition characterized by dilation and destruction of alveolar walls; it produces airflow obstruction as determined by pulmonary function testing.

Expiratory reserve volume**(ERV) is** the difference between FRC and RV. This is the maximal amount of air that can be expired starting at FRC.

Esophageal Balloon is a thin walled balloon positioned in the lower esophagus and attached to a strain gauge for estimating pleural pressure.

FEV1 is Forced expiratory volumein one second; the volume that a subject can exhale in the first second during a forced expiration test.

FEV1/FVCis the volume that a subject can forcibly expel in one second (FEV1) divided by the total volume that can be expelled (FVC); this result can be especially useful in diagnosing obstructive and restrictive disorders.

Forced Expiration is the recording of a maximal expiration from Total Lung Capacity (TLC). This permits the of forced vital capacity (FVC) and various of air flow.

Functional Residual Capacity (FRC) is the lung volume at the end of a normal expiration, when the muscles of respiration are completely relaxed; at FRC and at FRC only, the tendency of the lungs to collapse is exactly balanced by the tendency of the chest wall to expand.

FVC is Forced vital capacity; the total volume of air that can be exhaled from the lungs during a forced expiration following a maximal inspiration.

Gas Dilution is a method of ascertaining functional residual capacity (FRC) and residual volume (RV) by mixing the unknown volume of gas in the lungs with a known volume of gas containing a known concentration of a poorly soluble gas like helium.

Glottis is the true vocal cords; when one closes the glottis, no air can escape from the lungs.

Histeresis is the difference in the pressure-volume curves of the lung during inflation and deflation (The lung volume at any given pressure during deflation is larger than during inflation).

IRV is Inspiratory reserve volume; the difference between VC and FRC. This is the maximal amount of air that can be inspired starting at FRC.

Laminar Flow is Air flow in the lungs which is streamlined, low velocity, and obeys Poiseuille's Law; generally it is confined to the small peripheral airways.

Laplace's Law is the Equation expressing the relationship between the surface tension of a sphere and the resultant pressure:

P=2T/r, where P=pressure, T=surface tension, and r=radius (for a soap bubble or sphere with two surfaces, P=4T/r)

Muscles of Respiration

- During quiet inspiration: diaphragm and external intercostals
- During active inspiration: the muscles of quiet inspiration plus the scalenes and sternomastoids
- During quiet expiration: passive / active expiration: abdominal muscles, internal intercostals

Obstructive Disease is a respiratory abnormality characterized by delay in forced expiration of air from the lungs.

Palv is alveolar pressure, the pressure within the alveoli, conventionally given in cm H20, with reference to an atmospheric pressure of zero. Thus, a negative alveolar pressure indicates that the pressure is lower than atmospheric; a positive alveolar pressure indicates that the pressure is above atmospheric. Asthma, bronchitis, and emphysema are all considered obstructive conditions.

Parietal Pleura is the portion of the pleural membrane that lines the thoracic cavity.

Pbs is the pressure at the body surface, usually atmospheric pressure.

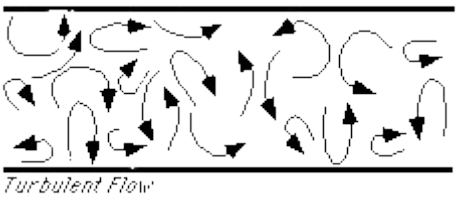
Pes is esophageal pressure.

PL is transpulmonary pressure The pressure difference across the lung. Alveolar pressure minus pleural pressure (Palv-Ppl), which is also known as the elastic recoil pressure of the lung.

Air Flow

Air flow occurs only when there is a difference between pressures. Air will flow from a region of high pressure to one of low pressure-- the bigger the difference, the faster the flow. Thus air flows in during inspiration because the alveolar pressure is less than the pressure at the mouth; air flows out during expiration because alveolar pressure exceeds the pressure at the mouth such that to double the flow rate one must quadruple the driving pressure.

When air flows at higher velocities, especially through an airway with irregular walls, flow is generally disorganized, even chaotic, and tends to form eddies. This is called turbulent flow, and is found mainly in the largest airways, like the trachea.

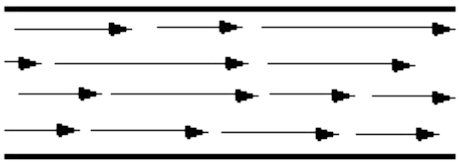


Turbulent Flow

A relatively large driving pressure is required to sustain turbulent flow. Driving pressure during turbulent flow is in fact proportional to the square of the flow rate such that to double the flow rate one must quadruple the driving pressure.

$\triangle P = K \dot{V}^2$ where $\triangle P$=driving force, K=constant, $\dot{V}$=air flow

When flow is low velocity and through narrow tubes, it tends to be more orderly and streamlined and to flow in a straight line. This type of flow is called laminar flow. Unlike turbulent flow, laminar flow is directly proportional to the driving pressure, such that to double the flow rate, one need only double the driving pressure.



Laminar Flow

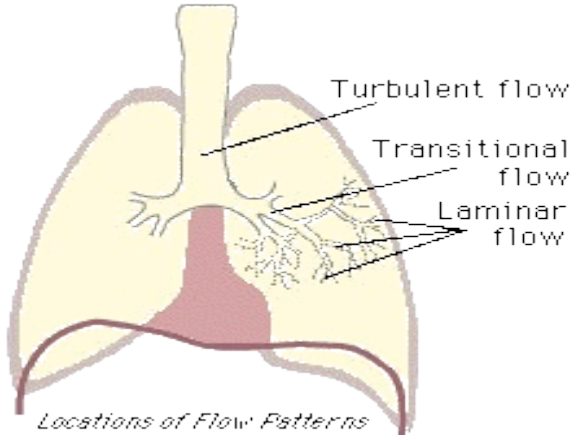
Laminar flow can be described by Poiseuille's Law:

Poiseuille's Law: $\triangle P = \dot{V}(8\eta l/\pi r^4)$

Where $\triangle P$=the difference in pressure between the two points, $\dot{V}$=air flow, r=the radius of the tube, η=gas viscosity, and l=length of the tube.

During quiet breathing, laminar flow exists from the medium-sized bronchi down to the level of the bronchioles. During exercise, when the air flow is more rapid, laminar flow may be confined to the smallest airways.

Transitional flow, which has some of the characteristics of both laminar and turbulent flow, is found between the two along the rest of the bronchial tree.



Airway

The airway consists of the entire pathway for air flow from the mouth or nose down to the alveolarsacs. The conducting airways consist of the oro- and nasopharynx, the larnyx, the trachea, the twomain bronchi, the five lobar bronchi (three on the right, two on the left), and the fifteen to twentydivisions of bronchi and bronchioles down to the level of the terminal bronchioles. The part of theairway that participates in gas exchange with the pulmonary capillary blood consists of therespiratory bronchioles, alveolar ducts, and the alveoli themselves.

The surface area provided by the respiratory bronchioles and alveoli for gas exchange is tremendous. It is estimated that the adult human lung has 300 million alveoli, with a total surfaceareaapproximately equal in size to a tennis court.

Airway Resistance

Airway resistance is the opposition to flow caused by the forces of friction. It is defined as the ratio of driving pressure to the rate of air flow. Resistance to flow in the airways depends on whether the flow is laminar or turbulent, on the dimensions of the airway, and on the viscosity of the gas.

$R = \triangle P / \dot{V}$

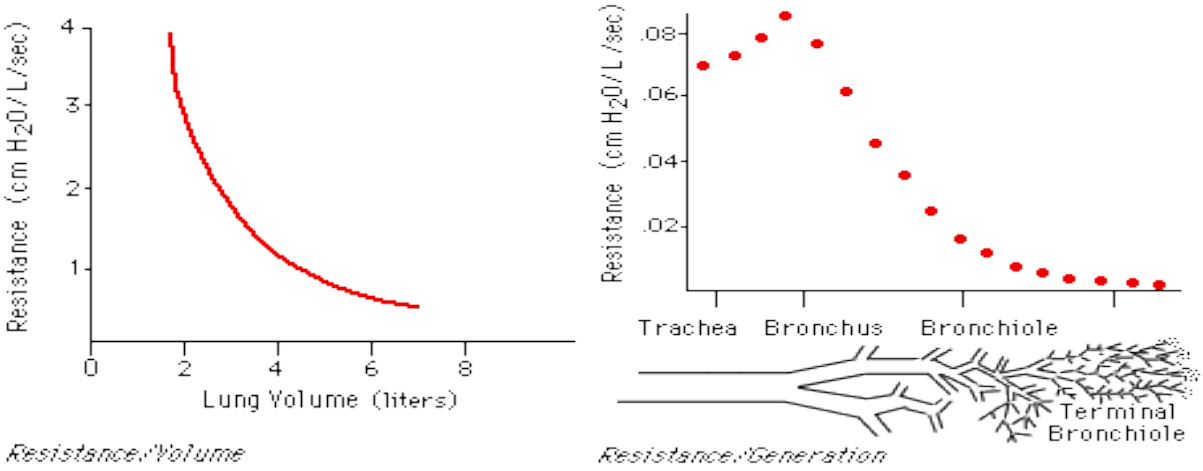
For laminar flow, resistance is quite low. That is, a relatively small driving pressure is needed to produce a certain flow rate. Resistance during laminar flow may be calculated via a rearrangement of Poiseuille's Law：

Poiseuille's Law: $R = 8l\eta / \pi r^{4)}$

Where l=length of the tube, η=gas viscosity, and r=the radius of the tube.

The most important variable here is the radius, which, by virtue of its elevation to the fourth power, has a tremendous impact on the resistance. Thus, if the diameter of a tube is doubled, resistance will drop by a factor of sixteen.

For turbulent flow, resistance is relatively large. That is, compared with laminar flow, a much larger driving pressure would be required to produce the same flow rate. Because the pressure-flow relationship ceases to be linear during turbulent flow, no neat equation exists to compute its resistance.



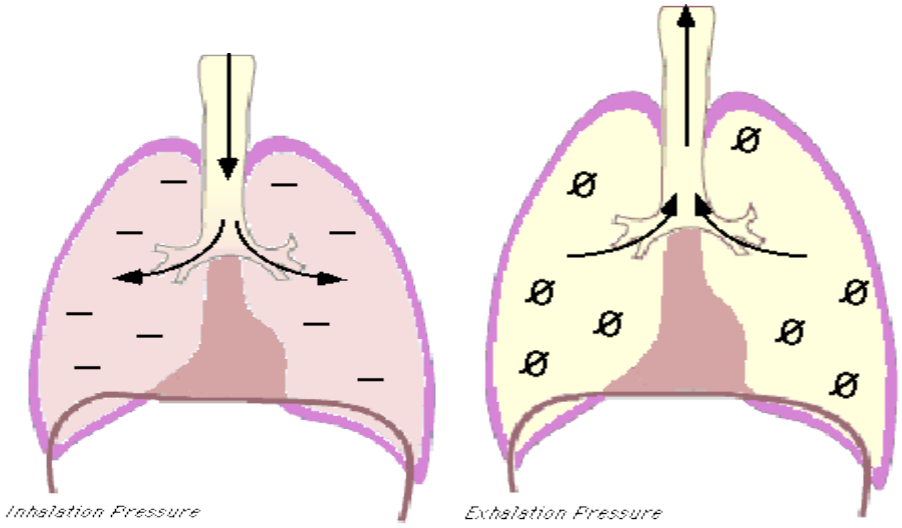
Resistance:Volume *Resistance:Generation*

While a single small airway provides more resistance than a single large airway, resistance to air flow depends on the number of parallel pathways present. For this reason, the large and particularly the medium-sized airways actually provide greater resistance to flow than do the more numerous small airways.

Airway resistance decreases as lung volume increases because the airways distend as the lungs inflate, and wider airways have lower resistance.

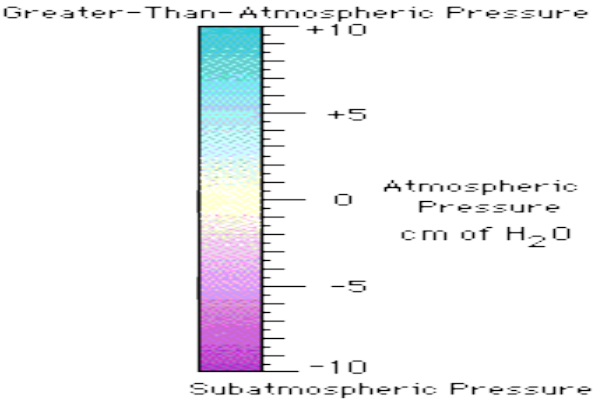
Alveolar Pressure

This is the pressure, measured in cm H20, within the alveoli, the smallest gas exchange units ofthe lung. Alveolar pressure is given with respect to atmospheric pressure, which is always set tozero. Thus, when alveolar pressure exceeds atmospheric pressure, it is positive; when alveolar pressure is below atmospheric pressure it is negative.

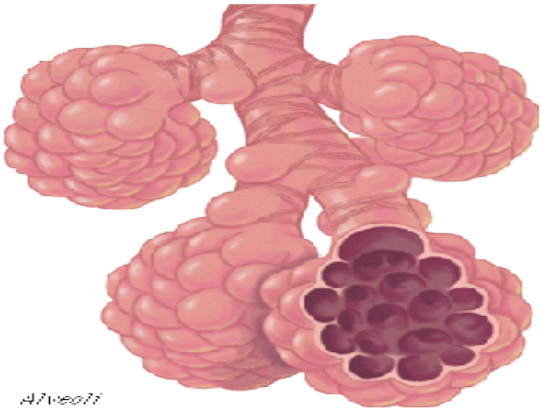


Inhalation Pressure *Exhalation Pressure*

Alveolar pressure determines whether air will flow into or out of the lungs. When alveolarpressure is negative, as is the case during inspiration, air flows from the higher pressure at the mouth down the lungs into the lower pressure in the alveoli. When alveolar pressure is positive,which is the case during expiration, air flows out.At end-inspiration or end-expiration, when flow temporarily stops, the alveolar pressure is zero (i.e., the same as the atmospheric pressure).



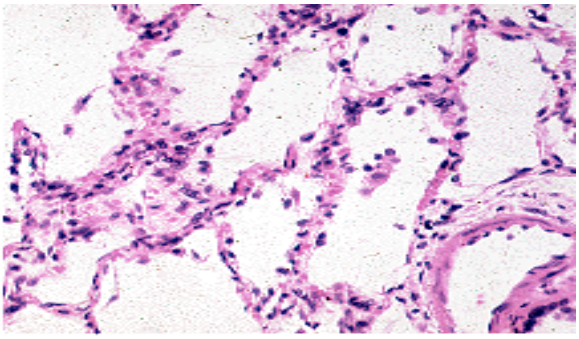
Alveoli



The alveoli are the final branchings of the respiratory tree and act as the primary gas exchange units of the lung. The gas-blood barrier between the alveolar space and the pulmonary capillaries is extremely thin, allowing for rapid gas exchange. To reach the blood, oxygen must diffuse through the alveolar epithelium, a thin interstitial space, and the capillary endothelium; CO2 follows the reverse course to reach the alveoli.

There are two types of alveolar epithelial cells. Type I cells have long cytoplasmic extensions which spread out thinly along the alveolar walls and comprise the thin alveolar epithelium. Type II cells are more compact and are responsible for producing surfactant, a phospholipid which lines the alveoli and serves to differentially reduce surface tension at different volumes, contributing to alveolar stability.

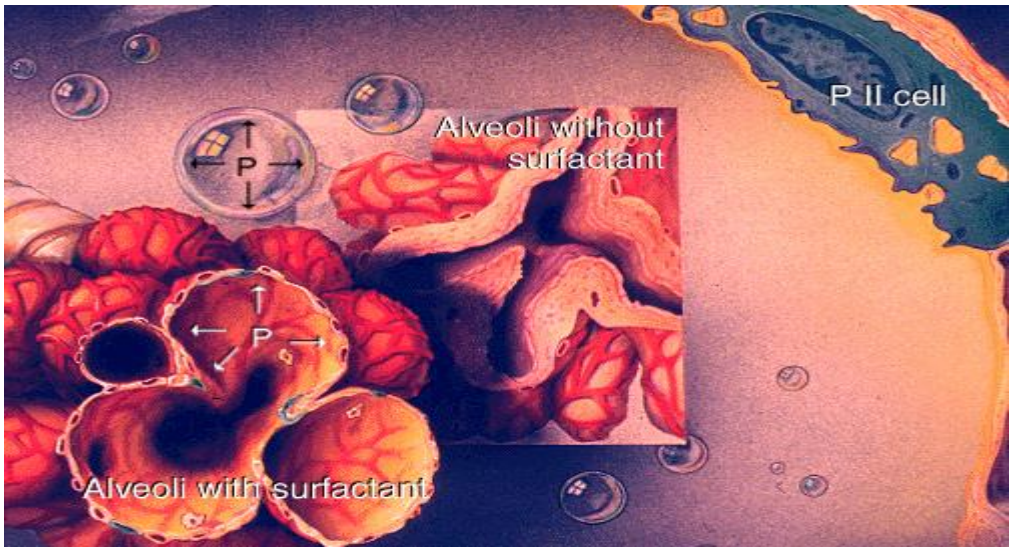
Scanning Electron Micrograph
Normal Alveoli



Histology Section
Normal Alveoli

Surfactant

Surfactant is a complex substance containing phospholipids and a number of apoproteins. This essential fluid is produced by the Type II alveolar cells, and lines the alveoli and smallest bronchioles. Surfactant reduces surface tension throughout the lung, thereby contributing to its general compliance. It is also important because it stabilizes the alveoli. LaplaceÕs Law tells us that the pressure within a spherical structure with surface tension, such as the alveolus, is inversely proportional to the radius of the sphere (P=4T/r for a sphere with two liquid-gas interfaces, like a soap bubble, and P=2T/r for a sphere with one liquid-gas interface, like an alveolus: P=pressure, T=surface tension, and r=radius). That is, at a constant surface tension, small alveoli will generate bigger pressures within them than will large alveoli. Smaller alveoli would therefore be expected to empty into larger alveoli as lung volume decreases. This does not occur, however, because surfactant differentiallyreduces surface tension, more at lower volumes and less at higher volumes, leading to alveolar stability and reducing the likelihood of alveolar collapse.



Surfactant is formed relatively late in fetal life; thus premature infants born without adequate amounts experience respiratory distress and may die.

Interactive Lab Exercises

Labs are interactive work areas that encourage students to compare and contrast scenarios, adjust model parameters, and see results. The Disease States Lab encourages students to compare spirogram tracings, compliance curves, and expiratory flow rates for normal, obstructive, and restrictive pulmonary diseases. Students may use a question bank to focus their exploration. The Statics Lab enables students to specify a patient's lung volume and glottis state. The resulting lung and chest-wall recoil pressures are depicted using illustrations, graphs and equations.

Lab. 1- Gas Exchange Lung Model

Objective: User will be able to interactively change ventilatory variables, inspired oxygen, and introduce values typical of various pathologic conditions to see their effect on blood gas concentrations.

Topics:

Effects of ventilation

V̇ Q̇ Imbalance
Diffusion
Shunt
Cardiac Output
Hemoglobin
VQ Mismatch

Estimated time to complete lab when used in conjunction with the on-line user guide: 2 hours

Lab. 2- Disease States

Objective: User will be able to identify the spirometer tracings, compliance curves, and expiratory flow rates of patients with obstructive, and restrictive diseases.

Topics:
- Obstructive disorders
- Restrictive disorders
- Spirometer tracings
- Compliance curves
- Expiratory flow rate

Estimated time to complete tutorial: 20 minutes

Lab. 3- Statics

Objective: Users will be able to demonstrate the relationship between chest wall and lung recoil at various percentages of total lung capacity.

Topics:
- Static pressures
- Chest recoil
- Lung recoil

Estimated time to complete tutorial: 10 minutes

Tutorials/ presentation excesses

Tutorials are linear presentations of concepts with questions interspersed. Illustrations and animations are used to reinforce the ideas. They are designed to be the initial introduction to the topic.

1- Static Elastic Properties of the Lung and Chest Wall

Objective: User will be able to understand the origin of the pressure-volume curve of the lung and chest wall and how to interpolate the graph.

Topics:
- Lung compliance
- Statics
- Recoil pressure of the lung
- Recoil pressure of the chest wall

Estimated time to complete this tutorial: 15 minutes

2- The Mechanics of Quiet Breathing

Objective: User will be able to describe the sequence of events that occur during quiet breathing.

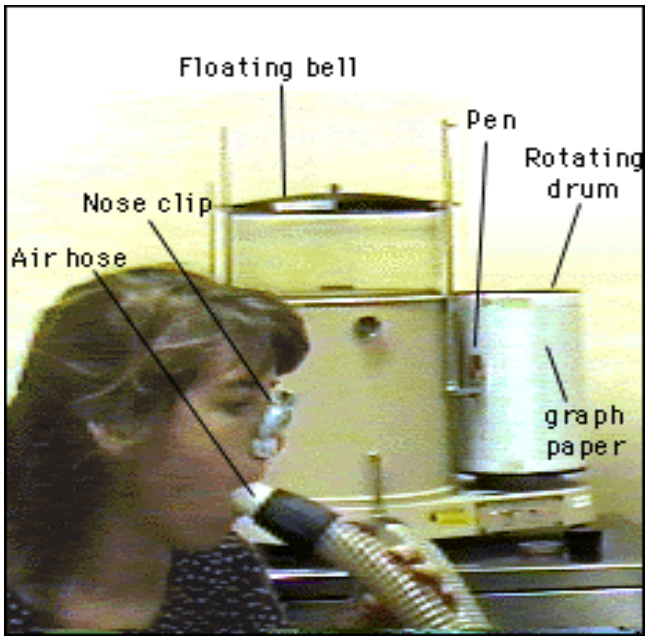
Topics:

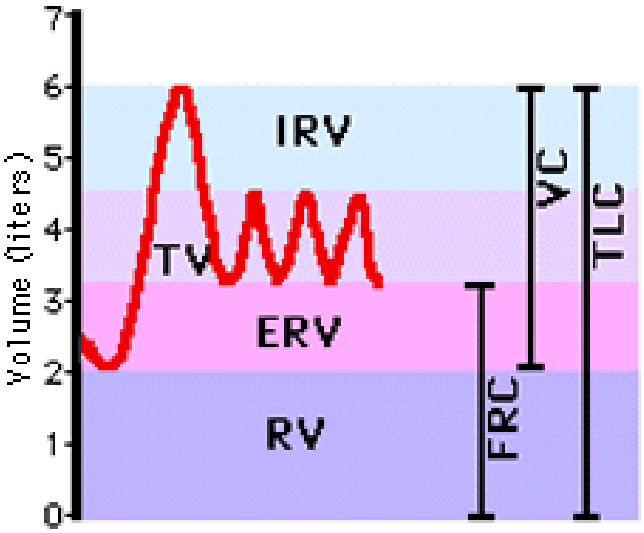
- Pressures causing air to flow
- Atmospheric pressure
- Pleural pressure
- Alveloar pressure

Estimated time to complete tutorial: 8 minutes

Spirometry

Spirometry is the classic pulmonary function test, which measures the volume of air inspired orexpired as a function of time. It can monitor quiet breathing and thereby measure tidal volume, andalso trace deep inspirations and expirations to give information about vital capacity. Spirometrymay also be used to measure forced expiration rates and volumes and to compute FEV1/FVC ratios (seethe encyclopedia page on forced expiration for more information).





Normal Spirometer Tracing

Spirometry cannot, however, access information about absolute lung volumes, because it cannot measurethe amount of air in the lung but only the amount entering or leaving. Thus information aboutfunctional residual capacity, and lung volumes computed from FRC, such as total lung capacity andresidual volume, must be computed via different means, such as body plethysmography or gas dilution.

Engineering the Heart lung Machine basic principle operation

Coronary bypass surgery, widely used to treat cardiovascular disease, involves redirecting a patient's bloodflow around the heart in order to allow surgeons to operate. Heart-lung machines synthetically oxygenate and pump blood during such surgeries in order to keep the patient alive. The first heart-lung machine dates back to the 1930s and consisted of many of the same components as the machines of today. The design of each of these components is inspired by different principles of physics and engineering, including fluid dynamics and pressure gradients. Engineers are now applying these same concepts to create new heart-lung machine models such as miniaturized or portable versions. With its foundations in biology, physics, and engineering, the heart-lung machine has proven to revolutionize the treatment of heart disease.

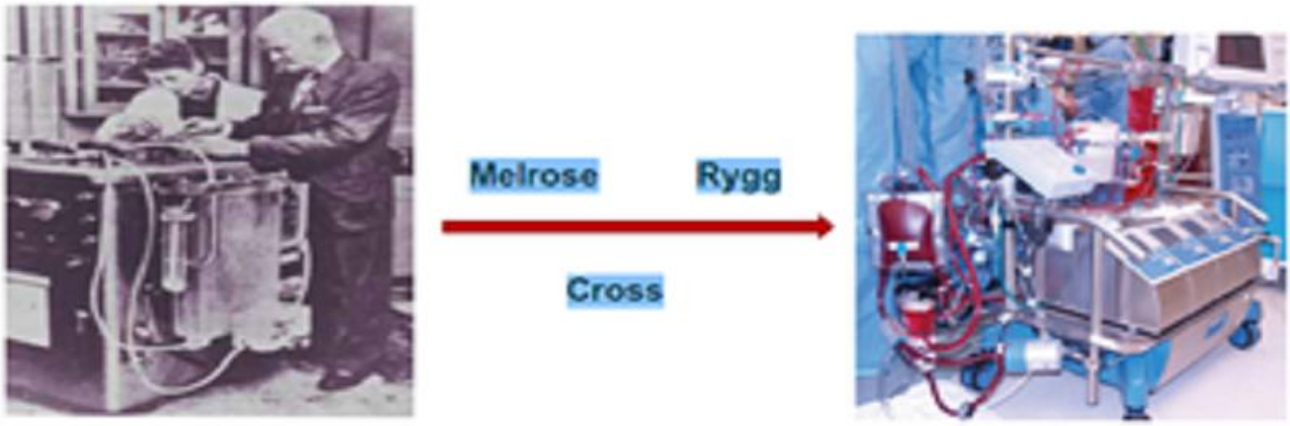
Introduction

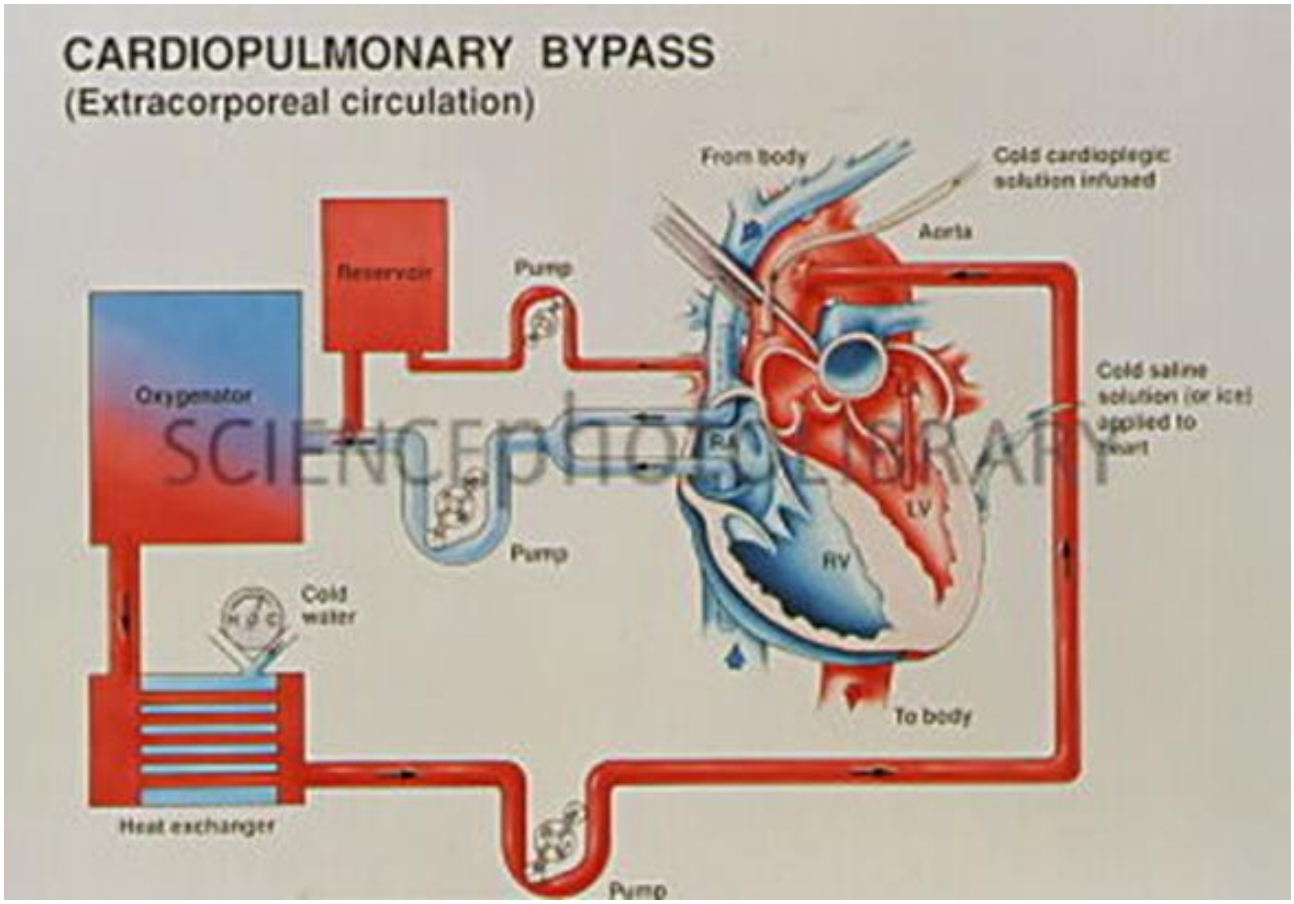
Heart disease is a major health problem facing Americans today. According to the American Heart Association, 80 million men and women suffered from cardiovascular disease in 2006. In 2005, over 860,000 cardiovascular disease patients died. Despite these statistics, the situation is not hopeless. Different solutions exist, such as lifestyle changes, medicines, or in the most severe cases, coronary bypass surgery. Patients can undergo different types of cardiac bypass surgery to repair their faulty hearts or blood vessels. The surgery is commonly referred to as open heart surgery because the doctors actually open up the patient's chest cavity, expose the heart, and operate on it. In order to allow such a surgery to be performed, the heart must be temporarily stopped from beating.

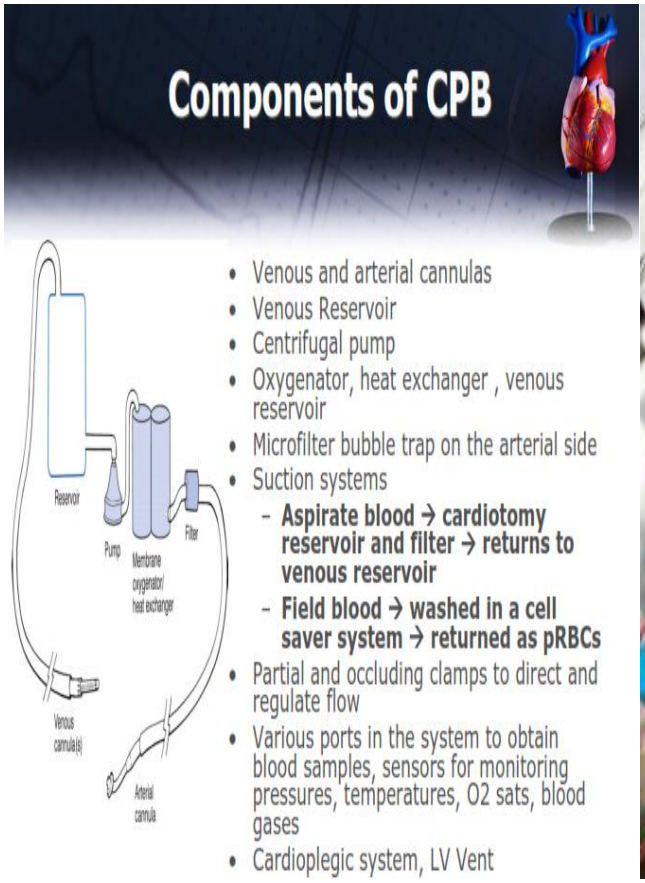
Obviously the heart is an essential organ. If it stops beating, oxygen-carrying blood cannot be circulated through the body, and a person will die shortly afterward. This presents quite a predicament for cardiovascular surgeons: how can they stop the heart to operate on it, yet keep the patient alive? The answer lies with a special apparatus, called the heart-lung machine, or cardiopulmonary bypass machine. The heart-lung machine is a device that is connected to the blood vessels and serves as the person's heart and lungs for a period of time. In other words, the patient's blood bypasses the heart to enter the machine instead, where it is oxygenated just as it would be in the lungs. From there, the machine pumps the blood out into the rest of the body (Fig.).

In doing so, the heart-lung machine essentially replaces the most vital organs, thereby sustaining the patient's life. From its original development to the components of current models to its future applications, the heart-lung machine is truly an impressive feat of technology that integrates the engineering principles of fluid flow, pressure gradients, and heat transfer into one life-saving device.

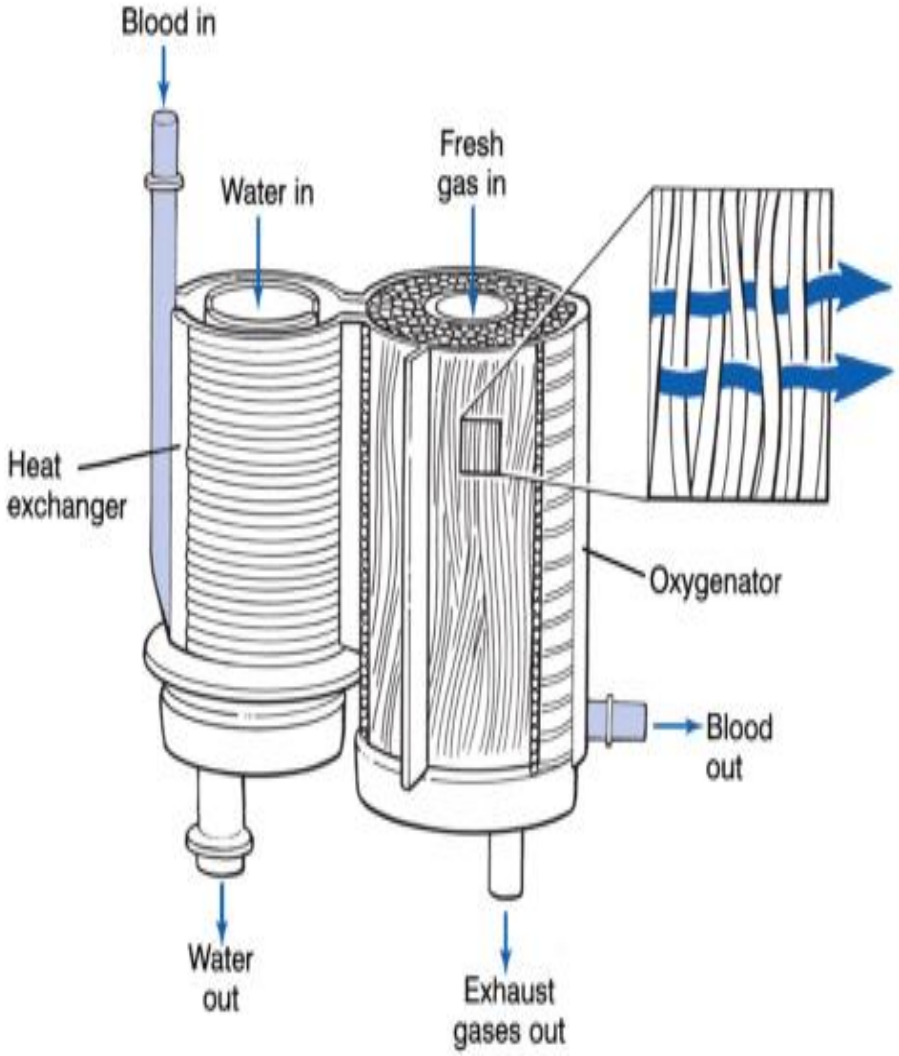

...More than 40 years of Innovation,
Research, and Hard Work.....


Melrose
Rygg
Cross


CARDIOPULMONARY BYPASS
(Extracorporeal circulation)
From body
Cold cardioplegic solution infused
Aorta
Reservoir
Pump
Oxygenator
Cold saline solution (or ice) applied to heart
RA
LV
RV
Pump
Cold water
To body
Heat exchanger
Pump


Components of CPB
Reservoir
Pump
Membrane oxygenator/ heat exchanger
Filter
Venous cannula(s)
Arterial cannula
• Venous and arterial cannulas
• Venous Reservoir
• Centrifugal pump
• Oxygenator, heat exchanger , venous reservoir
• Microfilter bubble trap on the arterial side
• Suction systems
- Aspirate blood → cardiotomy reservoir and filter → returns to venous reservoir
- Field blood → washed in a cell saver system → returned as pRBCs
• Partial and occluding clamps to direct and regulate flow
• Various ports in the system to obtain blood samples, sensors for monitoring pressures, temperatures, O2 sats, blood gases
• Cardioplegic system, LV Vent


Oxygenator


Blood in
Water in
Fresh gas in
Heat exchanger
Oxygenator
Blood out
Water out
Exhaust gases out

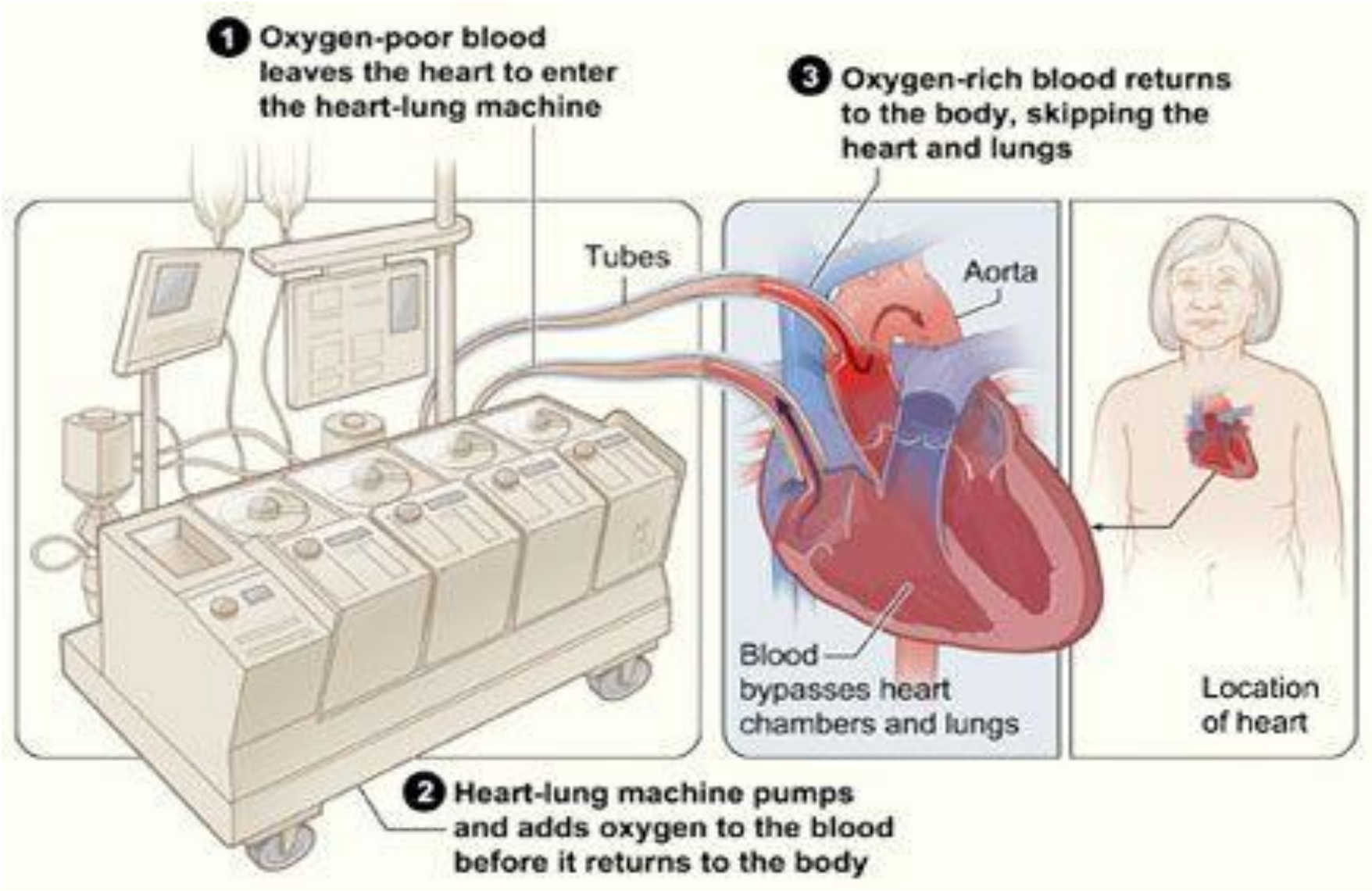
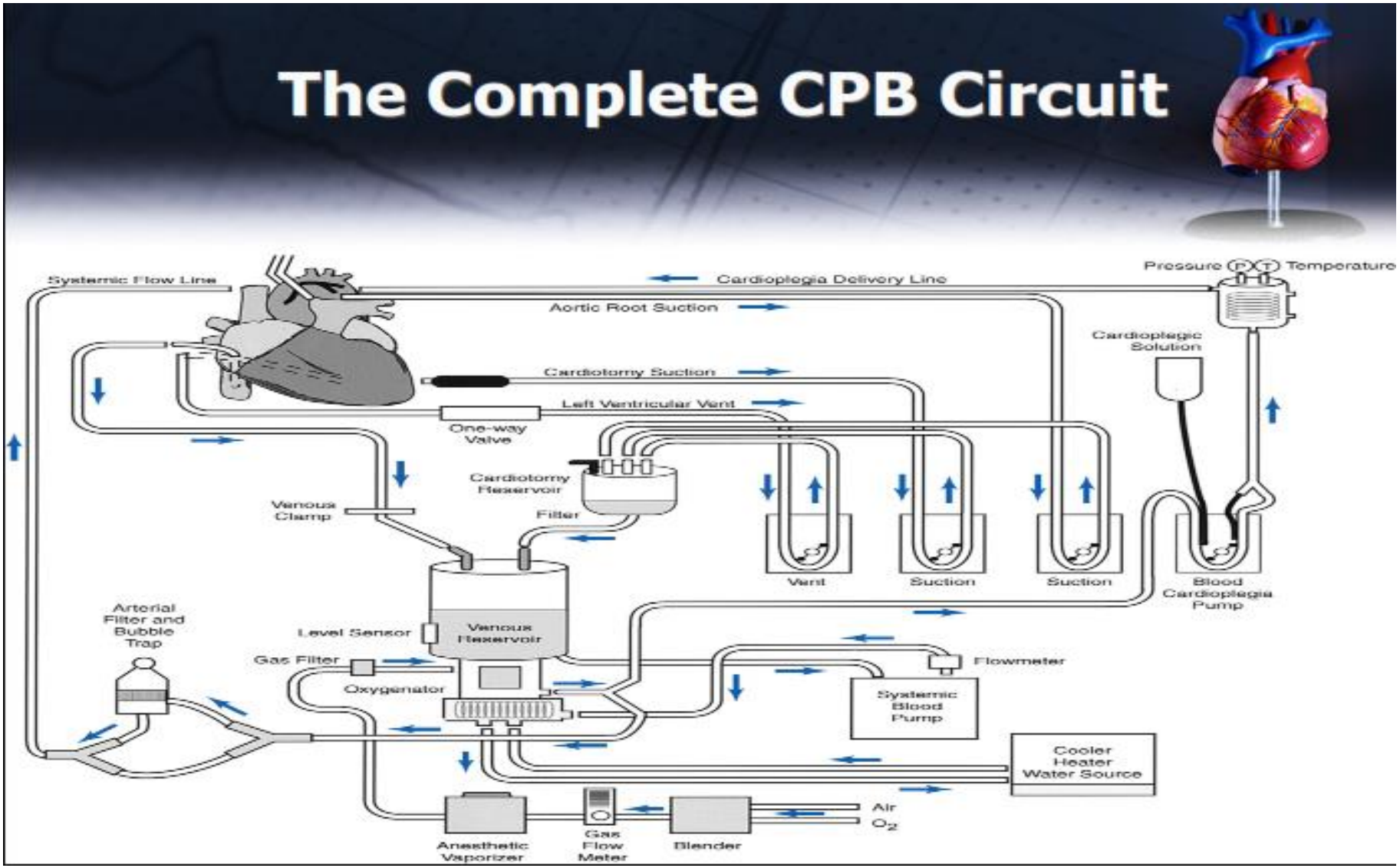


Figure: A schematic demonstrating the sequence of blood flow between the heart-lung machine and the body.


The Complete CPB Circuit
Systemic Flow Line
Cardioplegia Delivery Line
Pressure
Temperature
Aortic Root Suction
Cardioplegic Solution
Cardiotomy Suction
Left Ventricular Vent
One-way Valve
Cardiotomy Reservoir
Venous Clamp
Filter
Vent
Suction
Suction
Blood Cardioplegia Pump
Arterial Filter and Bubble Trap
Level Sensor
Venous Reservoir
Gas Filter
Oxygenator
Flowmeter
Systemic Blood Pump
Cooler Heater Water Source
Air
O_2
Anesthetic Vaporizer
Gas Flow Meter
Blender

History……

Today's Machine: A Journey Through its Components[3]

In an open-heart surgery, the surgeon first connects the bypass machine to the patient by inserting tubes called the venous cannulas into the vena cavae, the large blood vessels leading to the heart . This redirects the flow of blood into the heart-lung machine, bypassing the heart completely. Engineers must design the venous cannulas such that a precise and controlled amount of blood will flow through them into the machine. They do so by creating the tubes in varying sizes and resistances [8]. According to fluid dynamic principles, the larger a tube is, the more liquid can flow through it at a given point in time. On the other hand, if a tube has a greater resistance, which is controlled by surface roughness and fluid viscosity, then less fluid may pass through. By adjusting these two properties, an engineer can create venous cannulas that allow specific rates of blood to flow from the body and into the machine.

From the cannulas, the blood flows into the venous reservoir, a chamber made of plastic or polyvinyl chloride (PVC) that collects and stores the blood from the patient's body. The reservoir must have a large volume capacity to accommodate a large volume of blood. According to Boyle's Law, pressure and volume are inversely related under constant temperature; as one increases, the other decreases. Thus, the venous reservoir's large volume gives it a low pressure. All solvents naturally move from regions of higher pressure to regions of lower pressure. Therefore, since the reservoir has a low pressure, blood flows from the high-pressure vessels in the body into the bypass machine's venous reservoir.

Upon leaving the venous reservoir, blood next travels into the heart-lung machine's pump, which utilizes compression force or centrifugal force to drive blood flow. A pump may come in either one of two types: roller pumps or centrifugal pumps. In a roller pump, the blood enters a curved track of tubing made of a flexible material, often PVC, latex, or silicone [8]. As the blood enters, two cylindrical rollers rotate and slide forward, constricting the tubing. This compression reduces the volume in the tube, giving the blood no room to go but forward. Just as squeezing a tube of toothpaste pushes the paste forward and out of the tube, compressing the roller pump forces the blood to flow forward, through the rest of the bypass machine. While roller pumps may be used as the primary pump in a heart-lung machine, centrifugal pumps are often used as an alternative. The centrifugal pump is comprised of a plastic wheel that rotates rapidly, propelling the liquid away from the center of rotation [8]. Imagine spinning a bucket of water overhead fast enough so that water is pressed outward against the bucket and does not fall out. The same force is utilized in the heart-lung machine as the rotation of the centrifugal pump forces the blood to flow past the spinning wheel and out towards the next section of tubing. While some heart-lung machine manufacturers prefer this type of pump because they believe it reduces the formation of harmful clotting elements in the blood, at this point in time, both types of pumps are widely used.

Blood flows from the pump into the heat exchanger, which uses the concept of heat transfer to cool the blood down to the optimal temperature for surgery. The human body normally maintains an internal temperature of 37 degrees Celsius but during cardiac surgery, physicians lower the patient's

[3] Eugene A. Hessel, II, and L. Henry Edmunds, Jr. "Extracorporeal Circulation: Perfusion Systems." *Cardiac Surgery in the Adult.* [On-line] New York: McGraw-Hill, Available: http://cardiacsurgery.ctsnetbooks.org/cgi/ content/full/2/2003/317 2003, [30 Jun2009].

core temperature to a state of moderate hypothermia or 5 to 10 degrees lower than usual [8]. Oxygen gas is more soluble in cold blood than in warm blood. Thus, lowering the temperature maximizes the amount of oxygen the patient's blood cells can carry.

Following the basic principle of heat transfer, a warmer object will always transfer heat to any colder object with which it is in contact. Similarly, if a cold object touches a warmer object, the warmer object will be cooled. That is precisely what occurs in the heart-lung machine's heat exchanger. It consists of a thermally adjustable compartment of cold water with plastic rubes submerged in it. As blood flows through the tubes, thermal energy is transferred between the water and the tubing, and then between the tubing and the blood. The warmer object, the blood, becomes colder, while the cooler object, the water, becomes warmer. Thus, the heat exchanger cools the blood to the desired temperature.

From the heat exchanger, the cooled blood enters the oxygenator, where it is imbued with oxygen. Today's heart-lung machines use an oxygenator that attempts to mimic the lung itself. This oxygenator, aptly called a membrane oxygenator, consists of a thin membrane designed like the thin membranes of the alveoli, the air-filled sacs that comprise the lungs. Venous blood from the heat exchanger flows past one side of the membrane, while oxygen gas is stored on the other. Micropores in the membrane allow oxygen gas to flow into the blood and into the blood cells themselves. Just as blood spontaneously flows along a pressure gradient, gases also move from regions of high pressure to regions of low partial pressure. The oxygenator is designed such that the oxygen pressure on the gas side of the membrane is much higher than the pressure in the blood. Thus, oxygen passes through the membrane into the blood, following the natural high-to-low pressure gradient.

At this point in the journey through the heart-lung machine, the blood has been collected, cooled and oxygenated, so it is nearly ready to return to the patient's body. Before this can happen, however, it must pass through a filter to eliminate the potential for embolisms. Anything that could lead to blockage of a blood vessel, whether it is an air bubble, a piece of synthetic material, or a clotting protein, poses a great risk to the patient and must be filtered out of the returning blood. The filters used in the heart-lung machine are comprised of nylon or polyester thread woven into a screen with small pores [8]. The small pores trap the harmful bubbles or particles, allowing purer blood, free from dangerous embolism-causing particles, to flow through. After being filtered, the blood travels through plastic tubes called arterial cannulas. Arteries, the blood vessels that deliver oxygen-rich blood from the heart to the rest of the body, have the highest speed of any vessel. In order to imitate this, engineers designed the arterial cannulas to be very narrow [8]. In fluid dynamics, the flow rate of a liquid through a vessel is equal to the cross-sectional area times the speed of flow. Thus, tubes like the arterial cannulas that have a smaller diameter allow for a higher blood velocity. During surgery, the physician inserts the cannulas into one of the major arteries of the patient, such as the aorta or the femoral artery. Blood then leaves the last component of the cardiopulmonary bypass machine, enters the patient's own vessels, and again makes its natural journey through the circulatory system.

Heart-Machines of the Future

There are dozens of heart-lung machines currently on the market today that are widely used in operating rooms across the nation. Most of these machines employ the same basic components and functions. However, like most areas of science and engineering, the technology of the heart-lung machine is not stagnant. Recent breakthroughs of biomedical engineers give a glimpse of the

cardiopulmonary bypass machines of the future. In 2007, the world's first portable heart-lung machine received the CE mark, which officially allowed it to be sold across Europe. Weighing only 17.5 kilograms and powered by a rechargeable battery, the Lifebridge B2T can be transported to different parts of a hospital, giving paramedics or emergency room physicians the chance to start extracorporeal circulation in critical patients before even reaching the operating room (Fig).

European Hospital/European Hospital

Figure: The compact 17.5 kg heart-lung machine Lifebridge B2T.

Another new development of the heart-lung machine is the MiniHLM, a miniaturized heart-lung machine developed for infants. Instead of having all the components spaced separately, as with normal-sized machines, the MiniHLM integrates the functions so the machine is much smaller and more compact. This allows cardiac bypass surgery to be performed on neonates, something that will surely expand the capacity with which heart conditions in newborns can be treated.

Current implementations of the cardiopulmonary bypass machine have advanced far past John Gibbon's original idea almost 80 years ago. Yet no step in the process has been insignificant, as every improvement has improved the safety and usability of the machine. Engineers continue to consider both the biological needs of the human body and the basic principles of physics in order to create a functional biocompatible device that performs what was once unthinkable, sustaining human life without the use of one's heart or lungs. Hundreds of thousands of patients undergo open-heart bypass surgeries every year, intense procedures which require extracorporeal circulation. That's hundreds of thousands of lives saved with the help of one essential biomedical device: the heart-lung machine.

[8] Eugene A. Hessel, II, and L. Henry Edmunds, Jr. "Extracorporeal Circulation: Perfusion Systems." *Cardiac Surgery in the Adult.* [On-line] New York: McGraw-Hill, Available: http://cardiacsurgery.ctsnetbooks.org/cgi/ content/full/2/2003/317 2003, [30

Chapter 3. **Oxygen Cylinders and Flowmeters**

Introduction of Medical gas supply
Beside a functioning supply of water and electricity also the gas supply is important for a hospital. Medical gases are used in the operating room for anaesthesia and in the wards (oxygen) as an additive to the breathing air.

The gas supply includes the procurement of gas cylinders, the transport, the maintenance of the tubing, the repair of regulators and the understanding of dangers while dealing with gases and high pressure cylinders.

The gas cylinder

Oxygen Cylinders

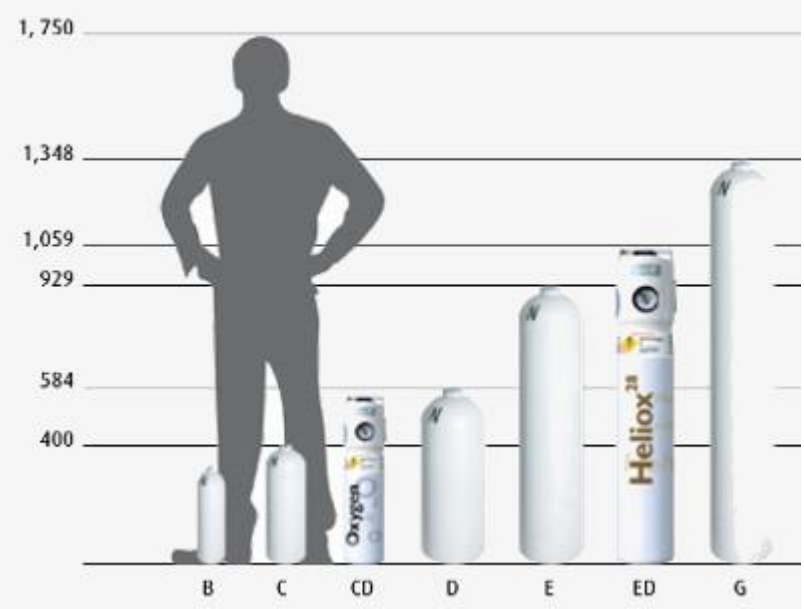
What are the different sizes of Oxygen Cylinders?

Two sets of names are used to differentiate between oxygen cylinder sizes. The original set uses an alphabetical system, starting with A for the smallest size and E for the largest portable size. The new naming system begins with the letter "M," for "medical," followed by a number that signifies the amount of cubic feet of oxygen in that can be compressed into the cylinder. So the original B cylinder is now often referred to as an M-6 cylinder because it can hold 6 cubic feet of oxygen. Below, see the handy chart that matches oxygen cylinder sizes with their dimensions, capacity and accessories.

How do I know which size is best for my client?

The optimal size will depend on a client's lifestyle and prescribed flow rate. The most common size is the M6. However, if the client is confined to a wheelchair, a larger E cylinder with a wheelchair bag may be more appropriate. Or, if he or she only leaves the house for short periods of time and weight is an issue, a smaller M4 cylinder may be better.

To determine how long an oxygen cylinder will last, there are several factors to consider: The patient's prescribed flow rate in L/minute; the tank capacity in liters and whether they are using a regulator or a conserver. A regulator will provide continuous flow at a given flow rate. A conserver will sense when the patient is breathing and only expel oxygen when the patient is breathing in. Most conservers allow the tanks to last three to five times longer, but can be up to 10 times as expensive as regulators and are not reimbursed by insurance companies so they are not always worth the extra cost.
The gas cylinder is a tank used to store gas under high pressure. The cylinder is long and narrow and stands upright on a flattened bottom. Such a pressure cylinder is usually made out of steel. Aluminium cylinders and cylinders made from carbon fibre also exist but are not common.



The height in mm for the commonly used standard cylinders sizes B to G

The size of a gas cylinder is quoted in litres, which means the volume of a cylinder. Gas cylinders are available from 1.2 to 50 litres. Unlike liquids, gases can be compressed. Their density increases under pressure. That is why a gas cylinder of 50 litres volume under pressure can contain gas that expands to 10 000 litres of volume when released to normal atmospheric pressure.The typical gas pressure for a full 50 l cylinder is 200 bar or 2,900 psi.The pressure of smaller cylinders (3 l-16 l) is usually lower at 140 bar or 2,015 psi.

Gas cylinders are found in the operation theatre or if the hospital has a central gas supply in a special gas supply room. Here the gas cylinders are connected through a pipe system with the anaesthesia machines in the operation theatre.Oxygen cylinders are also found in the wards where the oxygen is given to patients with breathing or lung problems in addition to the normal air. As an alternative to oxygen cylinders, often oxygen concentrators are often used which produce the oxygen by extraction from the surrounding air.

On top of the gas cylinders are the outlet connector and a stop valve. To prevent mixing up the different gases, medical gas cylinders also use a pin-index system. Only the correct pressure regulator (with the correct pin) fits to the correct cylinder.When a gas cylinder is to be transported, the metal protection cap should always be mounted. It protects the valve from tearing off in case the cylinder falls over.

Pressure regulator

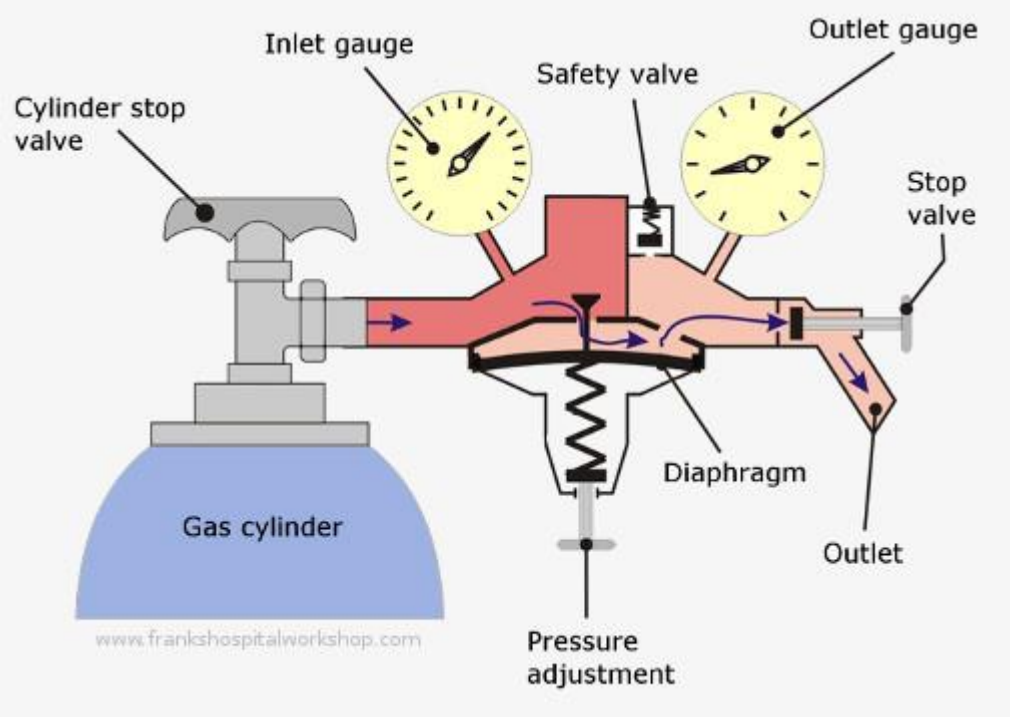
A pressure regulator is first of all a pressure reducer. It reduces the high cylinder pressure to a low, usable pressure for our applications. Furthermore, this outlet pressure is regulated and kept stable regardless of the filling level of the cylinder and how much gas (flow) is demanded.

The pressure regulator usually has two gauges, one showing the cylinder pressure (which corresponds to the amount of gas in the cylinder), the other the reduced outlet pressure. Often this outlet pressure is adjustable with a knob or screw. For a typical anaesthesia machine a gas pressure of 3 - 6 bar (45 - 85 PSI) is required.

Standard adjustable pressure regulator with gauges for cylinder pressure and outlet pressure

Note! Pressure regulators are **always** used in combinations with other equipment (e.g. anaesthesia machine, welding torch) and **never** with a patient.

The main components of a pressure regulator are a diaphragm (sometimes a piston), a spring which is located on one side of the diaphragm and a valve on the other side.



In standby state with no inlet pressure the spring presses against the diaphragm and keeps the valve open. When the pressure increases the gas pressure works on the diaphragm, against the spring pressure and slowly closes the valve. The higher the inlet pressure the more the valve closes. Is the pre-set outlet pressure reached the valve closes completely.The spring force and thus the outlet pressure can be adjusted by preloading the spring by a hand wheel.When the valve does not close

completely due to a defective gasket, the outlet pressure would slowly increase and the safety valve would open.

By the way, regulators for gas and for water operate on the same physical principle but in practice they must not be interchanged. Furthermore, not all gas regulators must be used in conjunction with oxygen.

Pressure regulators should correctly fit to the gas cylinder. Unfortunately there is large number of different types of connectors depending on the country of manufacture and the type of gas. Sometimes it is difficult to find the right regulator.

When purchasing a new regulator, make sure that

- the outlet pressure is within the needed range
- the connection thread fits to your cylinder
- it is suitable for oxygen (when an oxygen cylinder has to be connected)

Tip! Oxygen regulators designed for gas welding can be perfectly used for medical applications. These regulators are much cheaper than 'medical' regulators and are locally available.

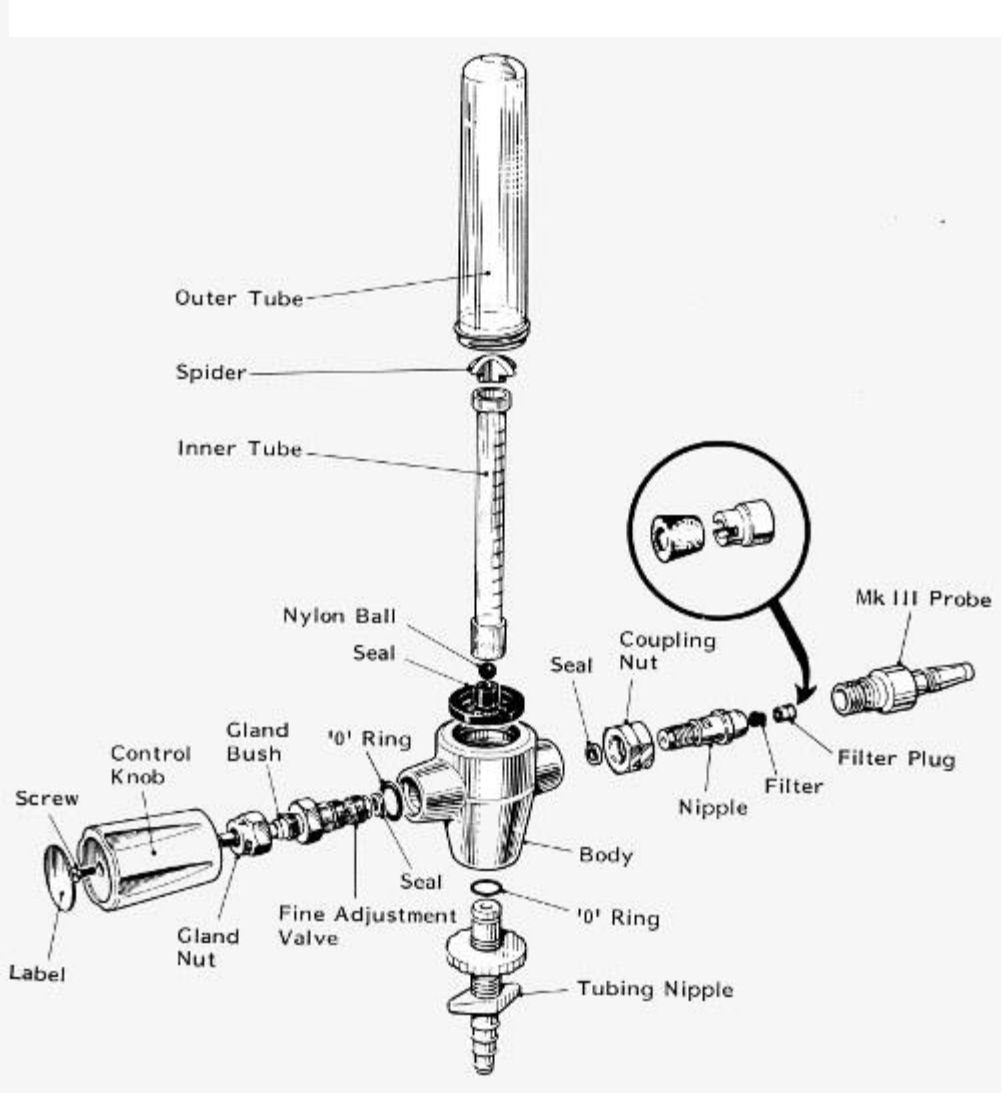
Flow regulator

Flow regulators are only used together with oxygen and in connection with a patient. They are the interface between patient and machine.

A flow regulator might also have two gauges, one showing again the cylinder pressure and the other to indicate the amount of gas coming out of the cylinder, the flow. This flow is always adjustable.
A typical flow regulator allows adjustment of the flow between 1 and 5 l/min).

Flow regulator are only used together with oxygen.

Often flow regulators do not have a round gauge for the flow but a rotameter. This is a transparent plastic tube with a scale. Inside this cylinder floats a little ball. The hight of the ball indicates the flow of the oxygen. With a knob under this tube the flow of oxygen can be adjusted.



Pressure regulator or flow regulator

A flow regulator attached to a gas cylinder is only used in combination with oxygen. Also, a flow regulator always delivers oxygen directly to a patient, never to a machine.

This also applies the other way round: Pressure regulators are only used in combination with a machine, never directly to a patient.

This is very important. Sometimes you may find anaesthesia machines are connected to an oxygen cylinder via a flow regulator, but this is absolutely wrong and will damage the machine.

Gas pressure

Gases can be stored in a gas cylinder as a gas or as a liquid, depending on the type of gas. Propane for example, which is used as a cooking gas, is liquid under high pressure. You can feel the liquid when shaking the cylinder. The disadvantage of 'liquid' gases is, that the pressure in the cylinder is in no relation with the amount of gas inside. The pressure does not fall until the cylinder is nearly

exhausted. You would need to measure the weight of the cylinder to get an indication of the amount of gas left.

The medical gases used in the hospital are gaseous in the cylinder. A connected pressure gauge shows the actual pressure which depends on the amount of gas. Half the pressure means the cylinder is half full.

The SI unit for gas pressure is pascal (Pa), bar or psi (pounds per square inch)
200 bar = 20 MPa = 2,900 psi

All cylinders, no matter if big or small are under a pressure of 200 bar when they are completely filled.
An empty and open gas cylinder of 20 l contains 20 l of air. The surrounding atmospheric air pressure is 1 bar (1,013 mbar). This is also called the absolute pressure.
When a compressor is connected to the cylinder the pressure inside the cylinder increases and the cylinder gets filled with more air. The amount (litres) of gas gets more. At 200 bar absolute pressure the cylinder contains 4,000 l of gas.

Pressure (bar) x Cylinder volume (l) = Gas volume (l)

A 20-litre-cylinder contents:

Absolute pressure	Gas amount
1 bar	20 l
10 bar	200 l
100 bar	2,000 l
200 bar	4,000 l

Gauge pressure and absolute pressure

As per definition, the surrounding air pressure on sea level is 1 bar (1,013 mbar). This is the true or **absolute pressure**.But a pressure gauge shows 0 bar. That means 0 bar **gauge pressure** means 1 bar absolute pressure. Or in other words: The gauge pressure is 1 bar less, than the absolute pressure.

As a result, we have to subtract 1 bar from the result in the table to get the pressure shown on the pressure gauge.

Now we know that a cylinder with 100 bar is only half full and contains 2,000 l of gas. But how long will the gas last? This depends on the flow.

Flow

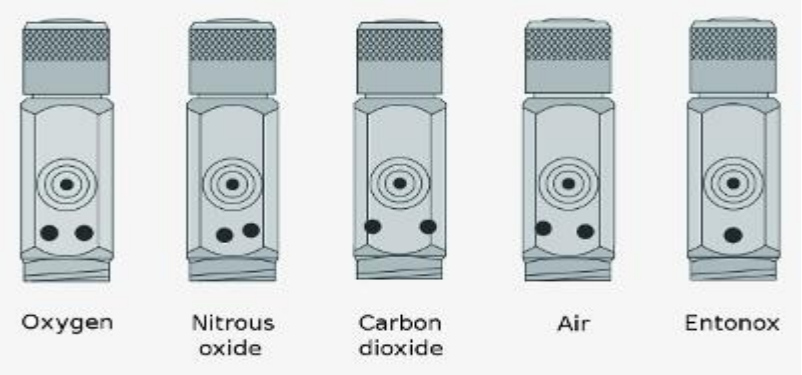
For applying oxygen to a patient it is important to know how much gas the patient should receive in a certain time. This is the flow, which can be measured with a flow-meter. The unit is litres per minute (l/min).

Example: A doctor prescribes for a patient 4 l/min of oxygen and the patient is connected to a full 10 l-cylinder. **How long does the cylinder last?**

A 10 l cylinder contains 2,000 l of oxygen under a pressure of 200 bar (200 bar x 10 l).
At a flow of 4 l per minute the patient can get oxygen for 500 minutes.
(2,000 l / 4 l/min = 500 min)
500 minutes are **8 hours and 20 minutes**.

Different gases

The most common gas which is needed in hospitals is oxygen. Other gases are nitrous oxide, nitrogen, carbon dioxide and medical air. They are all filled in cylinders and have to be purchased at a local gas supplier. The gases are available in two different standards: Industrial gases and medical gases. In some areas medical gases are often difficult to get and very expensive. It is said that medical gases are specially filtered but usually it is the same gas as sold as industrial gas. The only difference is the connecting system of the cylinder. For medical gases a special pin-index connector is used. This system makes it impossible to interchange the different gases when connecting.



Pin-index system. Each gas has a different connection

In order to distinguish the different gases, all cylinders are marked by different colours. The cylinder itself is mostly black (industrial), green (food) and white (medical) but the shoulders have different colours depending on the gases they contain. The US has its own standard.

Oxygen (O_2)

Oxygen is needed in the operation theatre during anaesthesia and for patients with breathing or lung problems as an additive to the breathing air.Medical oxygen and industrial oxygen are produced by the same process. The gases are practically the same. Industrial oxygen is perfectly fine for medical use.

The oxygen concentration in a gas mixture is measured with an oxygen meter. Normal breathing air contains 21% of oxygen.

Oxygen cylinders are indicated by a white shoulder. In the US the oxygen cylinders are completely green.Oxygen supports combustion and in high oxygen concentration almost everything burns. That is why connectors, valves and regulators have to be clean and oil free. Grease or oil will burn in

combination with pure oxygen. Therefore all pipes, fittings and threads which are exposed to oxygen and have been touched with oily hands must be cleaned.

Nitrous oxide (N_2O)

Nitrous oxide is an anaesthesia gas. It is commonly known as laughing gas, nitrous, nitro or NOS. The shoulder of the cylinder is dark blue. American cylinders are completely blue

Compressed Air

Compressed air is required in hospitals to operate machines such as some ventilators for anaesthesia machines and some surgical instruments such as pneumatic drills and saws. It is not used for patient care.Cylinders with compressed air have black and white shoulders, in the US they are completely yellow.Along the coasts, compressed air cylinders can be also filled up cheaply by scuba dive shops. Instead of bottled compressed air, normal air compressors (with tanks) can also be used when a reliable power supply exists.

Entonox

Entonox is a medical gas mix of 50% nitrous oxide (N2O) and 50% oxygen (O2). It is frequently used in childbirth and emergency medicine situations.The shoulder of the cylinder is white and blue.

Changing a cylinder

Changing a gas cylinder is not difficult. But there are some things to consider:

- Gas cylinders should only be transported with their protective metal cap in place.
- Be sure that the cylinder contains the right gas.
- The valve must be closed and the pressure has to be released completely before disconnecting the regulator.
- The valve must not be damaged and must be free of dirt, dust and grease.
- When the regulator has an O-ring, check if it is correctly in place and not damaged.
- Do not use Teflon tape on the high pressure side.
- Use the right spanner key or spanner for tighten or loosen the pressure regulator.
- Do not use too much force. Never use a longer lever or a hammer to tighten a regulator. The regulator will tighten itself under pressure.
- Open the cylinder valve slowly.
- Check for leaks around the regulator. Listen to hissing sounds. After closing the cylinder, valve the pressure shown on the pressure gauge should remain stable. In case of a doubt use a leak detection liquid (see below).

Safety

Gas cylinders in the operation theatre or wards have to be secured against falling over. The easiest way to do so is to secure the cylinder with a chain against the wall. Keep also the following in mind:

- Large cylinders should be carried only by two people. Never carry a large cylinder by yourself.
- Open flames should be kept away from gas cylinders. Smoking close to gas cylinders is dangerous and therefore prohibited.
- Do not use oil or grease in combination with pure oxygen.

Storage

Gas cylinders have to be stored in a dry and well ventilated room. The room must not contain inflammable materials like fuel or paints. The room has to be locked all the time. Smoking and open flames are prohibited in and around this room. Warning signs in the local language should indicate this.

Large cylinders should stand upright and against a wall fixed with a chain or stored in a metal rack. Small cylinders should lie horizontal in a shelf. The different gases should be stored separately. When the storage room is big enough, empty cylinders should also be separated from full cylinders. It is a good idea to remove the plastic caps from empty cylinders.

Typical repairs and common problems

It is recommended that when buying oxygen cylinders from a doubtful source, check the purity of the oxygen with an oxygen meter. An oxygen meter should be present in any workshop especially when also oxygen concentrators have to be maintained or repaired.

Oxygen concentrators can be an alternative for oxygen gas cylinders. In theory. They produce the needed oxygen but at some cost, as these machines need intensive maintenance and a reliable power supply.

Often anaesthesia machines require medical oxygen. But in fact it is not the gas itself that is required but just the special pin-index connection. In this case it is a good idea to replace the 'medical' pressure regulator by an industrial one. Industrial oxygen is not only much cheaper than medical oxygen, it is also available in every little town. You can buy a suitable oxygen pressure regulator at the gas supplier or in hardware shops.

'Welding regulator' in the operating theatre

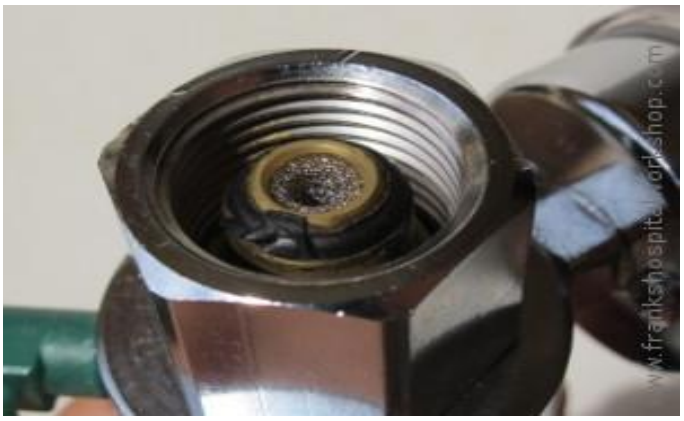
Here are more common problems:

- Leakages

  Leakages make a hissing sounds. To locate the source of the leakage, use a soap water solution for detection on the fitting. Apply the soap water with a brush to the suspected connection. The escaping gas will create bubbles.

- Damaged O-rings and Botok washer

  A Botok washer is a metal ring with an embedded neoprene washer. It is only used in regulators with pin-index gas connections. Both, Botok and normal rubber washers are inexpensive and should be present as spare parts in every workshop.



- Wrong pressure regulator

  Flow regulators or often seen in connection with anaesthesia machines. But machines need a **pressure regulator**. You should also note the required pressure range of a connected machine and adjust the pressure regulator accordingly.

- Broken gauges

  Broken or damaged gauges of pressure and flow regulators are very common. Sometimes they can be fixed but often not. It is anyway a good idea to keep all broken gauges or complete regulators in your workshop, as it is often possible to make one functioning out of two damaged ones.

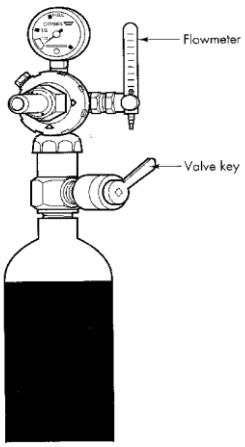
- Leaking hoses

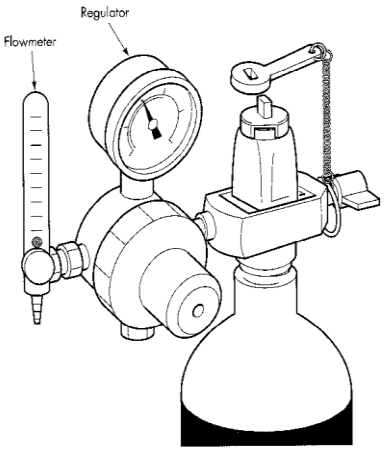
  Low pressure hoses from the pressure reducer to the anaesthesia machine are often leaking. Rubber or plastic tubes do age and become brittle and develop cracks. Often it happens at the ends of the hose where the adapter and the anaesthesia machine is mounted. Then the broken part can be cut off. Otherwise exchange the hose completely. Buy only best quality, reinforced with fabric for example. Hoses are available at welding accessories shops.

Function of Oxygen cylinder

Medicalgasessuchasoxygen,nitrousoxideand othersareintendedforadministrationtoapatientinanaesthesia, therapyordiagnosis. Anoxygencylinderisacylindricallyshapedmetalcontainerusedtostoreoxygenthathas beencompressedtoaveryhighpressure.Oxygencylinders,whichcomeindifferentsizes,areusuallyblack colouredwithawhitetop;insomecases,itmaybeasmallcylinderthatisentirelyblack.Theblackcolourhelps todifferentiateitfromothersubstancesthatarestoredinsimilarcontainers.Cylindersarefittedwithcustomiz ed valves(either bullnoseorpinindex type)withvalveguards,whichareopenedwithvalvekeys.

Aflowmeterisaninstrumentusedtomeasuretheflowrateofaliquidoragas.Inhealthcarefacilities,gas flowmetersareusedtodeliveroxygenatacontrolledrateeitherdirectlytopatientsorthroughmedicaldevice s. Oxygenflowmetersareusedonoxygentanksandoxygenconcentratorstomeasuretheamountofoxygen reachingthepatientoruser.
Sometimesbottlesarefittedtohumidifytheoxygenbybubblingitthroughwater.





Troubleshooting –Oxygen Cylinders and Flowmeters

Fault	Possible Cause	Solution
1. Nooxygenisflowing	Emptycylinder	Replacecylinder
	Flowmeterknoborcylinder valveisclosed.	Openvalves,thencheckflow meterregistersflow
	Faultyregulator	Closeallvalvesandreplace regulator
2. Leakagefromcylinderor flowmeter	Cylinderisnotconnectedto pressureregulatorproperly	Tightenallfittings
	Faultyormissingwasherbetween regulatorandcylinder	Replacewasher
	Flowmetersealdamagedorloose	Tightenflowmeter
	Cylinderfaulty	Label Faulty andreturnto manufacturer
3. Leakagecannotbelocated	Leakagetoosmalltobeheard	Applydetergentsolution(NOT oilysoap)tojoints. Bubbleswill showatleakpoint. Clean/replace washerandtightenatthatjoint.
4. Flowmeterballnotmoving,yet oxygenisflowing	Faultyflowmeter	Closeallvalves,disconnect flowmeterandcleaninside. Reconnectandtest.
		Ifproblempersists,replace flowmeter
5. Pressuregaugedoesnotshow pressure,yetoxygenisflowing	Faultypressuregauge	Refertobiomedicaltechnicianfor replacement

User Maintenance Checklist– OxygenCylinders and Flowmeters

Daily	
Cleaning	✓ Ensure delivery tubes and masks are sterile ✓ If humidifier bottleis used, refillwith cleanwater
Visual checks	✓ Checkcylinder is correct type and marked oxygen ✓ Check allparts arefittedtightlyand correctly
Function checks	✓ Before use, ensurecylinder is filledandflow is present ✓ Close cylinder valve aftereachuse.

Weekly	
Cleaning	✓ Cleancylinder, valve and flowmeter with damp cloth
Visual checks	✓ Check forleakage:hissing sound or reduction in pressure
Function checks	✓ Remove valve dustwithbrief, fast oxygen flow ✓ Check flow canbe varied using flow control

Every six months
BiomedicalTechniciancheck required

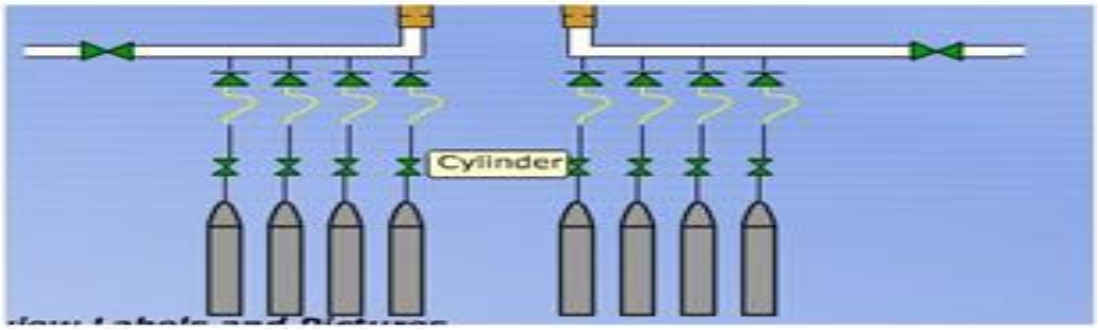
Cylinder / Tank Specifications Chart

a. ***Measure your Cylinder Length = H,***
(From the BOTTOM of the Cylinder to the TOP of the Chrome Valve as shown)
b. ***Measure your Cylinder Diameter = D***
Then matches it to the chart below, find the Cylinder Size, Capacity, Pressure, and Weight.

Gas in Cylinder

- A cylinder manifold system shall have two banks(Groups) of cylinders or cylinder bundles
- The banks alternatively supply the pipeline,
- Each bank having its cylinder connected to a common header with a separate manifold pressure regulator.
- The secondary bank comes into operation automatically when content of the primary bank becomes exhausted.

Cylinder Size	Oxygen Capacity	Service Pressure	Cylinder Length = H	Cylinder O.D.= **D**	Cylinder Weight
	CU. - LITERS	***PSI - BAR***	***IN. - MM***	***IN. - MM***	***LBS. - KG***
M2	1.4 - 40	2200 - 153	9.0 - 228	2.5 - 63.5	.74 - .34
M4 = A	4 - 113	2200 - 153	12.0 - 305	3.2 - 81	1.6 - .74
M6 = B	6 - 165	2200 - 153	15.0 - 381	3.2 - 81	2.8 - 1.50
ML6	6 - 165	2200 - 139	10.68 - 245	4.38 - 111	3.4 - 1.60
M9 = C	9 - 255	2000 - 139	14.1 - 358	4.38 - 111	3.7 - 1.69
D	15 - 425	2000 - 139	20.0 - 508	4.38 - 111	5.3 - 2.41
Jumbo D	22.6 - 640	2000 - 139	20.0 - 508	5.25 - 133	8.1 - 3.68
E	24 - 680	2000 - 139	29.0 - 737	4.38 - 111	7.9 - 3.58
M60 - CGA540	61.4 - 1738	2200 - 153	23.0 - 584	7.25 - 184	21.7 - 9.86
MM - CGA540	122 - 3455	2200 - 153	35.75 - 908	8.0 - 17.55	38.6 - 17.55
H (K) - CGA540 (steel)	212 - 7842	2000 - 136	55.0 - 1120	9.0 - 29.0	120 - 83.9



Medical Cylinder Information

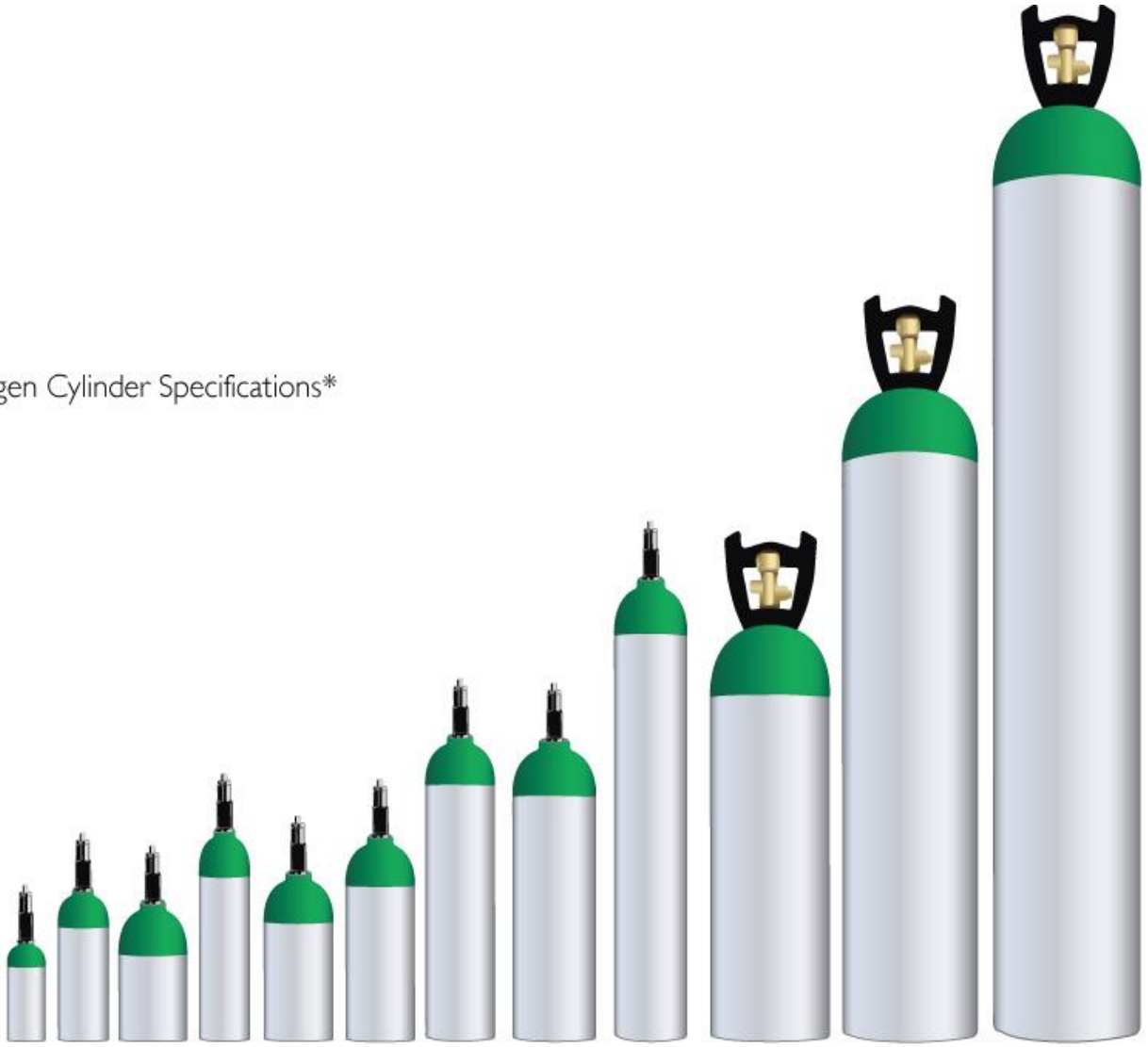
MEDICAL IS ALWAYS A "LETTER" AND INDUSTRIAL IS A NUMBER				
OXYGEN	O2 (CYLINDER COLOR IS GREEN)			
LETTER	CUBIC FEET	LITERS	D.O.T. #	FULL
D	14	367	2015	2100
E	25	708	2015	2100
M	125	3538	2015	2100
K	251	7103	2100	2200
J or S	282	7952	2265	2400
T	337	8490	2400	2600
NITROUS OXIDE	N2O (CYLINDER COLOR IS BLUE)			
LETTER	POUNDS	LITERS	D.O.T. #	FULL
E	6.7	1590	2015	
F	20	2413	2015	500
M	33	4942	2015	TO
G	50 TO 56	14163	2015	700
H	64	16057	2265	
T	75	18550	2400	
NITROGEN NF	N2 (NF NITROGEN IS BLACK)			
LETTER	CUBIC FEET	LITERS	D.O.T. #	FULL
E	21	551	2015	2100
K	230	6044	2100	2200
H	255		2265	2400
T	304	7989	2400	2600
MEDICAL AIR	MEDICAL AIR (CYLINDER ARE YELLOW)			
LETTER	CUBIC FEET	LITERS	D.O.T. #	FULL
E	22		2015	2100
M	116		2015	2100
K	234		2015	2100
CARBON DIOXIDE	MEDICAL CO2 (CYLINDER ARE GREY)			
LETTER	POUNDS	LITERS	D.O.T. #	FULL
E	7		2015	500
G	50		2015	TO
H	64		2265	700

Fig. Non-Magnetic MRI Oxygen Cylinder, regulator, Flowmeters, Manifolds and Brackets

The Oxygen Delivery systemincludes a mobile tank and cart madeof high-quality aluminum alloy. Thetank has a green top for easyidentification with a brushed clearcoating finish for low maintnance.The oxygen regulator is alsoconstructed of metals unaffected bymagnetic fields.

OxygenCylinder Guidance

Sample Oxygen Cylinder Specifications*



Older Name		A		B		C	D	JD	E			H
Newer Name	M-2	M-4	ML-6	M-6	M-7	M-9	M-15	M-22	M-24	M-60	M/MM/M122	M250
Diameter (in.)	2.5	3.2	4.3	3.2	4.3	4.3	4.3	5.3	4.3	7.3	8	9
Height (in.)	5.3	8.5	7.6	11.5	9.1	11	16.5	16.5	25.5	23	36	52
Empty Weight (lb)	0.7	1.6	2.8	2.2	3.3	3.7	5.3	8	7.9	22.3	39.5	114
Capacity (L) at 2,200psi	42	113	165	164	198	255	425	640	680	1738	3455	7080
Transport Method	Carrier Bag	Carrier Bag	Carrier Bag	Carrier Bag	Carrier Bag	Carrier Bag	Carrier Bag	Carrier Bag	Wheelchair Bag or Cart	Not Portable	Not Portable	Not Portable
Regulator Type	CGA 870	CGA 870	CGA 870	CGA 870	CGA 870	CGA 870	CGA 870	CGA 870	CGA 870	CGA 540	CGA 540	CGA 540

*This information is intended to be used as a guide. Dimensions and names may vary by manufacturer.

D/M15 Cylinder
Approximate Remaining Supply Time

Pressure Gauge Reading	Liter Flow Per Minute				
	1	2	3	4	5
2000 psi	5 Hours	2 Hours	1 Hour, 15 Minutes	1 Hour	Not recommended
1500 psi	3 Hours, 30 Minutes	1 Hour, 30 Minutes	50 Minutes	45 Minutes	Not recommended
1000 psi	2 Hours	2 Hours	30 Minutes	20 Minutes	Not recommended
500 psi	1 Hour	1 Hour	5 Minutes	0	Not recommended

D/M15 Cylinder (Pediatric)
Approximate Remaining Supply Time

Pressure Gauge Reading	Liter Flow Per Minute				
	1/16	1/8	1/4	1/2	3/4
2000 psi	3 Days	1 Day, 12 Hours	20 Hours	9 Hours, 30 Min.	6 Hours, 30 Min.
1500 psi	2 Days, 12 Hours	1 Day, 6 Hours	15 Hours	7 Hours, 15 Min.	4 Hours, 45 Min.
1000 psi	1 Day, 12 Hours	18 Hours	9 Hours	4 Hours, 30 Min.	3 Hours
500 psi	18 Hours	9 Hours	4 Hours	2 Hours	1 Hour, 15 Min.

E/M24 Cylinder
Approximate Remaining Supply Time

Pressure Gauge Reading	Liter Flow Per Minute				
	1	2	3	4	5
2000 psi	8 Hours	4 Hours	2 Hours, 30 Min.	2 Hours	1 Hour 30 Min.
1500 psi	6 Hours, 30 Minutes	3 Hours	2 Hours	1 Hour, 30 Min.	1 Hour
1000 psi	4 Hours	2 Hours	1 Hour, 15 Min.	1 Hour	30 Min.
500 psi	2 Hour	1 Hour	25 Min.	15 Minutes	5 Min.

E/M24 Cylinder (Pediatric)
Approximate Remaining Supply Time

Pressure Gauge Reading	Liter Flow Per Minute				
	1/16	1/8	1/4	1/2	3/4
2000 psi	6 Days	3 Day	1 Day, 10 Hours	16 Hours	11 Hours
1500 psi	4 Days, 12 Hours	2 Days, 6 Hours	1 Day	12 Hours	8 Hours, 30 Min.
1000 psi	2 Days, 20 Hours	1 Day, 10 Hours	17 Hours	8 Hours	5 Hours, 30 Min.
500 psi	1 Day, 10 Hours	17 Hours	8 Hours	4 Hours	2 Hours, 30 Min.

H/M250 Cylinder
Approximate Remaining Supply Time

Pressure Gauge Reading	Liter Flow Per Minute				
	1	2	3	4	5
2000 psi	4 Days, 6 Hours	2 Days	1 Day, 12 Hours	1 Day	19 Hours
1500 psi	3 Days, 3 Hours	1 Day, 12 Hours	1 Day	17 Hours	14 Hours
1000 psi	2 Days	1 Day	15 Hours	12 Hours	9 Hours
500 psi	1 Day	12 Hours	7 Hours	6 Hours	4 Hours

H/M250 Cylinder (Pediatric)
Approximate Remaining Supply Time

Pressure Gauge Reading	Liter Flow Per Minute				
	1/16	1/8	1/4	1/2	3/4
2000 psi	68 Days	34 Days	17 Days	8 Days, 12 Hours	5 Days, 12 Hours
1500 psi	52 Days	26 Days	13 Days	6 Days, 12 Hours	4 Days, 6 Hours
1000 psi	34 Days	17 Days	8 Days, 12 Hours	4 Days, 6 Hours	2 Days, 18 Hours
500 psi	16 Days	8 Days	4 Days	2 Days	1 Day, 9 Hours

Formula for determining time to run a cylinder at a set flowrate:

$$\frac{\text{(tank pressure in PSI} - 200) \times \text{cylinder conversion factor}}{\text{empty flow rate L/minute}} = \text{time until cylinder is}$$

Cylinder Conversion Factors and Max Tank PSI

Cylinder Size	Conversion Factor	Max PSI*	Amt. of oxygen when full
D	0.16	4000	350 liters
H or K	3.14	4500	6,900 liters
M	1.56	3450	3,000 liters
E	0.28	6000	625 liters

*(Max PSI can vary by tank manufacturer;the above numbers are the most common)

B.OxygenApparatus
Portableoxygenunitcontainingaquantityofoxygensufficienttosupplythepatientatthe appropriateflowratefortheperiodoftimeitisanticipatedoxygenwillbeneeded,butnotless than10litersperminutefor15minutes.Thisunitmustbecapableofbeingmanuallycontrolled andhaveanappropriateflowmeter.

- Have sufficient oxygen to run at 10L/minute for 15 minutes

The minimum PSI* is listed below

D	1150 PSIminimum
E	750 PSIminimum

B.OxygenApparatus
Installedoxygensystemcontainingasufficientquantityofoxygentosupplytwopatient flowmetersattheappropriateflowrateforthеperiodoftimeit isanticipatedoxygenwillbe needed,butnotlessthan10litersperminutefor30minutes.Thisunitmustbecapableofbeing manuallycontrolled,havetwoflowmeters,andhaveanattachmentavailableforasingle-use humidificationdevice.

- Have sufficient oxygen to run at 10L/minute for 30 minutes

The minimum PSI* is listed below

M	392 PSIminimum
H or K	300 PSI minimum

Chapter 4. Oxygen Concentrators

Function

Anoxygenconcentratordrawsinroomair,separatestheoxygenfromtheothergasesintheairand deliverstheconcentratedoxygentothepatient.Whensetatarateoftwolitresperminute,thegasthatis deliveredbytheconcentratorismorethan90%oxygen. Itisusedforsituationswherebottledgassupplyis impracticalorexpensive,andcanbeusedbypatientsinthehospitalorthehome.

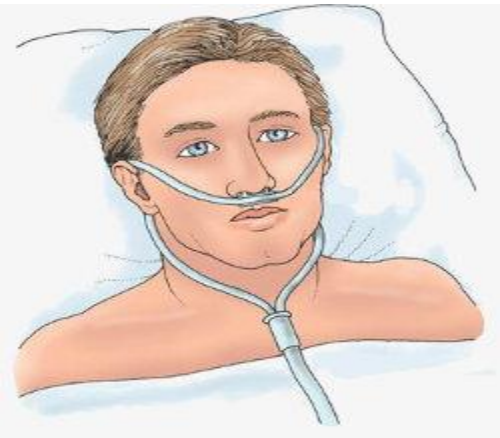
Howitworks

Atmosphericairconsistsofapproximately80%nitrogenand20%oxygen.Anoxygenconcentratoruses airasasourceofoxygenbyseparatingthesetwocomponents.Itutilizesthepropertyofzeolitegranulesto selectivelyabsorbnitrogenfromcompressedair.Atmosphericairisgathered,filteredandraisedtoapressure of20poundspersquareinch(psi)byacompressor.Thecompressedairisthenintroducedintooneofthecanist ers containingzeolitegranuleswherenitrogenisselectivelyabsorbedleavingtheresidualoxygenavailablefor patientuse.Afterabout20secondsthesupplyofcompressedairisautomaticallydivertedtothesecondcaniste r whereth eprocessisrepeatedenablingtheoutputofoxygentocontinueuninterrupted.Whilethepressureinth e secondcanisterisat20psithepressureinthefirstcanisterisreducedtozero.Thisallowsnitrogentobereleased fromthezeoliteandreturnedintotheatmosphere.Thezeoliteisthenregeneratedandreadyforthenextcycle.

Byalternatingthepressurebetweenthetwocanisters,aconstantsupplyofoxygenisproducedandthezeolitei s continuallybeingregenerated.Individualunitshaveanoutputofuptofivelitresperminutewithanoxygen concentrationofupto95%.

The oxygen concentrator produces oxygen by filtering the oxygen out of the ambient air.

A compressor aspirates air and presses the air at high pressure through molecular sieves. These sieves are designed to let oxygen pass and to keep back the nitrogen. The concentrated oxygen is then collected in a tank and finally applied through a flow regulator to the patient. The oxygen is delivered to the patient through a nasal cannula. The patient breathes surrounding air through the nose which is additionally enriched with the oxygen through the nasal cannula. In Europe and the US oxygen concentrators are home care equipment. They are used by patients at home for long term oxygen therapy. In hospitals oxygen concentrators are not often found because the needed oxygen is provided there by the central gas supply or by oxygen cylinders. In other regions, however, oxygen concentrators are very often found in hospitals of all levels. They are not only used in the wards but also in operating theatres and ICUs because a central gas supply usually does not exist and gas cylinders are too expensive and too difficult to obtain. In operating theatres the oxygen concentrator is connected directly to the anaesthesia machine. Common oxygen concentrators are moveable on casters and weigh between 15 and 20 kg.



Patient with nasal cannula

Oxygen

Oxygen is a colourless and odourless gas with the formula O_2.The ambient air consists of 21% oxygen (O_2) and 78% nitrogen (N_2) but only the oxygen is vital for living beings. The oxygen is absorbed by the lungs and transported with the blood, which is pumped by the heart to all our body cells. The waste product of the cells is carbon dioxide (CO_2) which again is transported with the blood and pumped through the heart back to the lungs where it is exhaled.

If the human body does not get oxygen for more than a few minutes [5min or two breath], unconsciousness and death will be the result.
The hospital technician measures the oxygen concentration of an oxygen concentrator with an oxygen meter (oxygen analyzer).Medical doctors and nurses are interested in the amount of oxygen which is dissolved in blood of a patient. They measure the oxygen concentration of the blood with a pulse oximeter.

Dangers of oxygen

Highly concentrated oxygen promotes rapid combustion. The addition of concentrated oxygen to a fire increases its intensity greatly and can even support the combustion of materials which normally do not burn.
For this reason it is not allowed to work with oil and grease on any material which comes in contact with oxygen. Oil and grease already burn under normal conditions and easily ignite together with oxygen.

Caution!
Oxygen supports combustion. In high concentration almost everything will burn.
All components and material which come in contact with oxygen have to be cleaned thoroughly.
Do not go near to any open flames when using oxygen.
The use of oil and grease is strictly forbidden.

Oxygen concentrators in district hospitals

In smaller hospitals oxygen concentrators are often used as the main oxygen supply. They are used to replacing oxygen cylinders which are often too expensive or, specially in remote areas, not easy to obtain. This works well but there are some restrictions.

The produced oxygen from a concentrator cannot be stored. Whenever oxygen is needed, the concentrator has to run. Therefore electricity must be available all the time. This is probably the biggest challenge, especially in remote areas where power fluctuations and long power outages are common. A simple power backup with a small UPS is not possible due to the high power consumption of an oxygen concentrator.

Also high air humidity causes problems in tropical countries and along the coasts. In such situations the granules in the sieve tanks clog rather fast and the concentrator becomes unusable. Finally, lack of maintenance is a limiting factor. Oxygen concentrators are complex machines which need frequent maintenance by qualified technicians. In addition, special spare parts are needed.

An oxygen concentrator in combination with an anaesthesia machine

The following list shows the advantages and disadvantages of using concentrators as the main oxygen supply in a hospital:

Pros

- Oxygen is always available (when electricity is present)
- Produced oxygen is cheap

Cons

- Electricity is always needed
- High power consumption (400 - 600 W)
- Battery back-up is not possible
- Frequent maintenance is needed
- Spare parts like filters for maintenance are needed
- Special parts for repairs are needed
- Problematic in areas with high humidity

Conclusion: Oxygen concentrators are the better and cheaper option - as long as the electricity supply is assured or gas cylinders as a backup are available.

Usage

Before switching on the oxygen concentrator check the connected tubing for kinks and blockages. When the concentrator is used for therapy, fill the humidifier with the right amount of distilled water. The lid has to be closed firmly.

Switch on the concentrator and wait at least for two minutes. Only then the oxygen concentration is high enough for usage. But even with low concentration in the beginning the machine delivers air so that you can check the tubing and the humidifier. If everything is all right, the humidifier makes bubbles.

All concentrators have a flow meter with an adjustment option for the flow rate, which is indicated by a little ball floating in a glass tube. Set the flow meter to the required flow value.

Finally, check the alarm function. Pull the mains plug without switching off the concentrator. An alarm must sound.

Usage in areas of high humidity

The sieve filters are sensitive to humidity. When moisture enters the filters, the filter material swells up, clogs the filter and the oxygen cannot pass through any more. When this happens the filters have to be replaced then, which is often not economically. This is a big problem especially in coastal areas where the humidity of the air is very high. The only solution is simple: The concentrator has to run, even when it is not in use. When the concentrator runs the filters get flushed and thus also the humidity.

This applies particularly to the concentrators in the storage rooms of the hospitals or to the ones of an equipment donation or other shipment which are left for late use in the container. Put them into operation as soon as possible or they are soon ready for the scrap heap!

Hint! A concentrator has to run regularly. Even when it is not in use, it should be switched on for half an hour every week.

Humidifier

Usually the oxygen concentrator is used for therapy and the oxygen is applied to the patient through a nasal cannula. To this end the oxygen has to be moistened, otherise the nasal mucosa of the patient would dry out.

The humidifier is nothing else but a plastic bottle with a bubbler, filled with water. The oxygen from the concentrator passes through the water and picks up moisture. In order to prevent lime scale only distilled water should to be used. If distilled water is not available, fresh drinking water (bottled water) can also be taken. But whatever water is used, it has to be changed for hygienic reasons every day. In general the humidifier is connected directly to the outlet of the flow regulator without a tube in between. But sometimes the concentrator is not placed beside the patient but at a distance and a longer tube is needed. In this case it is better to add the long tube ($\geq$ 2 m) between the concentrator and the humidifier. If a long tube would be connected after the humidifier, the moistened oxygen would condensate in the tube and the water would block the tube.

Another method to prevent condensed water in long tubing is to insert a 'water trap'. This is just a plastic tube with a bigger diameter where the condensed water gets collected. Therefore the 'water trap'

has to be inserted at the lowest point and of course emptied frequently. For this reason it is always better to prevent condensation by moving the humidifier closer to the patient.

Filters

The user has access to two filters which have to be cleaned or changed frequently. First there is a coarse filter made out of foam. This filter absorbs the dust from the air at the air intake and should be cleaned once a week. The filter is washable. Directly after the dust filter follows another filter, a fine bacterial filter. This filter should be exchanged or at least checked twice a year. It is a disposable filter which cannot be cleaned.

Caution! Never run the concentrator without a filter!

Alarm

Concentrators are equipped with an audible alarm function. In case of a power outage or whatever the internal pressure gets too high or too low a beeper gives an alarm.Many concentrators also check the oxygen concentration at the outlet. When the concentration drops under approximately 80% the concentrator also gives a signal. During the first minutes when the concentrator does not yet deliver sufficient concentration, this alarm function is deactivated.A 9 V back up battery provides the power for the alarm unit during times of power blackouts.

User manual

User manuals are always delivered with new oxygen concentrators. It is a good idea to copy the manual and leave one issue with the equipment and keep the other in a file with other technical manuals in the hospital workshop.With donated, used concentrators however the manuals are usually missing. In this case try to download the manual from the manufacturer's website. If this is not possible, try it underUser manuals.

Tip! It is always a good idea to create a quick user chart with just a few words in the local language about the usage and the cleaning. Such a quick user chart can be laminated in plastic and attached to the concentrator or close to it to the wall.

User maintenance

In order to keep the oxygen concentrator in good condition the user has to do regular checks and cleaning. The cleaning procedures should be integrated in the daily or weekly routine of the respective hospital department.

- Change the water of the humidifier daily and rinse the humidifier. Use distilled water only.
- Wash the intake air filter weekly.
- Let the concentrator run for half an hour every week if it is not in regular use.

Common usage problems

The most common problems which occur during the usage are a blocked airway or a leaking humidifier.

Here the typical problems and their causes:

- No oxygen flow, no bubbles, ball not floating → Blocked tube, kinked tube or water in the tube.
- No oxygen flow, only a few bubbles, ball floating No oxygen flow, only a few bubbles, ball floating → Leaking humidifier, lid of humidifier not tight. Leaking humidifier is caused by lid of humidifier not properlytight.

The concentrator itself can also make trouble. In order to find out if the concentrator causes the problem or the attached accessories, disconnect everything from the concentrator. Close the outlet with your thumb. You should feel the pressure and the ball in the flow meter should fall (no flow).

Installation

Before an oxygen concentrator is purchased or set up some requirements have to be met.

- Is the power supply suitable, is the voltage correct? Does the machine have a suitable plug? Donated concentrators from the US (120 V) do NOT work in Africa on 230 V! An additional transformer would be much too big and too expensive.
- Is the electrical installation appropriate?
  The concentrator takes a lot of power (400 - 600 W).
  Therefore you should not use cheap extension cables or cheap multi sockets.
- The room should be dust free and well ventilated, not too hot and not too humid.
- The intake must be free and must not be covered at any time.
  Place the concentrator not too close to the wall, the patient bed or a curtain.
- Avoid using long tubing, which creates problems with kinks and condensed water.
  Place the machine as close to the patient as possible.

When the concentrator is used in the operating room:

- Place it away from other gases such as ether.
- Place an additional oxygen cylinder nearby with an easy change-over possibility in case of a malfunction or power outages.

Explain the correct usage to the user, the doctors and the nurses. Point out the problems with blocked and kinked tubes and explain the cleaning of the humidifier and the filter.

Finally hand over the user manual to the responsible person and let them sign a handover protocol. In such a form the user declares that the installation is completed, the machine is functioning and uses have been instructed.

Attention! It is NOT the task of the technician to give recommendations about the application of oxygen in terms of flow rate or duration of treatment.

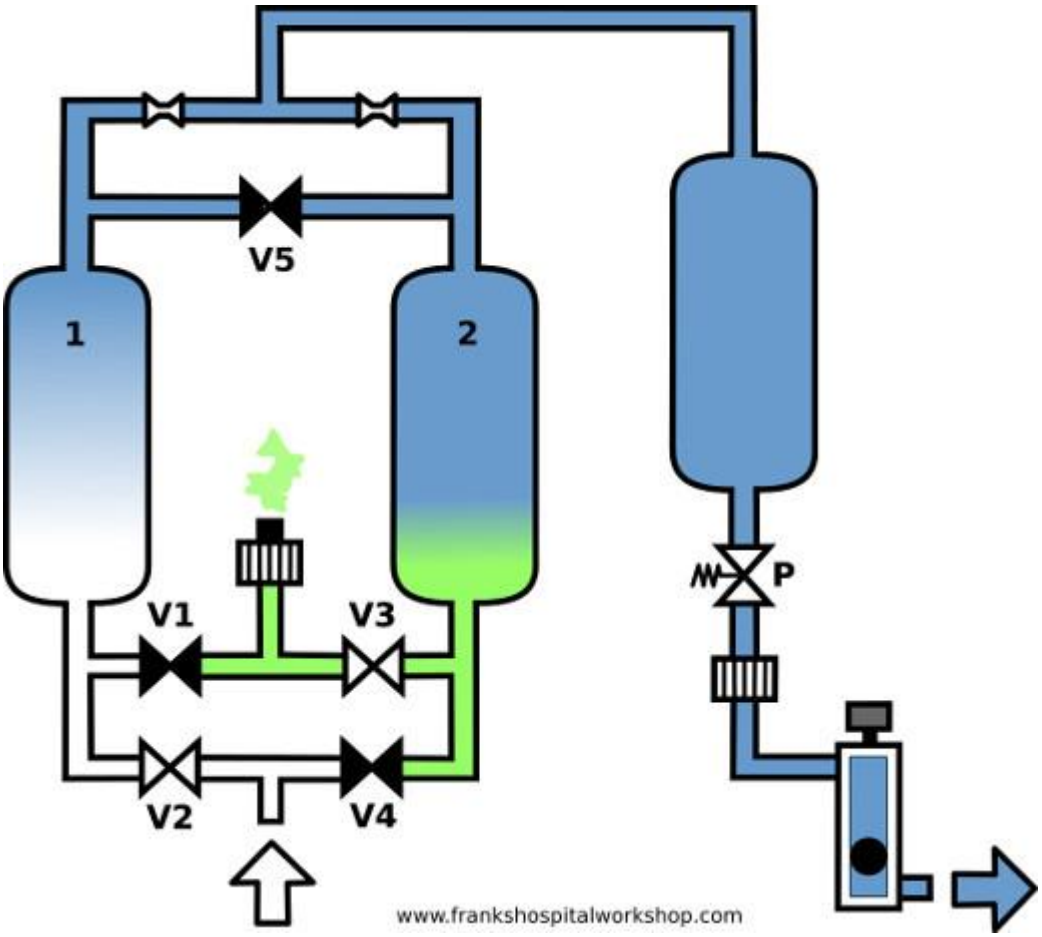
Function

An oxygen concentrator uses molecular sieves (or sieve filters / sieve bed filters / sieve tank) that bind nitrogen and let oxygen pass through. Since this technology only works under high pressure, a compressor is needed. Behind the sieve filter the oxygen pressure is again reduced, the flow controlled and then delivered to the patient.

Apparently the filters get saturated with nitrogen after a few seconds, so that the filters need to be flushed. This is done in reverse direction with a part of the just filtered oxygen. Therefore the inlet valve switches over to an exhaust opening. Because it takes time for building up pressure, flushing, switching over and releasing the nitrogen, the oxygen flow to the patient would be interrupted for some time. That is why oxygen concentrators always have two sieve filters which work alternately, one filters the oxygen while the other gets flushed. The slightly fluctuating oxygen pressure is then led into a buffer storage tank before it gets to the patient.

Here the functional process in detail:

Ambient air gets into the concentrator via a foam dust filter. One part of the air enters the compressor trough another fine filter, the other part is needed to cool the compressor unit. Behind the compressor a cooling coil with a fan cools down the warm compressed air before it gets into the sieve tank system.



1. Inlet valve V2 is open. Pressurized air from the compressor of 1.4-2 bar (20-30 psi) enters sieve tank 1.
2. Oxygen passes through filter 1 but nitrogen accumulates at the filter intake.
3. The oxygen gets through a restrictor into the reservoir tank. Through another restrictor a part of the oxygen enters sieve tank 2 through the outlet.
4. The trapped nitrogen of sieve tank 2 is flushed through the intake and gets through the open exhaust valve V3 and the muffler out of the concentrator.
5. After 7-8 sec V1 and V3 close and the equalization valve V5 opens for 1 sec. The different pressures of the sieve tanks get balanced.
6. Now V4 and V1 open. Air gets into sieve tank 2, oxygen from sieve tank 2 fills the reservoir tank and sieve tank 1 gets flushed.

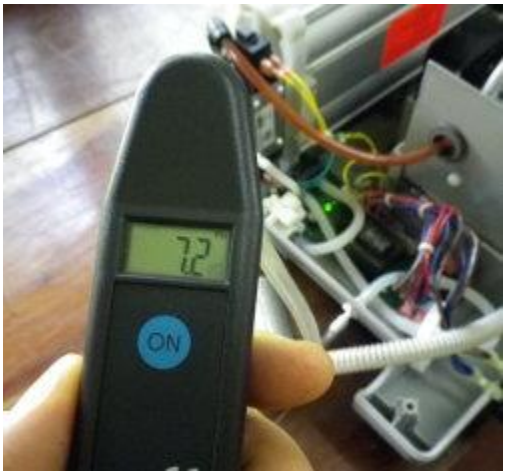
The reservoir tank is connected to a pressure regulator where the system pressure is reduced to patient pressure of 0.5 bar (8 psi). The flow can be adjusted with a flow meter within a range of 1 to 5 litres per minute. The value is shown by a little ball floating in a glass tube. Between pressure reducer and flow meter another bacterial filter is inserted. This filter does not only protect the patient but also the concentrator of humidity from the outlet when the concentrator is not in use.
For safety reasons an internal measurement device for the oxygen concentration is often connected between the reservoir tank and the flow meter. When the oxygen concentration drops due to a fault, an alarm is given. The alarm will also sound when the system pressure is too high or too low.

Tools

The oxygen concentration is measured with the help of an oxygen meter (or oxygen analyser). The oxygen meter is a hand-held device with a digital display. An external oxygen sensor is connected to the concentrator and the concentration is shown in the display in percent.

A frequent check of the oxygen concentration is important, because a flow at the outlet (bubbles in the humidifier) does not necessarily mean that the concentrator produces oxygen. It can be just air or oxygen of low concentration. That is why the oxygen meter is the most important tool the hospital technician needs for the maintenance of concentrators. It is a must in every hospital workshop. When the instrument is not used, the sensor should be stored in a sealed plastic box with a drying agent (silica gel) because it is sensitive to humidity.

The oxygen meter can be easily calibrated just by measuring the surrounding air. The display then should be set to 20.9%. Or attached to an oxygen cylinder it should display 100%. Breathing out from your lungs against the sensor, by the way, would let the concentration drop to approximately 17%. Because the measurement of the oxygen concentration needs a certain flow the meter cannot be connected directly to the outlet but only via a T-piece. A piece of foam should then be inserted in the free outlet of the t-piece in order to simulate a little flow resistance.



A pressure gauge is not needed for the maintenance but is helpful for troubleshooting. A tyre pressure gauge from the next car accessory shop works very well.
A cheap tyre pressure gauge shows the system pressure in a concentrator :

Maintenance

An oxygen concentrator can easily reach 40,000 working hours or more - when it is regularly serviced.

Cleaning

Humidifier, tubes and the inlet dust filter always have to be clean. It is the task of the user to clean them regularly. Nevertheless, the cleaning of the foam filter is also part of the maintenance. It can be washed with soap water but then it has to get dry before putting it back into place.
The following bacterial filter is a single use bacterial filter. It should be replaced once a year or every 5.000 hours. I case of a doubt, take the filter out and check the segments. They have to be white and clean.
This also applies to the bacterial filter situated ahead of the flow regulator.
The outside of the concentrator should finally be cleaned with a mild soap solution.

Function check

After cleaning and replacing the filters make a function check, measure the oxygen concentration at different flow rates and test the alarm.

- Start with a visual check. Check the housing for damages. Check also the power cord, plug and wall socket.
- Switch on the concentrator and let it run with humidifier and tubes. Bubbles must be

created immediately and the little ball of the flow meter has to float freely.

- Listen to the operating sound. Pumping and exhausting sounds of both cycles must sound identical. A complete cycle should have a period of 16-20 sec, depending on the manufacturer.
- Now block the outlet with your thumb. You should feel the pressure and the ball in the flow meter has to fall down. Listen to any hissing sound which indicates a leaking system.
- Disconnect the humidifier and connect an oxygen meter. The measurement equipment itself has to be calibrated before connecting to 21%. The concentrator should deliver full concentration 2 - 5 minutes after switching on and the concentration should be between 90 and 95%.
- Now check the flow. It should be adjustable between 1 and 5 l/min. The concentration may drop a bit when the flow is increased. But it should never be below 85% because such a low oxygen concentration has no medical effect.
- The alarm function and the alarm battery also have to be checked. Fore that the concentrator simply has to be disconnected from mains while it is running. The alarm must sound.
- Additionally check the 9 V alarm battery with a multimeter or replace it when it is older than two years.
- Finally fill out the maintenance report. Do not forget to write down the actual working hours. It is very helpful when a problem occurs later. Many concentrators get problems because they are NOT running (moisture in the sieve tanks). The hour counter will indicate that.

Lubrication

Lubrication is not allowed on any material which comes in contact with oxygen. Oil and grease already burn under normal conditions and ignite together with oxygen.
All connections which come in contact with oxygen have to be free from grease and oil. Even fingerprint have to be avoided. All connections should be wiped clean before assembling.
But there are special lubrication products on the market which are specially made for usage in combination with oxygen. Unfortunately they are difficult to obtain and furthermore 10-20 times more expensive than normal lubricants.

Possible products are:

- Krytox GPL 205, 206, 224
- Christo-Lube MCG 111
- Klüberalfa YV 93-302
- Zarox TYN142
- Halocarbon 25-5S

But in principle do not lubricate and consult the service manual for recommendations.

Repair

As always, troubleshooting starts with observing and listening to the machine. Make a function check (see ↑Function check). Listen to any abnormal sound and check the switching times.
If anything sounds abnormal, open the concentrator and have a closer look. Often the status of the valves are indicated by LEDs which are mounted on the control board.
Many concentrators also have ports where you can connect a pressure gauge. Consult the service manual. Here an overview about pressures and switching times:

- Pressure compressor: 1.4 - 2.0 bar (20 - 30 psi)
- Pressure reservoir tank: 1.4 - 2.0 bar (20 - 30 psi)
- Pressure patient outlet: 0.5 bar (8 psi)
- Equalization time: 1 sec
- Half cycle (filtering or flushing): 7 - 8 sec
- Complete cycle: 15 - 18 sec

Service manuals

While user manuals are relatively easy to obtain, service manuals are hard to come by. The manufacturers do not support the repair of their equipment by other technicians than their own. Service manuals for the most common concentrators you might under Service manuals.

Filters

A low oxygen concentration and a decreased gas flow can be the result of a blocked bacterial filter. Bacterial filters have a clear plastic housing and a dirty filter is easy to recognise. These are disposable filters which cannot be cleaned.
If you do not have a spare filter, you have to wait with the repair until you have got the right one. Do not run the concentrator without it.

Tip! Different concentrators use different filter designs, but most of them have the same connection system. If you have different concentrators in your hospital, it is worth to check the connection diameter. It may be that you only have to provide one type and it will fit all your oxygen concentrators.

Dust filters are washable and should last for several years. But sometimes they get smaller or lose their elasticity and fall out of the holder. Then of course they have to be replaced.

Tip! Dust filters are simple foam filters and can be cut out of (mattress) foam or better kitchen sponges. But be aware that you cut such filters thinner when the replacement foam is denser than the original.

The last type of filter which is found in concentrators is a noise filter, the muffler. It is often just a plastic tube with a piece of foam or felt. But sometimes it can happen that the felt has fallen out of the tube. In this case the concentrator will be getting very noisy then. You cannot miss that...

The inside of an oxygen concentrator. The compressor is in the centre, above the cooling coil and the fan and on top the filter unit with the two sieve filters and the reservoir tank in between. Attached on the left, the valve block. Left front the bacterial filter (white disk) and right front the run capacitor. The control unit is mounted in the cover (not in the picture).

Sieve tanks

The sieve tanks are filled with zeolite granules, a synthetic aluminium silicate. Zeolite acts as a molecular sieve which binds the nitrogen molecules and lets the smaller oxygen molecules pass. Unfortunately zeolite also has the ability to absorb water which can cause problems in areas with high humidity.
Sieve tanks should last at least 20,000 hours, and when regularly maintained even 40,000 hours or more.

Typical problems

Sieve tanks tend to lose their filter properties over time. High humidity is often the reason. Water then condenses inside the filter and clogs the granules. Too high system pressure and low oxygen concentration is an indicator for a blocked filter. You will also get an asymmetric concentration measurement results because one sieve tank will deliver more oxygen than the others as the control circuit periodically switches between them.

A clogged sieve which contains water also weighs more. If it is 50 g heavier than a new one the sieve tank contains too much water and has to be exchanged.
Please note, that sieve tanks should always be replaced in pairs, even when only one is defect. In industrial countries this is not a problem, because the tanks can be ordered easily and the prices are reasonable. But in other countries the situation is different. Due to the high shipping costs it does not always make sense to repair the concentrator.

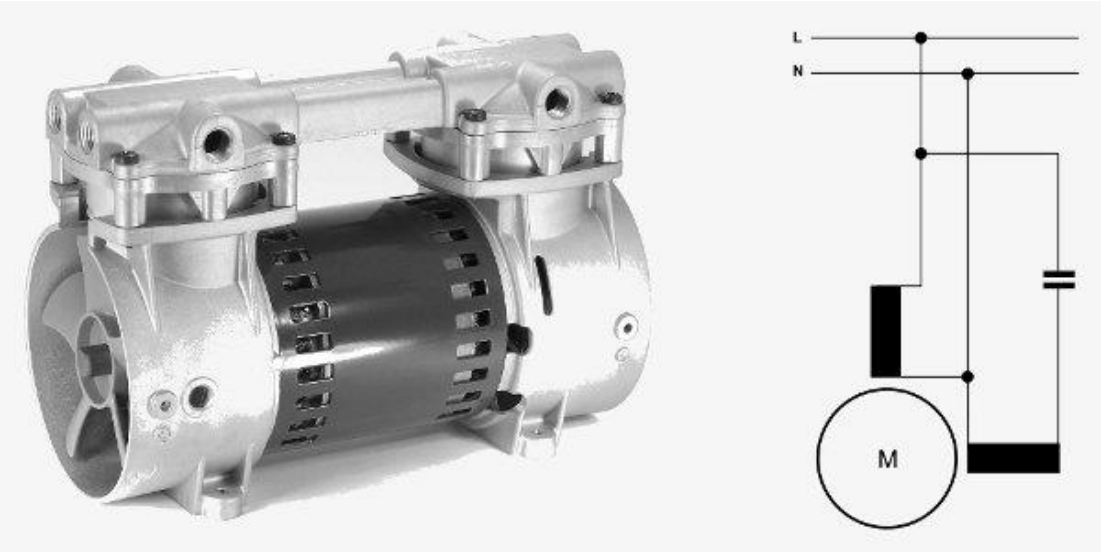
In principle it is easy to prevent moisture in the sieve tanks - the concentrator just has to run regularly. Concentrators which are not in use should be switched on for at least half an hour every week, in regions with high humidity maybe twice a week. Only when the concentrator can the sieves get flushed and not only the nitrogen but also the moisture is then removed out of the tanks.

The inside of a clogged sieve tank

Tip! An oxygen concentrator has to run, at least half an hour every week.

Compressor

The compressors in oxygen concentrators are piston type compressor with two pistons. A common type is the one from Rietschle Thomas. The working pressure is about 1.4 - 2.0 bar (20 - 30 psi).
The compressor is driven by an asynchronous motor with a run capacitor.



Typical problems

- A very common problem is a defective capacitor. In case the compressor does not start or blows the fuse or triggers the circuit breaker.
- Keep also in mind that often a temperature fuse is often attached to the motor windings. It rarely blows without a reason, perhaps the pressure is too high and the motor got too hot.
- If the capacitor is OK and the motor is still not starting, maybe the compressor itself is stuck or the filters are blocked (resistance too big). Disconnect the hoses from the compressor and restart the compressor.
- When the head gasket leaks, it is usually audible. Leakages can be made visible by applying soup water with a brush to the suspect areas. The escaping air will then create bubbles.
- When the pressure is too low and no leakages recognisable, then the piston rings could be the problem. Consult he service manual for further instruction.

Control board

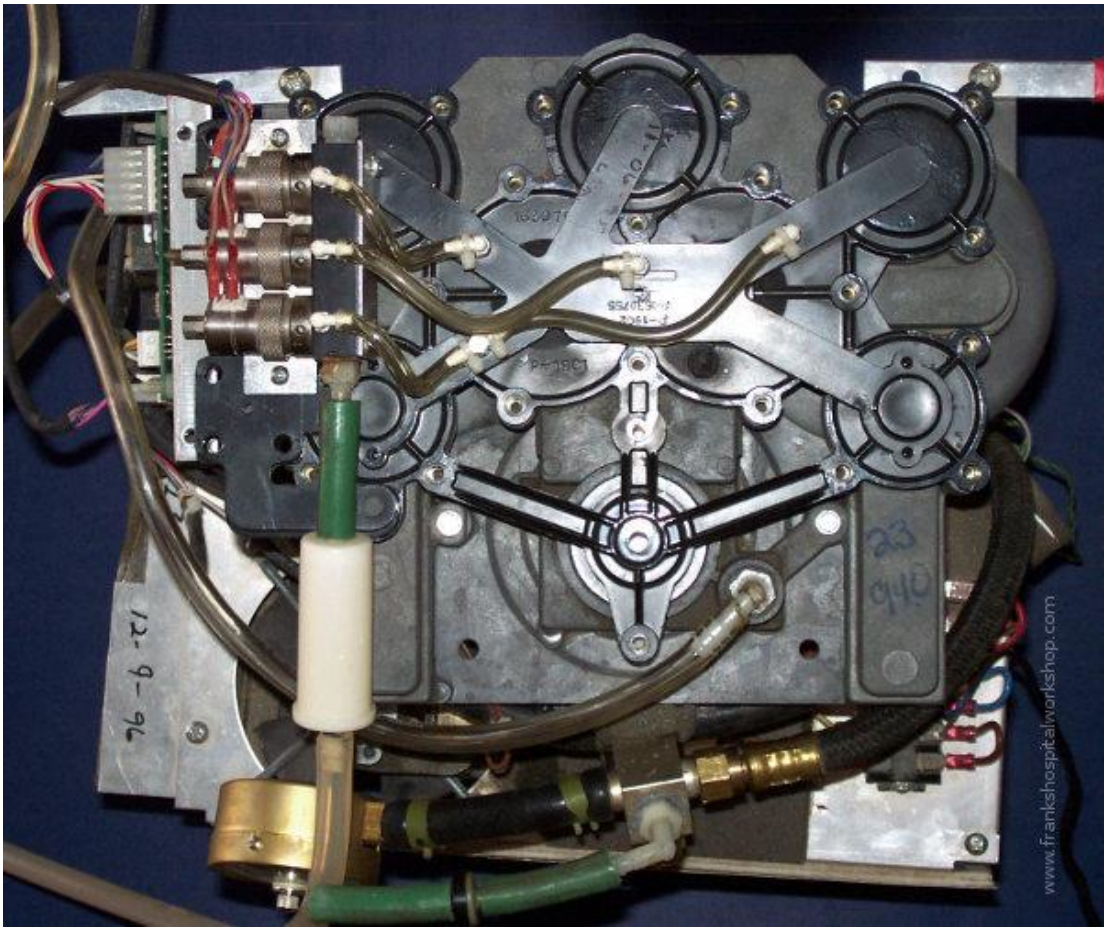
The control board generates the switching signals for the valves. In principle the electronics is simple and could be repaired easily but unfortunately the circuit diagram is never printed in the service manual.
Anyway, it is worth to check the switching times. If they are wrong the concentrator will not create enough oxygen or worse, will not flush the humidity out of the filters which causes irreparable damage.

The times proximately are:

- Filtering or flushing cycle: 7 - 8 sec
- Complete cycle: 16 - 20 sec
- Equalization time: 1 sec

Valves / Valve block

For intake and exhaust two types of valves are found in oxygen concentrators. Either the valves for the sieve filters are controlled directly by solenoids or we find pneumatic valves which are controlled by a pilot air pressure also controlled by solenoids. The advantage of the latter solution is, that the solenoids only have to release the valves which does not need much force. For closing the valves the air pressure from the compressor is used.
In total we find 5 valves, that is 2 intake valves, 2 exhaust valves and 1 equalization valve between the two filters. Intake valve 1 and exhaust valve 2 are always switched at the same time as well as intake valve 2 and exhaust valve 1.
Often the valves are not connected via tubes but they are embedded in a valve block which is directly mounted at the top of the sieve filters. Valve block and filters are then one mechanical unit.



For test purposes the block can be removed from the filters and be tested without them. You can then see the valve movements and feel the air pressure when closing the openings with your thumb.

Common problems

Sometimes the rubber diaphragms of the pneumatic valves tear. Then they have to be replaced.
Also the release pin of the solenoids tend to get stuck. A drop of WD-40 can often solve this problem.

Note! When disconnecting silicon tubes, do not pull the tube but push it from the

connector. When you pull, the tube diameter gets smaller and the connection tighter.

Manufacturer

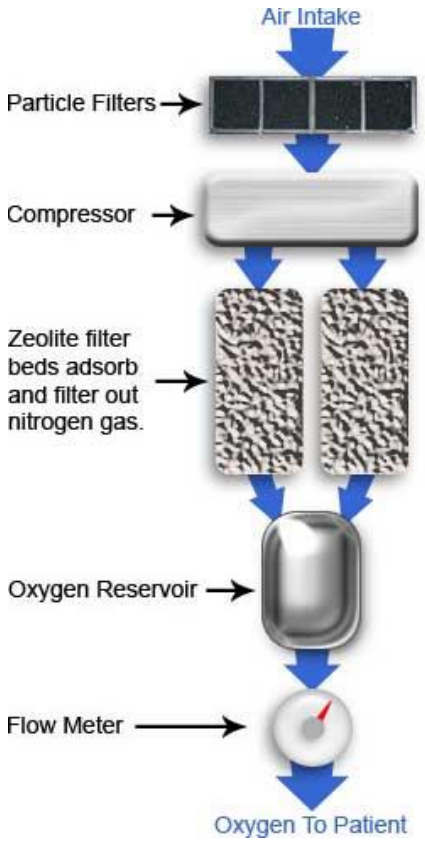
Important manufacturer of oxygen concentrators are:

- Airsep
- DeVilbiss
- Inogen
- Invacare
- Nidek
- Respironics
- Sequal
- Weinmann

Links and sources

Here are some Wikipedia Medical Equipment articles:

Oxygen concentrator
Oxygen therapy
Oxygen mask
Oxygen
Nitrogen
Oxygen saturation
Oxygen sensor


Air Intake
Particle Filters
Compressor
Zeolite filter beds adsorb and filter out nitrogen gas.
Oxygen Reservoir
Flow Meter
Oxygen To Patient

Troubleshooting –Oxygen Concentrators

	Fault	Possible Cause	Solution
1.	Unitnotoperating,powerfailure cableinserted.Replacefusewith	Nopowerfrommainssocket	Checkmainsswitchisonand alarmsounds correctvoltage/currentifblown. Checkmainspowerispresentat socketusingequipmentknownto beworking. Contactelectrician forrepairifrequired.
		Concentratorcircuitbreakerhas beensetoff.	Pressresetbuttonifpresent
		Electricalcablefault	Trycableonanotherpieceof equipment. Contactelectrician forrepairifrequired.
2.	Unitnotoperating,nopower failurealarm	Alarmbatterydead	Replacebatteryandtestasabove
3.	Nooxygenflow	Flownotvisible	Placetubeunderwaterandlook forbubbles.Ifbubblesemerge steadily,gasisindeedflowing
		Tubesnotconnectedtightly	Checktubingandconnectorsare fittedtightly
		Waterormatterblockingthe oxygentubing	Removetubing,flushthroughand dryoutbeforereplacing
		Blockedflowmeterorhumidifier biomedicaltechnician	Replacemeter/bottleorreferto bottle
4.	Temperaturelightorlowoxygen alarmison	Unitoverheatedorobstructed	Removeanyobstructioncaused bydrapes,bedspread,wall,etc. Cleanfilters. Turnunitoff,usingstandby oxygensystem.Restartunitafter 30minutes. Callbiomedicaltechnicianif problemnotsolved.
5	Electricalshocks	Wiringfault	Refertoelectrician

User MaintenanceChecklist –Oxygen Concentrators

Daily	
Cleaning	✓ Remove any dust /dirt with damp cloth and dry off ✓ Fill humidifier bottleup tomarker withcleandistilledwater
Visual checks	✓ Check allscrews, connectors, tubes and parts tightlyfitted
Function checks	✓ Check oxygen flow before clinicallyrequired

Weekly	
Cleaning	✓ Wash filter in warm waterand dry. Replaceifdamaged ✓ Clean humidifier bottle thoroughly and dry off
Visual checks	✓ Replacehumidifier bottleifcovered with limescale. ✓ If mainsplug, cableor socket aredamaged, replace
Function checks	✓ Run machine for two minutes and check no alarms occur ✓ Check (see bubbles) thatflow ratevaries with flow control

Every six months
BiomedicalTechniciancheck required

OXYGEN CONCENTRATORS

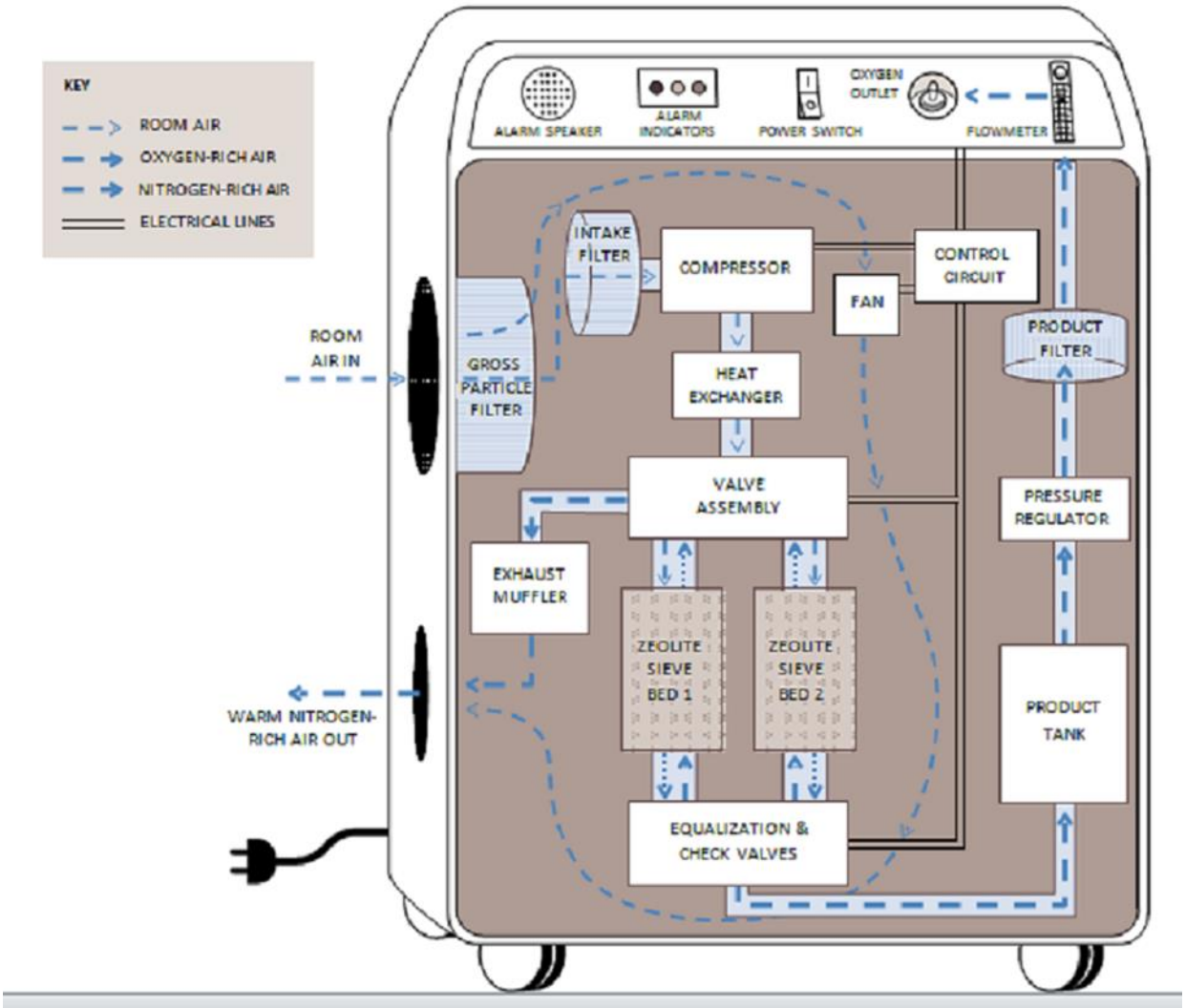
1: Definition

Oxygen Concentrator is Medical Equipment which has the mechanism of capturing oxygen from within the surrounding atmosphere to provide patients with reliable oxygen.

2: Types

- Domestic type i.e. has one Humidifier bottle and one flow meter basically for home use.
- Commercial type i.e. has two Humidifier bottles and two flow meters can serve two patients at the same time.

a. Commercial b. Domestic



3: Parts

- The Body: This comprises of all the external parts.
- On/Off Switch: switch on and off the concentrator.
- The flow meter: This measures the amount of oxygen to be administered to the patient.

- OxygenRegulator: It regulates the amount of oxygen to be administered to the patient which is indicated by the bobbin in the flow meter.
- Oxygen Outlet: This brings oxygen direct from the Humidifier bottle to the patient.
- The Vent: This allows in and out Air of the concentrator thus cooling the toner system.
- Filter: This covers the Air inlet vent and filters Air which enters the concentrator.
- Concentrator Meter: This indicates the hours the concentrator has served and when it is due for service e.g 5000 hours. (Depend on Model)
- Casters: These are used for movement.
- Humidifier Bottle: This contains distilled water which moistens Oxygen since dry Oxygen irritates and ulcerates the Airway.

Table. Typicalcomponentsandtheirfunctionwithinanoxygenconcentrator

Component	Other names	Function
Enclosure	Cabinet, interior	Encases internal components of concentrator
Gross particle filter	Cabinet filter, air intake filter, coarse filter	Filters coarse particulates to extend intake filter life
Compressor intake filter	Inlet filter, intake filter, compressor	Filters fine particles to protect compressor and/or valves
Compressor	Not applicable	Pressurizes and pumps air into the system
Fan	Cooling fan	Circulates cabinet air and cools the compressor
Heat exchanger	Aluminium pipe, coil, pipe	Dissipates heat created by gas compression
Control circuit	PCB, printed circuit assembly	Analyses the system state and controls the valves and compressor
Valve assemblies	Solenoid, check, rotary valves	Controls the flow processes for the sieve and exhaust
Sieve beds	Sieve columns, zeolite	Separates gases as air is moved in and out
Exhaust muffler	N exhaust muffler, muffler	Expels and quiets the N-rich air released back into the room
Product tank	Reservoir tank, accumulator tank, mixing tank, product tank	Gas accumulator for providing a steady and continuous flow
Flowmeter	Flow selector	Controls the delivered flow rate
Product filter	Outlet, output filter, final filter	Removes particulates from the product stream
Humidifier	Bubble humidifier, bubbler	Humidifies the delivered gas before inhalation
Oxygen monitor	Low oxygen alarm, oxygen concentration status indicator	Signals an alarm when oxygen concentration is below a preset level

4: Accessories

- Cable with a Top Plug
- Stabilizer
- Tubing
- Face mask and nasal catheters
- Connectors
- Filters

5: Preparation

- Make sure equipment is clean, complete and in good working condition.
- Put distilled water in the humidifier bottle.
- Connect the long tubing to the humidifier bottle
- It should stand in upright position, 30cm away from the wall and 15cm from the ground. This is to ensure good circulation of Air to the equipment.
- Prepare the patient in a comfortable position.

6: Operation

- Fix the plug in the socket and switch on the concentrator, then it will make an alarm which will go off after some few seconds. This indicates that the concentrator has begun to absorb Air from the surrounding (for the domestic type).
- Connect the tubing, facial mask/nasal catheter to the Humidifier and then to the patient.
- Adjust the Oxygen flow to the prescribed rate:
- e.g. 0.5-2litersper minute (infant); 2-4litersper minute (Adults).
- Continue monitoring the patient until the condition stabilizes, can use pulse oximeter to confirm whether a patient has received enough O2

7: Care

7. 1: Immediate care

- After the procedure remove the nasal catheter/face mask from the patient.
- Switch off from the equipment, stabilizer then from mains.
- Unplug from the socket and fold the cable properly.
- Disconnect the tubing, mask/catheter and decontaminate.

7.2: Routine care

- Daily dump dusting of the machine with a dump cloth.
- Inspect the gross particle on the filter for any dirt. If any dirt, clean as follows:
  - Detach the filter from the concentrator and replace with a clean one.
  - Wash the filter with soapy water, rinse in clean water, gently squeeze out the excess water and air dry.
- Switch on to confirm if it is in good working condition.
- Check the number of hours on the concentrator meter with your log book.
- When not in use; unplug from the socket and fold the cable to avoid dragging on the floor.
- Use distilled water in the humidifier bottle and always change it weekly to avoid clogging of the tubes and in case of rain or tap water change it daily.

Note:

- The oxygen concentrator uses electricity.
- Do not use any form of heat to dry the filter as it will be damaged.
- The room should not be crowded with people as this interferes with air circulation to the machine.
- Avoid using domestic type of concentratorfor more than one Patient at a time.
- Avoid flames/oils near the concentrator as Oxygen supports combustion.
- Use clear signs of danger (diagram)

Optional equipment for other applications of oxygen concentrators

Some oxygen concentrators can be used for other medical applications besides oxygen therapy. While some applications are possible through built-in features, other applications require additional equipment. The appropriate clinical guidelines and technical recommendations should be referred to, if available

Anesthesia

Oxygen concentrators can be used in some, but not all, anaesthesia machines. There are two different systems available for delivering anaesthetic gases and vapours to the patient, with which oxygen concentrators have been used: draw-over and continuous flow. In draw-over systems, volatile agents or compressed medical gases are added to an air stream that is delivered to the patient. The air is driven by the patient "drawing" in air through the system, rather than by a source of compressed oxygen, as is used in continuous flow anaesthesia systems. Therefore, oxygen concentrators can be used indraw-over systems. In contrast, not all continuous flow anaesthesia machines can work with oxygen concentrators since most concentrators do not produce sufficient pressure. Nonetheless, some continuous flow anaesthesia machines are designed to operate with oxygen concentrators

Overall, if oxygen concentrators are used as the primary oxygen source for anaesthesia, there must be a back-up power supply (such as a generator or UPS) or cylinder supply present to continue delivery in the event of a power failure. Furthermore, it is important to determine whether the concentrator can deliver oxygen at the necessary concentration and pressurerequired bythe type of anaesthesia system used.

For additional information, refer to the WHO manual surgical care at the district hospital, available at *http://www.who.int/surgery/publications/en/SCDH.pdf* and Integrated management for emergency and essential surgical care toolkit, available at *http:// www.who.int/surgery/publications/imeesc/en*.

- Bubble CPAP

CPAP is a respiratory technique to provide airway support inthe form of positive pressure, primarily for premature babies with respiratory distress syndrome. Bubble CPAP is a simple and inexpensive form of CPAP that can bemade using standard nasal prongs and an oxygen concentrator. However, in premature neonates less than 32 weeks of gestational age, blended gas is required as it is not safe to administer high oxygen concentration due to the risks of oxygen toxicity, including retinopathy of prematurity, brain damage and chronic lung injury. As a result, oxygen concentrators without blending functionalityare notsuitable for CPAP in premature infants since concentrators do not generate enough pressure to be used with an air-oxygen blender. However, certain concentrator-based bubble-CPAP systems have been designed to provide blended oxygen gas, having been demonstrated in neonatal wards For additional information, refer to the WHO Manual on clinical use of oxygen therapy in children (in preparation) for clinical guidelines and the WHO Technical specifications for medical devices for related equipment

- Nebulizers

A nebulizer is a device that entrains aerosolized liquid medication into inhaled air in order to deliver medication to the lungs. Examples of drugs that have been aerosolized and delivered orally or intra-nasally are surfactants, steroids, anti-inflammatory drugs, antibiotics and vaccines. There are three types of nebulizers currently available: jet nebulizers; ultrasonic nebulizers; and vibrating mesh membrane nebulizers.

If jet nebulizers are used, then concentrators with a built-in nebulizer function or that can provide high enough oxygen outlet pressure to power a nebulizer can be used. Some concentrators have an additional air outlet to supply pressurized air for a nebulizer. Such concentrators may reduce the need for other dedicated equipment and infrastructure to provide pressurized air.

Pulse Oximeters

Function

Apulseoximeterisadevicethatnon-invasivelymonitorstheoxygensaturationofapatient'sblood. Itmeasures theamountofoxygenina patientsartèrialblooddduringoperationsanddiagnosis.Thislevelofoxygen,or oxygensaturation ĩsoftenreferredtoSpO_2,measuredin%,andthisisdisplayedonthepulseoximeter. A pulseoximeteralsodisplayspulserate.

Howitworks

Thecolouredsubstanceinblood,haemoglobin,iscarrierofoxygenandtheabsorptionoflightby haemoglobinvarieswiththeamountofoxygenation. Twodifferentkindsoflight(onevisible,oneinvisible)are directedthroughtheskinfromonesideofaprobe,andtheamounttransmittedismeasuredontheotherside. Themachineconvertstheratiooftransmissionofthetwokindsoflightintoa%oxygenation. Pulseoximeter probescanbemountedonthefingerorearlobe.

Troubleshooting –Pulse Oximeters

	Fault	Possible Cause	Solution
1.	Equipmentisnotrunning	Nopowerfrommainssocket	Checkpowerswitchison. Replacefusewithcorrectvoltage andcurrentifblown. Checkmainspowerispresentat socketusingequipmentknownto beworking. Contactelectrician forrewiringifpowernotpresent.
		Battery(ifpresent)isdischarged	Rechargeorreplacebattery
		Electricalcablefault	Trycableonanotherpieceof equipment. Contactelectrician forrepairifrequired.
2.	SpO_2orpulseratenotdisplayed	Probeisnotmountedcorrectly	Connectprobeandcableproperly orunstable
		Probenotabletoreadthrough dirt,nailpolish,etc.	Removegrease,dirt,nailpolish andcleanprobe
		Patientmovement	Requestpatienttoremainstill
		PatientsSpO_2valueistoolowto bemeasured	Furtherclinicalexaminationof patient. Resiteprobeifnecessary
		Internalmalfunction	Callbiomedicaltechnician.
3.	Probeoff displayedonscreen	Probeisnotconnectedproperly	Connectthesensor
		Theconnectionbetweenthe probeandoximeterisloose	Refertobiomedicaltechnicianfor repair
4.	Error displayedonscreen	Faultyprobeorcontrolcircuit	Refertobiomedicaltechnician
5.	Continuousalarmsounds	Alarmlimitssettooloworhigh	Setappropriatealarmlimits
		Powerdisconnected	Connectpowercable
		Internalmalfunction	Refertobiomedicaltechnician
6.	Electricalshocks	Wiringfault	Refertobiomedicaltechnician immediately

User Maintenance Checklist –Pulse Oximeters

Daily	
Cleaning	✓ Remove any dust /dirt and replace equipment cover ✓ Remove any tape, paper or foreign body from equipment ✓ Cleanprobe with alcohol wipe aftereachuse
Visual checks	✓ Checkallpartsarepresentand connected ✓ Check cables are not twisted and remove from service if any damage isvisible
Function checks	✓ Check operation on healthy subject before use

Weekly	
Cleaning	✓ Unplug, clean outside with damp cloth and dry off
Visualchecks	✓ Tighten any loose screws and check parts arefittedtightly ✓ If plug, cableor socket aredamaged, replace
Function checks	✓ Check operation of alllights, indicators and visual displays ✓ Check probe disconnection alarm.

Every six months
BiomedicalTechniciancheck required

Chapter 5 Plants

OXYGEN - PRESSURE SWING ADSORPTION

Oxygenneedstobeproducedinlargevolumesformanyapplications. Perhapsthe commonestofthesareinmedicineandin thepulpandpaperindustry. Therearetwo methodsusedfordoingthis:cryogenicandpressure swing adsorption. Pressure swing adsorption,whichisoutlinedinthisarticle,ismostusefulforsmallapplicationssuchas oxygen production in the home for asthma sufferers.

Pressureswingadsorptionreliesonairbeing filtered through aluminosilicateminerals known as zeolites. The one used for PSA oxygen has been specially designed so that nitrogen gas is adsorbed onto it while oxygen (and argon) pass straight through. The zeoliteisquicklysaturatedwithnitrogen,so twozeolitebedsareusuallyusedtogether, one filtering air while the other is regenerated.

This process is very environmentally friendly and the technique is also potentially able to be used to remove other gases (such as CO_2)fromindustrial waste gas streams.

INTRODUCTION

Pressure Swing Adsorption (PSA) is one of the most popular methods used for the commercial production of oxygen gas. Whilst cryogenic manufacture by the Joule- Thompson method (fractional distillation of air at low temperature and pressure) is suited to large scale operations (over 200 tonne of oxygen per day), PSA technology is suited to small and mediumsized productions needs. A comparison between the two methods of oxygen manufacture is given in **Table**.

Table - The relative advantages of PSA and cryogenic oxygen production

	PSA	**Cryogenic production**
Temperature	ambient	low
Pressure*	maximumis 150 kPa	maximumis 13,000 kPa
Purity	95%	near 100%

* The usual car tyre pressure is 200 kPa

Micro (suitcase sized) PSA plants have replaced heavy high pressure oxygen cylinders in the homes of many asthma sufferers. Small PSA plants have been built to replace large numbers of oxygen cylinders used in some industrial situations. Large PSA plants are often located alongside pulp mills where the oxygen produced is used directly in the mill process. The Kinleith plant of IChemLimited provides up to forty tonne per day of high quality oxygen to the neighbouring pulp mill. The oxygen has replaced chlorine as the primary chemical used to de-lignify wood pulp.

THE PSA PROCESS

The PSA process (shown in **Figure**) consists of pumping air through a bed containing a filter mediumthat preferentially adsorbs nitrogen, while allowing oxygen to pass through unrestricted. Eventually, the filter bed becomes saturated with nitrogen and must beregenerated. It is the feature of the filter media that nitrogen is adsorbed at pressures above

150 kPa and is desorbed at atmospheric pressures. The desorbed nitrogen is then flushed away by a proportion of the purified oxygen. It is this cyclic pressurisation and depressurisation that gives the PSA process its name.

The filter mediumis a type ofzeolite. The properties ofzeolites in general and this zeolite in particular are discussed below.

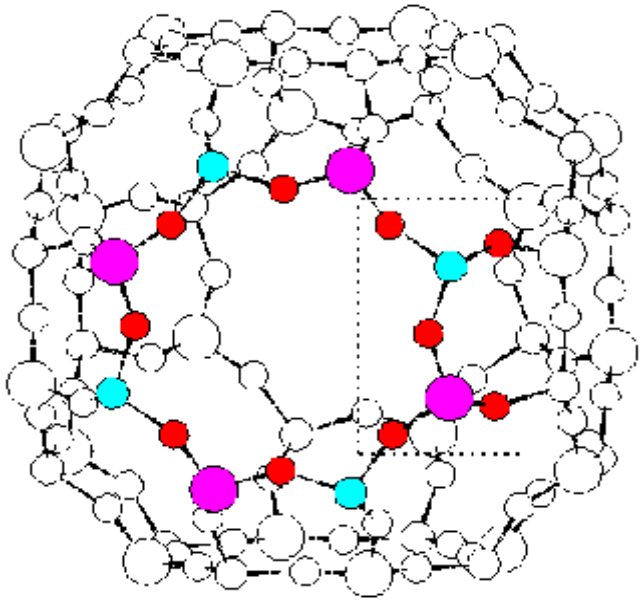


Figure - Structure of the zeolite used in PSA oxygen production

Zeolite

Scientists have known for many years the special properties of naturally occurring zeolites. Natural Zeolites Limited, based in Tokoroa, produces some of the highest quality zeolite in the world.

Naturally occurring zeolite was not selective enough for oxygen separation and it was not until the 1950's that scientists at Union Carbide in the USA developed synthetic zeolites. PSA technology experienced rapid growth during the 1980's with over five hundred patents being issued between 1985 and 1990.

Zeolites are aluminosilicateminerals with complex crystal structures made up ofinterlocking rings of silicon, aluminiumand oxygen ions. The chemical composition of the zeolite used for oxygen separation is $Na_{12}[(AlO_2)_{12}((SiO_2)_{12}].27H_2O$.It is the zeolite's shape which provides most of the ability to selectively adsorb nitrogen. The zeolite used for oxygen production is shaped like a die with holes drilled on each face to forman internal cage. The corners of the die (providing the framework) are $SiO_2$and AlO_2units. Cations (either Na or Ca) are exposed throughout the crystal lattice. This zeolite is shown in the above**Figure** .

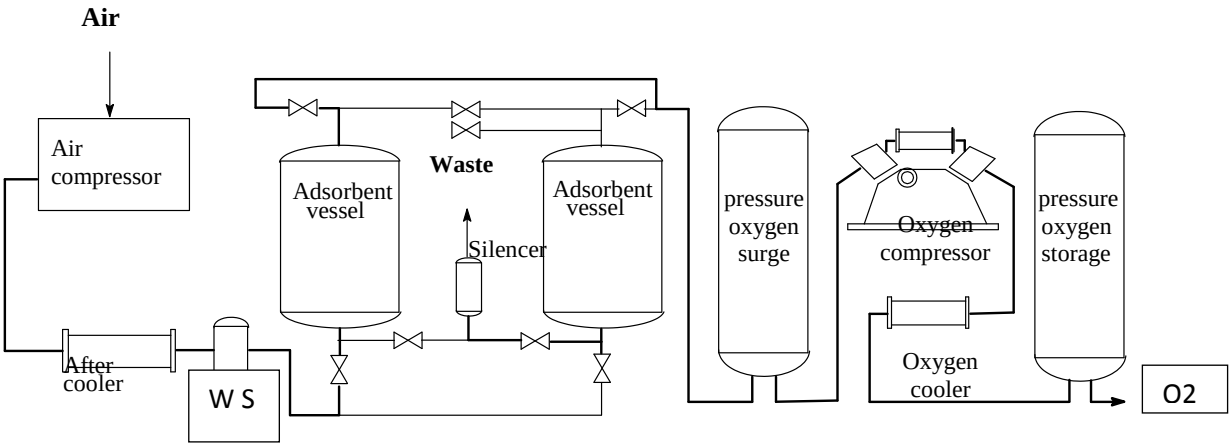

Air
Air compressor
Waste
Adsorbent vessel
Adsorbent vessel
Silencer
pressure oxygen surge
Oxygen compressor
pressure oxygen storage
After cooler
W S
Oxygen cooler
O2

Figure - Schematic representation of the PSA process O2

Zeolite is very efficient for two reasons.

1. *Physical adsorption*

When nitrogen is in close proximity to the exposed cations of the zeolite crystal, a charge induced dipole forms and the nitrogen is attracted into the zeolite crystal. Nitrogen is more polarisable than oxygen and the zeolite selectively adsorbs nitrogen allowing the oxygen gas to pass unrestricted. The internal surface area of zeolite is extremely large and so provides a high degree ofadsorption per volume ofzeolite.

2. *Steric hindrance*

The cage like structures ofzeolite have been carefully designed to allow only nitrogen to pass to their inside and to exclude the larger oxygen molecules. That is, the holes in the side of the zeolite dice are large enough to allow nitrogen entry but small enough to exclude oxygen. They also exclude argon which makes up approximately one per cent of the input air. Argon comprises five per cent of the volume of gas produced by an oxygen PSA plant.

The uniformity of the micropores has been the major advantage of synthetically produced zeolites.

The PSA Cycle

Practical design of PSA oxygen plants depends on many factors, including bed length, diameter, zeolite bed packing, and rate of infeed air. In domestic medical oxygen PSA plants, power efficiency is sacrificed in favors of robustness, process stability and oxygen purity. In larger commercial oxygen plants, the process is only economic whilst operating at maximumoxygen separation efficiency. The control of the cycling is critical.

PSA zeolite beds are always built in pairs, so that a portion of the oxygen produced fromone bed is used to regenerate the other bed. Clearly, the ratio of oxygen used for regenerating the other bed compared to that available for sale is critical. At the IChemLtd plant, each zeolite bed is saturated after only twenty-two seconds, requiring the pressurization and regeneration (depressurization and flushing with oxygen) sequence to be precisely computercontrolled.
The plant computer controls all aspects of running a large PSA plant. If there is a problem, the plant computer pages an operator. Apart fromroutine maintenance, the plant does not require the presence of an operator.

FURTHER APPLICATIONS OF PSA[4] TECHNOLOGY

The principles of PSA technology have been applied to separation of many mixed gas streams. Plants are available to produce nitrogen for uses like blanketing fuel tanks at airports. "Designer" zeolites have been produced to remove hydrogen fromwaste gas streams.

Currently, PSA technology is used to remove CO_2fromthe flue streams of the steel and lime industries. In the future, PSA plants may be used to extract the greenhouse gas CO_2fromthe flue streams of coal fired power stations.

ENVIRONMENTAL IMPLICATIONS

The PSA[5] process is an extremely clean operation. The only "raw material" is air, and the only other input is electricity to pump the air through the filters. The process removes approximately one third of the oxygen fromthe air. Larger PSA plants are computer controlled and run unattended. Their reliability is demonstrated by the thirty thousand PSA units in the USA providing medical oxygen in critical applications.

A **cryogenic oxygen plant**

It is an industrial facility that creates molecular oxygen at relatively high purity. Oxygen is the most common element in the earth's crust[1] and the second largest industrial gas. Pure oxygen can only be generated by cryogenic air separation. This process was pioneered by Dr. Carl von Linde in 1902.

Purpose

The cryogenic air separation achieves high purity oxygen of more than 99.5%. The resulting high purity product can be stored as a liquid and/or filled into cylinders. These cylinders can even be distributed to customer in the medical sector, welding or mixed with other gases and used as breathing gas for diving. Typical production ranges from 50Nm^3/hour up to 860.000Nm^3/hour.

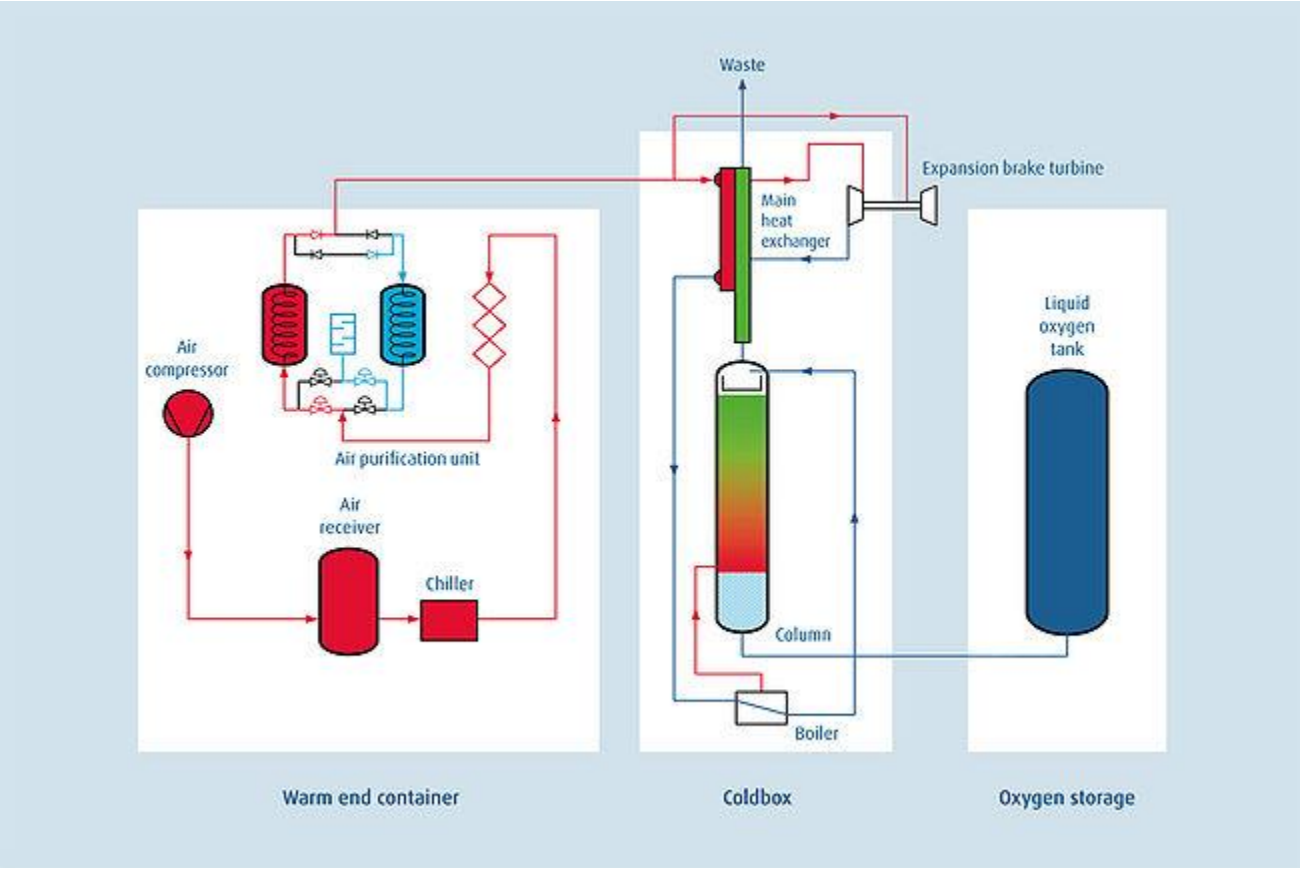
How the plant works

- ***Warm end process***

Atmospheric air is roughly filtered and pressurised by a compressor, which provides the product pressure to deliver to the customer. The amount of air sucked in depends on the customer's oxygen demand.

The air receiver collects condensate and minimises pressure drop. The dry and compressed air leaves the air to refrigerant heat exchanger with about 10°C.
To clean the process air further, there are different stages of filtration. First of all, more condensate is removed, then a Coalescing filter acts as a gravity filter and finally an adsorber filled with activated carbon removes some hydrocarbons.

- [4]Whiting, R. *Chemistry in New Zealand*; Vol 55, No 2, 1991.
- [5]Ruthven, D., Farooq, S. and Knaebel, K.;*Pressure Swing Adsorption*; VCH New York; 993



Flow liquid Oxygen Plant by Linde

The last unit process in the warm end container is the thermal swing adsorber (TSA). The Air purification unit cleans the compressed process air by removing any residual water vapour, carbon dioxide and hydrocarbons. It comprises two vessels, valves and exhaust to allow the changeover of vessels. While one of the TSA beds is on stream the second one is regenerated by the waste gas flow, which is vented through a silencer into the ambient environment.

- ***Coldbox process***

The process air enters the main heat exchanger in the coldbox where it is cooled in counter flow with the waste gas stream. After leaving the main heat exchanger the process air has a temperature of about –112°C and is partly liquefied. The complete liquefaction is achieved through evaporation of cooled liquid oxygen in the boiler. After passing a purity control valve process air enters on tip of the distillation column and flows down through the packing material.
The steam of evaporated oxygen vapour in the shell of the boiler vents back into the distillation column. It rises through the column packing material and encounters the descending stream of liquid process air.

The liquid air descending down the column loses nitrogen. It becomes richer in oxygen and collects at the base of the column as pure liquid oxygen. It flows out into the boiler to the cold box liquid product valve. An on-line oxygen analyser controls the opening of the liquid product valve to transfer pure low-pressure liquid oxygen into the storage tank.

The rising oxygen vapour becomes rich in nitrogen and argon. It leaves the column and exits the cold box at ambient temperature through the main heat exchanger as a waste gas. This waste gas provides purge gas to regenerate the TSA unit and to the cool the refrigeration turbine.

Turbines located at the base of the cold box provide refrigeration for the process. A stream of high-pressure gas from the main heat exchangers is cooled and expanded to low pressure in the turbine. This cold air returns to the waste stream of the heat exchanger to inject refrigeration. Energy removed by the turbine re-appears as heat in the turbine's closed-cycle air-brake circuit. This heat is removed in an air-to-air cooler by waste gas from the cold box.

- ***Storage and vaporising process***

Liquid from the tank is compressed to high pressure in a cryogenic liquid pump. It is then vaporized in an ambient air evaporator to produce gaseous oxygen. The high-pressure gas then can pass into cylinders via the gas manifold or fed into a customer's product pipeline.

Summary:

Table- Comparisonofoxygencylindersandconcentratorsasthebasisforoxygensystems

System	Centraloxygen (pipelinesystem)	Oxygencylinders	Oxygenconcentrators
Powersourcerequired	No	No	Yes,continuously(100–600 W,depending on model)
Transportrequirement	Thoseassociatedwith cylinders	Regularly; heavyand costlyto transport	Onlyattimeofinstallation
Exhaustiblesupply	Yes,ifpipesarerefilledfrom anoffsitesupplyfacility	Yes,dependingonthesize, storagepressure andpatient needs	No, continuoussupplyas long aspowerremains uninterrupted
Initialcosts[a]	Significant:generatorand cylinders(US$20 000), piping system(US$10000+), installation,commissioning andtraining	Moderate:cylinder,oxygen flowmeterandregulatorper cylinder(~US$200)[b]	Moderate:concentrator (US$300–3400)[b],spares, installation,commissioning andtraining
Operational costs[a]	Smalltomoderate: maintenance,continuousrefill ofpipelinebybankor tanks	High:cylinderrefillsand transportfromrefilling stationto hospital	Small:electricityand maintenance
Usercare	Minimal	Minimal:regularchecking, minimizesfirehazard(no greaseor flammables)	Moderate:cleaningoffilters anddeviceexterior,and minimizesfirehazard
Maintenance	Moderate: checkforpressure leakswithmanometer Maintenanceofoxygen pipelines to prevent leaksand oxygenwastage Significant:ifsupplyfacility isonsite	Moderate: checkforpressure leakswithgauge	Moderate: checkforlow oxygenoutputwithanalyser
Costper1000litresoxygen[c]	Data notavailable	US$10–30/kilolitrevarying withestimatedoxygen requirementandpower availability	US$2–8/kilolitre(greater depending oncostof powersource),varying withestimatedoxygen requirementandpower availability

Chapter 6. Standards

What is a standard?A standard

- Specifies the essential requirements for products or systems
- It is not a law
- In case of justification the judge will anyhow orientate to the essential requirements from the standards
- Within Europe, medical products may not be marketed and sold without CE-mark, which requires that systems are build according to the relevant standards

The equipment with which medical gases are applied to a patient, production process, or other task is strictly controlled. More than 225 standards relating to pharmaceutical and medical gases are available through the IHS Global Standards Store.

Due to the fact that all medical gases are considered drugs which are only available by prescription, the standards with which they are governed are strictly controlled by FMHACA. whose recommendations are legally enforced by the Food and Drug Administration. The FMOH-MSGD with FMOH-MCH CompressMedical Gas Guidelines and road map for Medical Gases serve as the foremost instruments of patient safety.Medical GasesManufacturing Guidelines should be developing and implementing as soon as possible. In addition, various manufacturer and healthcare facilities establish their ownstandards on the handling and use of compressed Medical gases.Due to the fact that medical gases can be combustible or act as oxidants, medical gas systems must adhere to FMHACA standard by adopting the NFPA 99.

Finally, all individuals who install or maintain medical gas systems must receive appropriate training and complete the Medical Gas Installer Exam. Those who administer or prescribe pharmaceutical-grade gases undergo extensive medical training and licensing programs.

Whatis the ISO 7396-1?

TheISO 7396-1is astandardpublishedby the **I**nternational**S**tandard**O**rganization for medicalgas pipelinesystemsIt canbeestablishedinany countryofthe world. In mostEuropeancountriesit is linkedto theMDD.

.

Ethiopia is the ISO memberstate countries most of the standard driven from ISO. Assume that if it has its own medical gas system standard it should be taken from the ISO.

Whatis the MDD?

TheMedicalDeviceDirectiveis a Europeanlawthat containsthe classificationfor medicaldevices.Accordingto MDD a risk analysishastobedoneforevery medicaldeviceandcertainother standardsfor electronicandsoftwarehavetobe followed.

Whatis the HTM02-01?

The**H**ealth**T**echnical**M**emorandum02-01is a guidelineforthe design,installation, validationandverificationof MedicalGas PipelineSystems.Theguidelineis publishedby the BritishDepartmentofHealth.

TheHTMis basedon standardsandbest practice,howevernota standardby itself.

Whatis the NFPA99?

*“This processbringstogether volunteersrepresentingvariedviewpointsand interests to achieve**consensus on fireand othersafetyissues**.While theNFPA administersthe*

processandestablishesrulesto promotefairnessinthe developmentof consensus,itdoesnotindependentlytest, evaluate,orverifythe accuracyofanyinformationor thesoundnessofanyjudgmentscontained inNFPADocuments."

Overview of the ISO / MDD Philosophy:

- ISO describes the state of technology and forms a framework for individual solutions of suppliers which have to fit in
- Manufacturer and installers have to perform their own risk assessment and Quality system
- Every project has to be certified by a notified body (acc. MDD)
- Ambitious integrated technology is used to create independency of the sources

Overviewof theHTM Philosophy:

- HTMcontainseverythingyouneedfor a MGPSproject includingdimensioning,installation,test andcommissioning
- Personsthat arerelatedtothe projectaretrainedindividually
- Usesimpleandreliabletechnology
- Securesystemswithhighredundancy

Distribution Systems Differences between ISO/HTM

Summarizing the Standard of ISO and HTM

ISO 7396-1	HTM 02-01
• definesminimumsafetystandards • asopenas possible • shouldensurefreetrade • ISOdrivenandgloballyagreed • createdbya committee,approvedby membercountries • registrationasmedicalproductacc.to MDDpossible	• givesexactguidance • aspreciseaspossible • tradeeffectsirrelevant • NationalHealthServicedriven • createdbyfew, approvedbynone • nointenttofollowMDD

BasicsPurposeandUse medical gas:

"A medical Gas Management System is supposedto delivery all required

ISO7396-1	HTM02-01
Pipelineidentification Acc.ISO5359 Markingintervalmax.10m	Pipelineidentification Acc.BS1710:1984 Markingintervalevery 3m
Pipe joiningfittings Acc.EN 1254-1	Pipejoiningfittings Acc.EN 1254-1 Mustbeindividuallysealedinbagsorboxes. *NOTE: Thisexistingrequirementwillbechangedin thenextrevisionoftheHTM–dueto resealable packageforfittingsis anacceptablepractise.*
Shut-offvalvesshallbelockableintheopenandclosedpositions;shut-offvalveswhichcannotbelockedintheopenorclosedpositionshallbe protectedfromoperationbyunauthorize	Shut-offvalvesshouldbecapableofbeinglocked with thevalveintheopenorclosedposition. Meansofphysicallyisolatingandblankingthe pipelinebothupstreamanddownstre

medical gases continually and securely in the required quantity (flow), pressure and quality."

From the above Medical gas basic utilization Principle we can obtained the following three parameters those needs standards in the continues and secure manner:

1. Flow (quantity)
2. Pressure
3. Quality

Chapter 7. Safety

Whatarethe fourbasic rulesofsupplysafety?

Quantity ofsupply
Thisis achievedbyensuringthatthedesignofthepipelineinstallationandcapacityofthesupplyplantis sufficientto provide the requiredflows of gasesand vacuumfortheintendednumberofpatientstobe treatedat anyonetime.Adequacyof supplyis establishedduringcommissioningofthesystems·

Identity ofsupply
Thisis achievedbyensuringthatallpointstowhichtheusercanconnectmedicalequipment(terminalunits)and user- replaceablecomponentsareprovided withgas-specificconnectors.Suchconnectorsarealsoidentifiedby symbolandoften colour.Thegasspecificityis maintainedby comprehensivetestsandchecksduringinstallationandcommissioning,and duringany work or maintenanceonthesystems.

Continuityofsupply
Thisis achievedbyinstalling,asaminimum,duplexcomponentsandprovidingadditionalmeansofsupplyprovisioninthe eventoffailureoftheprimaryandsecondaryplantor supplysystem.Systems arealsoconnectedto theessentialelectrical supply.

Quality ofsupply
Qualityofsupplyis ensuredbytheuseofgaseousorliquidsourcesthatareprovidedto anappropriateproductspecification, usuallyarecognisedEuropeanPharmacopoeia(Ph.Eur.) monogram.In thecaseofcompressor-basedsystems,filtration equipmentto aknownandagreedstandardis installed.Toensurethattheproductis notadulteratedinthedistribution system, pipelineinstallationsandcomponentsarerequiredto meetagreedspecifications.TherearestrictPh.Eur. requirementsformedicalgases.

7.1. Five things to make oxygen use safer in your hospital

- **Check that the oxygen you are giving is prescribed**
  Oxygen is a medicine and should always be prescribed. In an emergency, oxygen can be given immediately and documented later.
- **Measure and record saturation levels.**
  Oxygen is a treatment for hypoxaemia, not breathlessness. Establish whether the patient is

hypoxaemic and, if so, to what extent. Pulse oximetry is an essential tool in assessing the oxygen saturation of the blood and results should be recorded.

- **Adjust the flow rate, if required, to achieve target saturation**
  Maintain the target saturation range. The recommended initial target saturation range, unless stated otherwise, is 94-98%. If patients have chronic obstructive pulmonary disease (COPD) or other risk factors for hypercapnic respiratory failure, aim at a saturation of 88-92%.
- **Don't confuse oxygen and medical compressed air**
  Be aware of colour coding of flow meters and make sure they are not obstructed by curtains or other equipment.
- **Check the content of cylinders and calculate how long they will last**
  This is especially important for cylinders on resuscitation trolleys and when transferring a patient

7.1.2. The ***ABC***'s of Medical Gas Safety

- ***Always*** physical separate full and empty medical gas cylinders
- ***Be*** sure to label the cylinder clearly.
  - So that busy staff don't have to spend time choosing between full and empty cylinder
- ***Consider***any open cylinder as empty.

7.1.3. Find out how your hospital is putting these actions into practice:

- minimize use of oxygen cylinders on wards (it is more expensive and less safe than piped oxygen for clinical areas with regular use);
- ensure reliable and adequate supplies of oxygen cylinders in transfer and emergency situations;
- assess the risks of confusing oxygen and medical compressed air (for instance, covering air outlets when not in use);
- ensure that oxygen is prescribed and pulse oximetry is available in all locations where oxygen is used;
- Ensure a multidisciplinary group is responsible for the safe use of oxygen in your hospital; this includes reviewing oxygen related incidents, developing a local oxygen policy and a training program.

7.2.HOSPITAL MEDICAL GAS MONITORING SYSTEM

Centralized hospital medical gas monitoring system is designed to:

- ***Control*** the hospital medical gas system pressure in the gas sources, in the closure points of pressure regulation.
- ***Control*** supplied medical gas flows detecting possible gas leaks, while analyzing earlier periods of gas flow quantities.
- ***Perform*** consumed medical gas calculation for a day, a week, a year.
- ***Under*** the system given pressure and flow parameters signal to the central computer and the mobile communication system about impermissible deviations.
- ***Analyze*** the obtained information in the central computer about cause of fault alarm signals and theircorrection method.
- ***Perform*** the most important system's installation working time accounting, notify about the equipment'sservicing terms, register failures.

7.3. The system consists of:

- ***Gas pressure and flow measures*** with changers.
- Specialized analogical and discrete signals processing, storing and transferring to the RS-485 line interface ***modules***. These modules, depending on the number of control points, are built directly into the installation's composition or as separate devices.
- Three-wire system to which all system interface modules are connected in parallel.
- ***Audio and luminous signal sources*** which inform about a state of emergency.
- ***Specialized computer*** with RS 485 interfaces.
- ***Specialized software*** can be modified depending on the hospital's type and size of existing equipment.

Are you cleaning your cylinders according to the FDA CFR Section 211.80 to Section 211.94?

Drug product containers and closures play a critical role in assuring that the drug product provided to the patient has the appropriate same strength, quality, and purity. This presents unique risks to be considered that are not present in other industries where the containers and closures are used only once. Therefore, all high pressure cylinders and all cryogenic vessels and their associated valves are required to undergo strict pre-fill inspections, prior to filling with a medical gas. The agency is currently investigating the possibility of requiring dedicated medical drug containers.

Adequate cleaning procedures should be established and followed in order to prevent any contamination or impurities from being introduced into a medical drug container.

The FDA has received several reports of patients suffering injuries due to high pressure cylinders that were contaminated with unusual chemicals, such as Freon 14, benzene, chlorine, etc. All high pressure cylinders are required to be cleaned prior to the introduction of a medical gas.

To properly clean/disinfect cylinders, providers should:

1. Use the right cleaner/disinfectant on the cylinder body only (NOT on the valve opening). For label adhesive and grime, try Applied's Label Remover 3G.
2. Ensure NO contaminants are left behind by inspecting according to CGA G-4.1 and use a black light (Applied PN: 1100-9994).
3. If contaminants are found, use a CGA listed and approved oxygen cleaner (like Applied's Oxygen Equipment Cleaner).

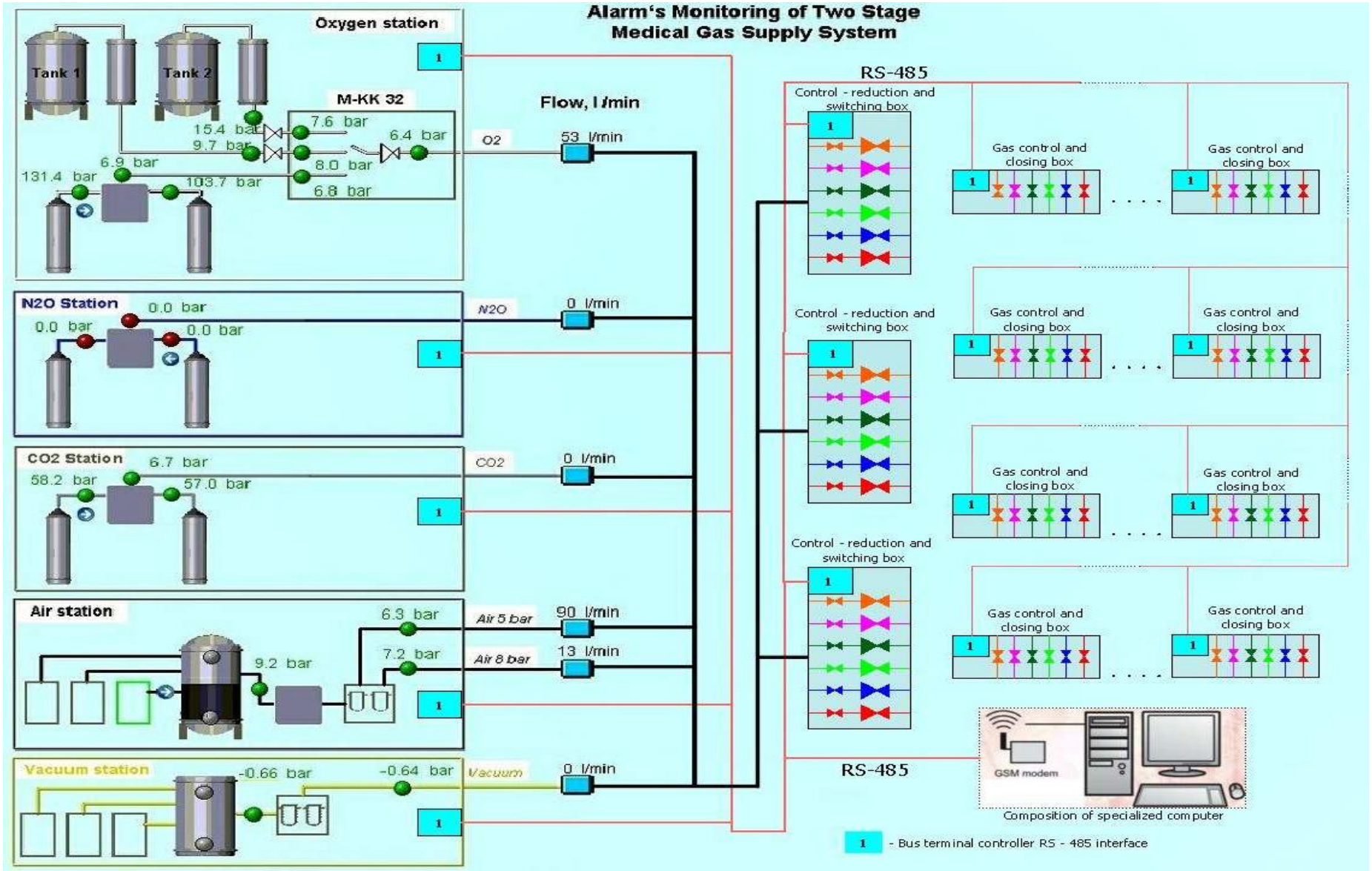


Fig. Hospital medical gas monitoring system-functional scheme

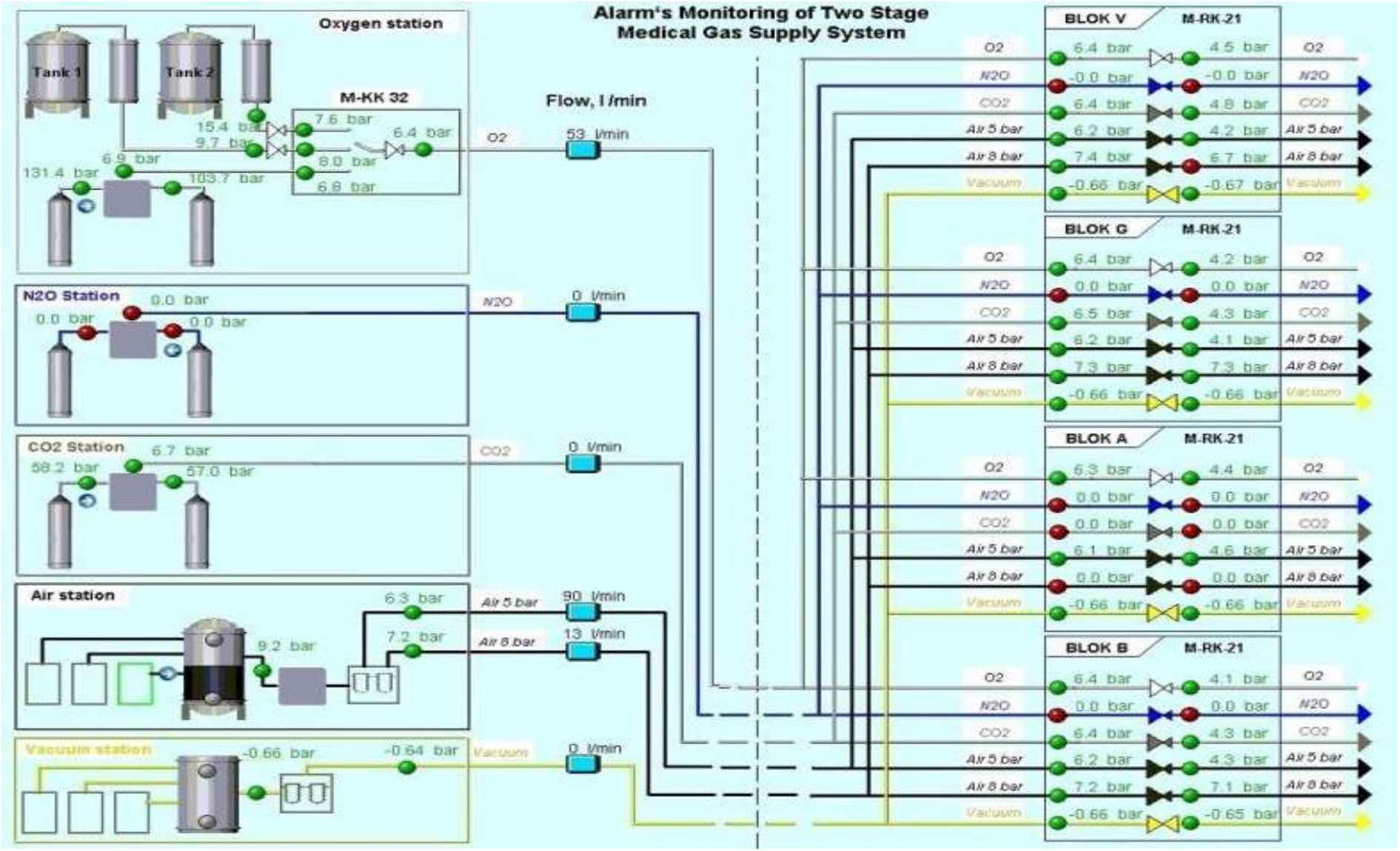


Fig. Medical gas pressure and flow drawing from working hospitalin 09.10.2010

Red part of the flow chart as taken one case an example to inform the leakage appear in the system

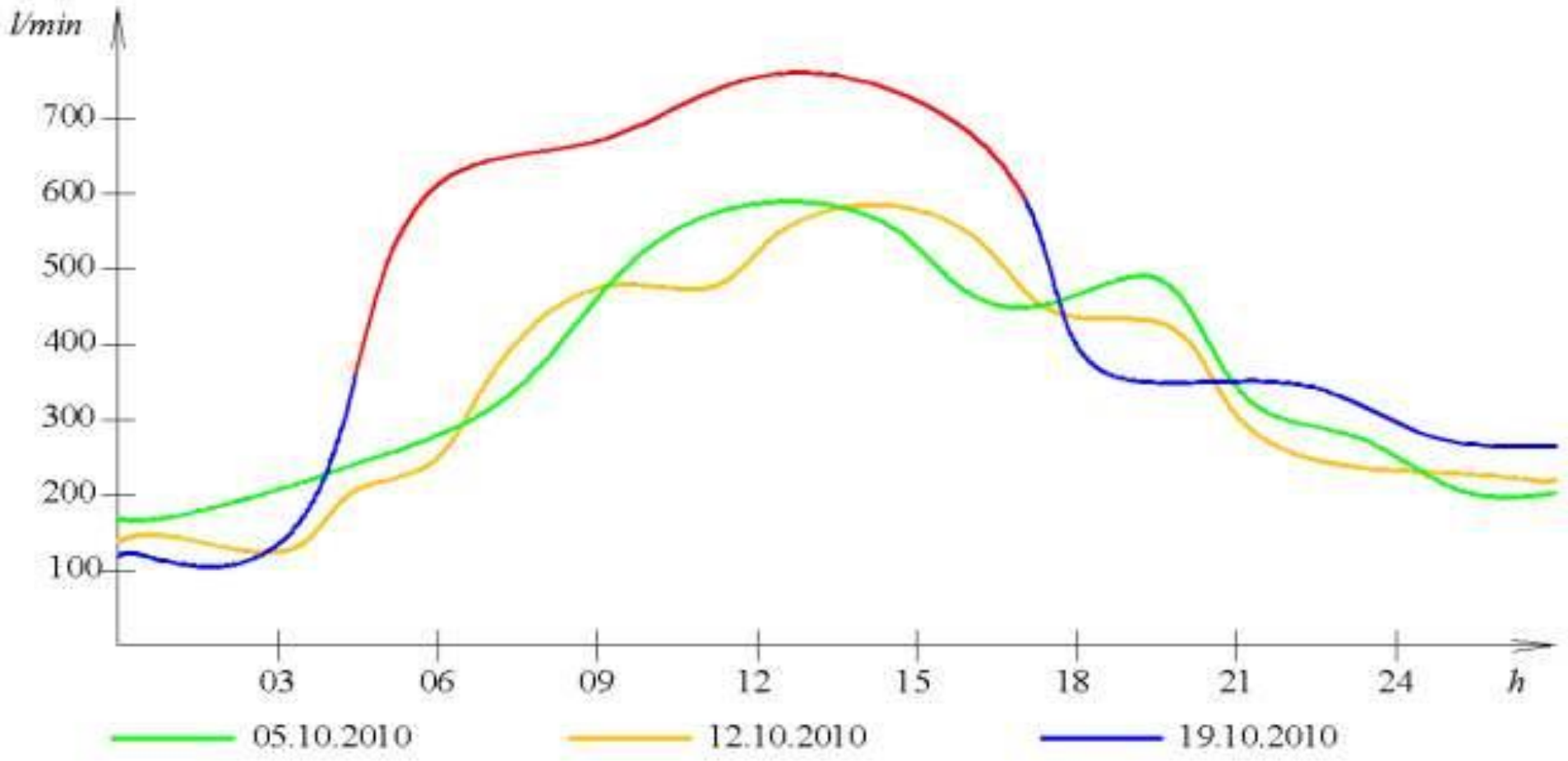


Fig. Oxygen daily flow compression chart

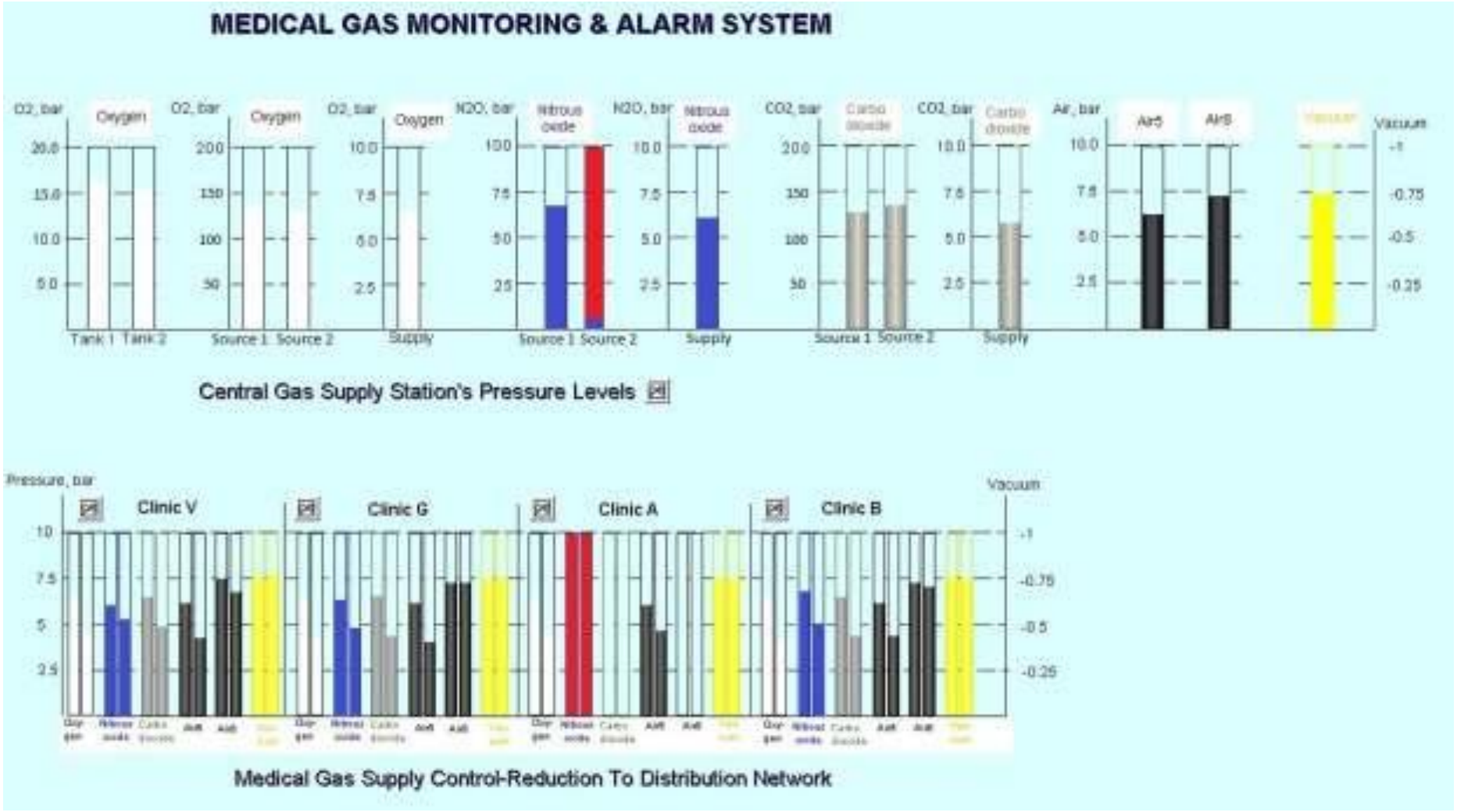


Fig. The main points of the control gas pressure bar graph

6. Resources

1. Airgas - Medical Gases

2. Wikipedia - Hydrogen; Xenon; Helium; Nitric oxide; Nitrous oxide; Carbon dioxide; Argon; Nitrogen; Medical gas supply; Instruments used in anesthesiology

3. Anesthesia Patient Safety Foundation - Medical Air

4. Medical Gas Research - Molecular hydrogen: an overview of its neurobiological effects...

5. Medical Gas Certifications Blog - Purpose and Uses of Medical Gas

6. BOC Healthcare - Medical carbon dioxide

7. Matheson Gas - Gas Applications used in Pharmaceutical and Biotechnology

8. Eugene A. Hessel, II, and L. Henry Edmunds, Jr. "Extracorporeal Circulation: Perfusion Systems." Cardiac Surgery in the Adult. [On-line] New York: McGraw-Hill, Available: http://cardiacsurgery.ctsnetbooks.org/cgi/ content/full/2/2003/317 2003, [30 Jun2009].

9. Quizlet - 3 Types of Medical Gases (slideshow)

10. PharmTech - USP Intitiatives for the Safe Use of Medical Gases

11. Images credits: Dunbar Mechanical; Butler Gas

12. Engineering Calculators Related to Pharmaceutical and Medical Gases

13. Compressible Flow Pressure Loss Calculator; Gas Density and Specific Volume Calculator

9. Annex

Annex A. pre – test and post -test on Medical Gas Management Training

1. What are the four basic rules of Medical Gas supply safety?
   Ans: Quantity, Identity, Quality and Continuity
2. List four of the clinical unit that uses oxygen gas supply in the hospital.
   Ans: OR. ER, ICU, NICU….
3. What type and made from the oxygen cylinder used in MRI room? Why?
   Ans: Aluminum….Nonmagnetic or Diamagnetic material.
4. Write the four phases in oxygen plant turnkey project.
5. What is MGMS? What are the requirements?
6. Compare Oxygen concentrator with oxygen cylinder.
7. Compare PSA Oxygen plant with cryogenic oxygen.
8. How long could you live without O2
9. Draw the flow chart of production process of PSA oxygen plant ****
10. Draw the flow chart of production process Oxygen concentrator****
11. List the four classification of medical gas based on their application. ***
12. List atleast five medical gases and their respective application in healthcare. ***
13. What is the main clinical purpose of Heart Lung machine?

FMOH with collaboration of AARHB

Name:…… Code…… Time: 30min

Instruction I – *Answer for the following Essay type question.*

Pre – test and post -test on Medical Gas Management Training

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12. List at least five medical gases and their respective application in healthcare. ***
13. What is the main clinical purpose of Heart Lung machine?

Remark: do all except the question with “****”, “***”and “**” mark. They are selective Questions.

That is: select one of the same “*”mark then ignore the other. The total Question should be 10.

God Bless You