The manufacture, storage and supply of medical gases

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Ⓟ Peer reviewed © Medpharm **S Afr Fam Pract 2013;55(3)(Suppl 1):S40-S43**

Introduction

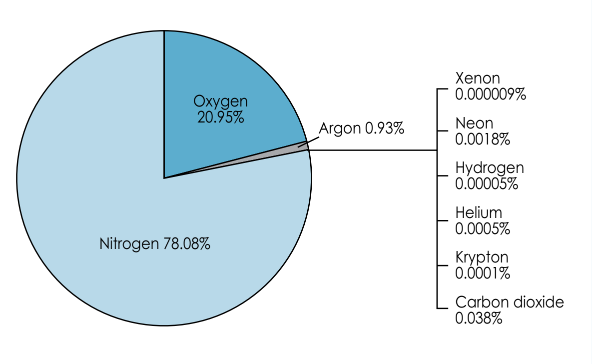


Figure 1: Composition of room air

Oxygen

Manufacture of oxygen

Various methods of producing oxygen exist,[1] including air separation, chemical and electrolysis. Both clinically relevant methods involve separating oxygen from air.[1-3]

Fractional distillation of air by cryogenic air separation

Fractional distillation of air by cryogenic air separation[1,2,4,5] is the bulk production of liquid oxygen, which can be transported cold and pressurised as a liquid by truck to sites which store it in a vacuum-insulated evaporator (VIE), or the liquid oxygen can be heated to a gas and bottled in cylinders.

Air is fed into the air separation unit. First, the air is filtered for dust and water. Then, it is compressed to 650 kPa (6.5 atm) and cooled to -181°C using a reverse heat exchanger.

The critical temperature of oxygen is -118°C. The boiling point at 1 atm is -183°C. The boiling point of nitrogen at 1 atm is -195°C. As the compressed air is cooled, the oxygen liquefies first and separates out of the gaseous air. Argon has a similar boiling point to that of oxygen (-185.7°C). A significant amount of argon liquefies with the oxygen, leaving the nitrogen alone in the gaseous phase.

This crude liquid oxygen and argon mixture is drained, decompressed to near atmospheric pressure, and passed through a second, low-pressure distillation column in order to separate. The final purified liquid product is 99.5% oxygen and 0.4% argon.

Oxygen concentrators

Smaller volumes of oxygen of lower concentrations (up to a maximum of 95%) are produced on site using portable electric-driven concentrating units.

Air is separated at ambient temperature. Units are used for home or remote field use. Oxygen concentrators[1,3] require a constant electricity supply in order to operate. Apart from a small reservoir in the circuit, there is no way in which to store the produced oxygen, so a cylinder back-up is necessary to cover electricity or machine failure.

There are two methods for this:

- *Membrane filter:* Air is pumped across a hole-free plastic membrane. It delivers 30-40% oxygen, regardless of flow rate. It is not a widely used method.
- *Molecular sieve:* This produces an output of 95% oxygen at five litres per minute. Air is entrained, filtered and pressurised to 20 psi. The air is then introduced into one of two parallel zeolite-containing canisters. Zeolite is a hydrated, porous aluminosilicate mineral that is found in volcanic rock, which selectively absorbs nitrogen. After approximately 20 seconds, the supply of compressed air is diverted to the second canister.

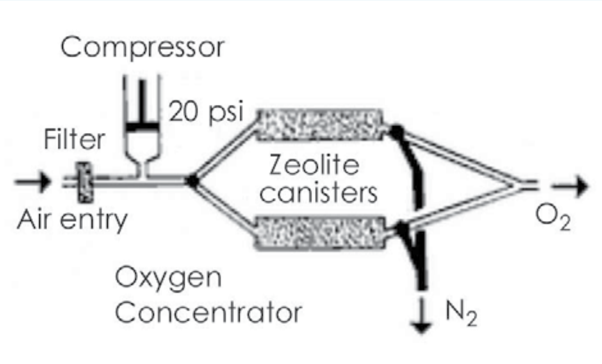


Figure 2: Oxygen concentrator

The pressure in the first canister is reduced to zero, allowing the nitrogen to be released from the zeolite and vented. This regenerated zeolite is then ready for the next cycle, 20 seconds later. By alternating canisters, a continuous oxygen supply is ensured.

Storage of oxygen

Oxygen can either be stored in cylinders, a vacuum-insulated evaporator or a manifold cylinder bank.

Cylinders

Most oxygen storage cylinders[1,2,5] are made of steel. Aluminium is used for MRI suite cylinders. They have a black body and white shoulders. A pin index system is utilised. The pins are placed at positions 2 and 5. The gauge pressure indicates how much gas is present. (It is assumed that O_2 behaves as a perfect gas at room temperature).

Boyles's law, ($P_1V_1 = P_2V_2$) can be used to calculate how much O_2 remains in the cylinder. The calculated volume in the cylinder, divided by the flow rate used, will determine how long the cylinder will last.

At the standard temperature and pressure (STP), the full cylinder has a pressure of 13 700 kPa.

New cylinders should be "cracked" slowly and carefully to avoid adiabatic heating of the cylinder gauge which could ignite any existing oil or grease.

Vacuum-insulated evaporator (VIE)

A VIE is basically a huge thermos flask that is used to store liquid oxygen on site (See Figure 3).[1,2,5,6] It is used at large hospitals which require oxygen at > 300 l per second or > 7 000 000 l annually.

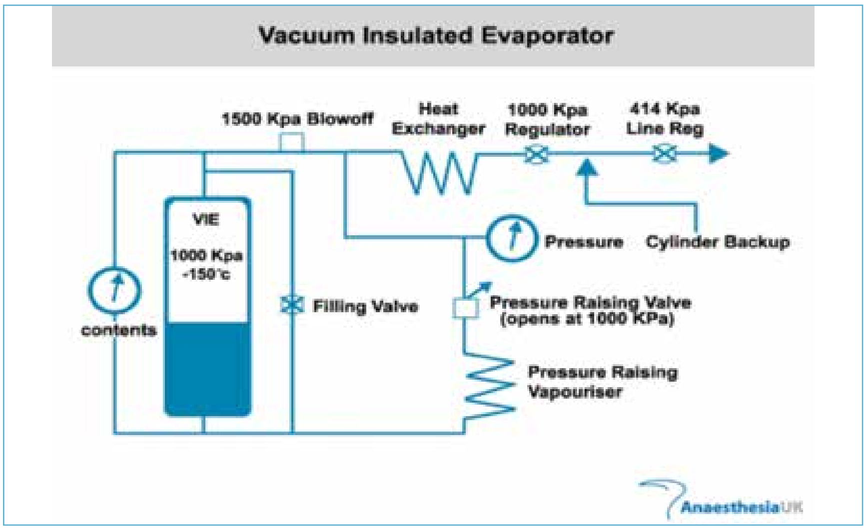
One litre of liquid oxygen is equivalent to 840 l of gaseous oxygen.

The inner shell is made of stainless steel, and the outer shell of carbon steel. An insulating vacuum gap of 0.16-0.3 kPa is maintained between the two steel shells. The contents of the VIE are kept at approximately 1 000 kPa and -150°C. The VIE is weighed to ascertain how much it contains. As the oxygen vapour is drawn off from the VIE for use, it is warmed to ambient temperature through a heat exchanger. The pressure is reduced to 410 kPa through a regulator, before joining the hospital pipeline.

The vacuum insulation is not perfect, so the ambient temperature, as well as the amount of oxygen being used, can influence the pressure in the VIE.

In very hot weather, the temperature of liquid O_2 in the VIE will increase. This causes pressure in the VIE to increase. A blow-off valve will open at 1500 kPa to allow vaporisation to the environment. Heat that is lost from the latent heat vaporisation of evaporating O_2 causes the liquid O_2 temperature to drop.

In very cold weather, the liquid oxygen temperature drops, as well as the pressure in the VIE. The pressure-raising valve opens at 1 000 kPa and allows liquid oxygen to shunt through a pressure-raising vapouriser. This allows environmental heat to enter the system and warm the liquid oxygen, causing the temperature and the pressure in the VIE to rise, until it is back to normal.



Reg: regulator, VIE: vacuum- insulated evaporator

Figure 3: Vacuum-insulated evaporator

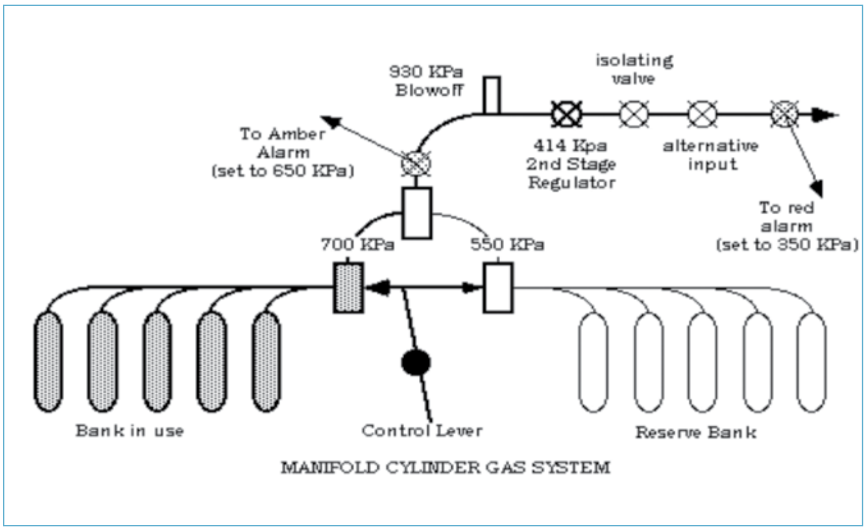


Figure 4: Manifold cylinder gas system

Manifold cylinder gas system (bank)

A manifold cylinder gas system[1,2,5] has two banks of at least 10-G-size (46.5-kg/7 600-l) cylinders, connecting five cylinders on each side by a manifold of piping. This system is used in smaller hospitals which do not have a VIE, or as a backup for the period during which a VIE is being filled at a larger hospital. One bank is used at a time.

The outlet regulator of the bank in use is set at 700 kPa. The outlet regulator of the second bank is set at 550 kPa to prevent it from being used. As the oxygen leaves the bank, it passes an overpressure safety valve which is set at 930 kPa. Then it passes a regulator which decreases the pressure to 410 kPa, before it joins the hospital pipeline. As the oxygen is used, the pressure in the bank begins to drop. When the pressure drops to 650 kPa in the outlet path, an amber warning light is activated in the hospital monitoring station. As soon as the pressure drops below 550 kPa, the second bank automatically begins to supply oxygen to the pipeline. The gas supplier should be notified immediately when the amber light comes on to ensure that the empty bank is filled before the second bank opens automatically. This should prevent both banks running empty. Should the pipeline pressure fall below 350 kPa, a red supply failure alarm will be activated.

Supply of oxygen

Oxygen is supplied either via pipeline or cylinders.

Pipeline

The pipeline[1,2] for the supply of oxygen extends from the VIE and manifold cylinders via degreased, sealed and steam-cleaned copper piping to the theatres and other wall outlets. The pipe diameter must be sufficient to prevent a pressure drop across the system. Pipe outlets are specific for each gas. Each theatre or gas delivery area is fitted with its own set of isolation valves which can be shut off to the area in the event of a fire.

A gas status or alarm panel is required in the recovery room, as well as in the gas supply office or switchboard office. A green light indicates normal operating pressure, amber denotes "on-reserve" but still a normal pipeline pressure, and red signifies a failure with the pipeline pressure < 350 kPa.

A pipeline pressure gauge for all the gases must be present on all the anaesthetic machines in theatre as well. New pipeline installations must be checked twice before the theatre may be opened for use: once by the engineer and then by the engineer and a medical officer together. When a white cloth is held over the end of the pipe, it must remain clean on purging. There should be no smell at all. Pressure loss over a 24-hour period must be zero. The correct gas composition must be confirmed using an oxygen analyser.

Cylinder

The cylinder[1,2] is mounted directly onto the anaesthetic machine. A pin index system has been designed to prevent the cylinders from being connected incorrectly. This may be circumvented by force, removing the pins or adding washers. The used gas should always be verified by checking the oxygen analyser on the anaesthetic machine.

Nitrous oxide

Manufacture of nitrous oxide

When manufacturing nitrous oxide,[1,2,5,7] ammonium nitrate (NH_4NO_3) is heated to 250°C (NH_4NO_3 + heat → N_20 + 2 H_20). In addition, a number of toxic higher oxides of nitrogen byproducts are formed, including NH_3, N_2, NO, NO_2 and HNO_3.

As the gas mixture cools, the ammonia and nitric acid reform ammonium nitrate, which is recycled. The remaining gas mixture is passed through a caustic soda "scrubber" to remove the remaining toxic higher oxides of nitrogen. Then the gas is chemically dried to have < 45 ppm of water. (This is to prevent the regulators from freezing). Finally, the N_2O is cooled and compressed to a liquid at 4 400 kPa, which is stored in cylinders.

Storage of nitrous oxide

Nitrous oxide is stored in cylinders.[1,2,6,7]

The storage cylinders are made of steel and are painted a blue colour. The pin index system is utilised, with the pins at positions 3 and 5. The gauge pressure reflects the pressure of vapour that is present above the liquid phase. The cylinder must be weighed to determine how much liquid nitrous oxide remains.

The cylinders are filled to approximately two thirds of their capacity, so that should the ambient temperature reach 65°C, the pressure in the cylinder will only reach 85% of the cylinder's maximum pressure rating. The filling ratio is the weight of the fluid in the cylinder, divided by the weight of water required to fill the cylinder completely. In hotter countries, like Australia and South Africa, a ratio of 0.67 would be used, and that of 0.75 in colder countries, such as the UK.

A manifold cylinder bank is used by most hospitals to store N_2O for pipeline delivery.

Supply of nitrous oxide

Nitrous oxide is supplied either via pipeline or cylinders.

Pipeline

Copper piping from the manifolded bank of cylinders is used.

Cylinders

Cylinders are mounted directly onto the anaesthetic machine.

Air

Manufacture of air

Two methods are used to manufacture air.

> *Compression of atmospheric air:*[1,2,5] When atmospheric air is compressed, air is entrained, filtered for dust and oil, dried and compressed. Then it is cooled and bottled in cylinders. Most medium to large clinics and hospitals have their own compressor on site. The air that is produced is clean and dry, but not sterile. The air inlet must be situated as far as possible from any potential contaminating source, like a car park, chimneys, a dusty area or any other airborne pollutants. The compressed air, for medical tools like saws and drills, is produced in the same manner, but is delivered at 700 kPa, and contains oil as a lubricant.
>
> *Blending of oxygen and nitrogen:*[5] One hundred per cent pure, sterile, medical-grade air is produced by blending oxygen and nitrogen. This is an expensive process. This air is usually reserved for experimental laboratory use.

Storage of air

The cylinders[1,2] that are used to store air are made of steel. The body of the cylinders is painted black and the shoulders are black and white. A pin index system is utlilised, with pins at positions 1 and 5. The gauge pressure indicates how much gas is present. A full cylinder at STP has a pressure of 13 700 kPa.

Supply of air[1,2]

Small sites may have a manifolded cylinder bank within which to store air.

Most sites, even relatively small ones, find it more cost-effective to own their own compressor which delivers air directly to the air pipeline at 410 kPa. With such a direct system, air is not stored on site, and relies on a constant electricity supply in order to remain available.

Carbon dioxide

Manufacture of carbon dioxide

Carbon dioxide[1,2] is a byproduct of manufacturing processes and fossil fuel burning. Gaseous CO_2 is collected, filtered, dried, compressed and liquefied. It is then stored as a liquid in cylinders.

Storage of carbon dioxide

The cylinders used to store carbon dioxide are made of steel, which are green in colour, but grey and white in other countries. The pin index system is utlised, with pins in positions 1 and 6. The gauge pressure reflects the pressure of the vapour that is present above the liquid phase. The cylinder must be weighed to determine how much liquid carbon dioxide remains.

The cylinders are filled to approximately two thirds of their capacity, so that should the ambient temperature reach 65°C, the pressure in the cylinder will only reach 85% of the cylinder's maximum pressure rating.

Supply of carbon dioxide

Used in cylinder form connected directly to laparoscopic surgical equipment.

Antiquated anaesthetic machines contained a yoke for cylinders, but these are no longer available.

Entonox

Manufacture of entonox

Entonox[2] is a blend of oxygen and nitrous oxide.

Storage of entonox

Entonox is stored in cylinders that are made of steel. They have a white body with a blue and white shoulder. A pin index system is utilised, with one single central pin.

Supply of entonox

Entonox is mostly used in dental practices that have a self-administration circuit.

Vacuum[5]

A high-volume,low-pressure system. Forty litres per minute, per wall outlet volume, at a pressure of -50 kPa. The total number of litres per minute for the entire installation depends on the size of the hospital. (If there are more than nine theatres, the engineers start to decrease the number of wall units that they expect to be open at the same time).

References

1. Shung J. Medical gas manufacture and storage. FCA 1 Refresher course; 2010.
2. Thompson C. The anaesthetic machine: gas supplies [homepage on the Internet]. 2012. Available from: http://www.anaesthesia.med.usyd.edu.au/resources/lectures/gas_supplies_clt/gas_supplies.htm
3. Eltringham R. The oxygen concentrator. NDA [homepage on the Internet]. 1992. Available from: http://www.nda.ox.ac.uk/wfsa/html/u01/u01_009.htm
4. Overview of cryogenic air separation and liquefier systems [homepage on the Internet]. Available from: http://www.uigi.com/cryodist/html
5. Morgan GE, Mikhail MS. The operating room: medical gas systems, environmental factors and electrical safety. Clin Anaesth. 1-6
6. Storage of oxygen: the VIE. Anaesthesia UK [homepage on the Internet]. Available from: http://www.frca.co.uk/printfriendly.aspx?articleid=100342
7. History of nitrous oxide. Anaesthesia UK [homepage on the Internet]. Available from: http://www.frca.co.uk/printfriendly.aspx?articleid=100358