Principles of Anesthesia Equipment

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The memory of Professor Phaneendra Nath Thota, a teacher par excellence.
His inspiration helped us to embark on this project.

Yasodananda K Areti
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Foreword

For a long time, there was a felt need for a comprehensive book on anesthesia equipment in our continent, written by Indian authors. This is because the standards differ in different countries. Most books on equipment are based on American standards as there are stringent rules prescribed by ASTM (American Society for Testing and Materials, International) to be followed. Moreover, nomenclature differs from one country to another that raises lot of doubts in the minds of residents. This book has been written predominantly by authors of Indian origin who felt the need for such a book.

The chapters in the book have been logically organized for a better understanding of the subject. Special effort has been taken by the authors to detail the illustrations. The diagram and pictures are laid out to make understanding better. Though it is impossible to cover extensively all the equipment used in anesthesiology, basic principles involved in the design of these equipment are well covered. Most chapters in the book are written by Dr Yasodananda K Areti, whose interest in anesthesia equipment and vision to share the expertise for the benefit of a budding anesthesiologist has resulted in the compilation of this book.

There is a good mix of young as well as experienced anesthesiologists' contribution to the book. It is written in a simple language that makes the reading a pleasure. The chapter on preuse check of anesthesia equipment sticks to one practice guideline and clear. The chapter on sterilization is very informative. The chapters on monitoring, neuraxial blocks and simulation are well illustrated and written.

On the whole, the book is a treasure for anesthesiology residents to learn the basics of the equipment used in anesthesia. I hope the book will have acceptance from all quarters.

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Foreword

This book is a treasure trove of facts and detailed information about how things work in anesthesia and the physics, mathematics, and engineering that serve as their basis. Clear, and straightforward figures drawn to show basic principles provide great clarity. Simple language effectively teaches both simple and complex concepts. Nomenclature is different in different countries and this book explains their relationships. Adding to Dr Yasodananda K Areti's teaching in developing countries, Dr Bhavani Shankar Kodali's teaching ventilation monitoring (www.capnography.org; www.capnography.com) based in a well-developed country (USA) for twenty years brings out the latest anesthesia advances.

As I read the book, I found the following to be most striking:

- Chapter 1 on Applied Physics, the relationship of measurement units used in various parts of the world is clearly explained.
- Chapter 3 on Anesthesia Machine or Workstation describes technological progression from the oldest to the newest technical advances and functionalities by major machine manufacturers including End-Tidal Control of anesthetic agent on GE Aisys, Draeger Zeus and Maquet FLOW-i in many countries.
- Chapter 5 on Anesthesia Ventilators clearly diagrams and describes modern ventilator capabilities.
- Chapter 7 on Monitoring Technology beautifully describes and diagrams the numerous technologies available.
- Chapter 9 on Electrical Safety and Devices succinctly and clearly teaches the basic electronics needed by anesthetists in any country.

This book has great value for anesthetists in all parts of the world. It conveys understanding to those who use the oldest and those who use the newest of the many technologies described.

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Preface

"Learning gives creativity, Creativity leads to thinking, Thinking provides knowledge, Knowledge makes you great."

—*APJ Abdul Kalam*

Applied physics, equipment and clinical monitoring form a major portion of the curriculum for postgraduate students. These topics cover nearly 25% of examination topics. They are quite complicated, and the concepts are difficult to understand for many postgraduate students. We are always challenged with the question as to how much applied physics any anesthesiologist must know. We always opine that if one is armed with knowledge, it will never be regretted. If learning was to be limited, the technological developments in the last five decades would never have been witnessed. Consequently, our specialty and our patients would have been exposed to obsolete technology.

Our aim in producing this postgraduate review is to bring all the essential aspects of applied physics for anesthesiologists into one book and make it simple to understand. One must be able to use equipment safely without placing their patient at risk because of lack of understanding of basic principles. In addition, one must be able to monitor their patients without errors.

We would like to thank all the people who contributed to the preparation of this book, particularly Professor Seetharaman, for his constant assistance. We hope that this venture will be successful in making anesthesiologists acquire the basic knowledge regarding anesthetic equipment.

Yasodananda K Areti MD
Bhavani Shankar Kodali MD

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We would also like to thank Mr Jitendar P Vij (Group Chairman), Mr Ankit Vij (Group President), Ms Chetna Malhotra Vohra (Associate Director), Mr Umar Rashid (Development Editor), Ms Geetanjali Singh (Deputy Manager–Production) and Production team of Jaypee Brothers Medical Publishers (P) Ltd., New Delhi, India.

Contents

CHAPTER 2

Medical Gas Supply, Vacuum, and Scavenging

Yasodananda K Areti

"If anything can go wrong, it will"

INTRODUCTION

Though infrequent several accidents and mishaps have been reported during the use of medical gases. Every precaution possible must be taken to ensure that such accidents do not occur, and adequate backup measures must be drilled into the system in the event of such mishaps.

In US, Department of Transportation (DOT) published requirements for manufacturing, marking, labeling, filling, transportation, storage, handling, and maintenance of medical gas cylinders and containers. The Department of Labor (DOL) and the Occupational Safety and Health Administration (OSHA) regulate matters affecting safety and health of employees in all industries. The National Fire Protection Association (NFPA), the Compressed Gas Association (CGA), Canadian Standards Association (CSA), and the International Standards Organization (ISO) have published a number of standards, and many regulatory agencies have made adherence to these standards mandatory. The handling of compressed gases in India is governed by Gas Cylinder Rules (amended in 2010), and Bureau of Indian Standards.

Medical grade gas is supplied to the operating room via two delivery mechanisms, *central supply* and *portable cylinders*. Most anesthetizing locations will have access to a central supply of the three most commonly used medical gases: oxygen, nitrous oxide and air. These and all other gases may also be supplied via gas cylinders, most commonly the "E" type cylinder, mounted on the anesthesia machine. A waste anesthetic gas (WAG) scavenging system and a medical suction system for surgical and anesthetic use are also provided centrally.

MEDICAL GASES AND SUPPLY

Oxygen

Medical grade oxygen (99% pure or greater) is a necessity in any operating room. Oxygen is synthesized commercially by first liquefying compressed air (Joule-Kelvin Effect). The boiling points of oxygen (90.2°K) and nitrogen (77.4°K) are different. Hence, oxygen is separated from liquid air by using fractional distillation. Nitrogen evaporates first leaving liquid oxygen (LOX), which is then evaporated. Oxygen is dried and purified and is supplied as compressed gas in cylinders at ambient temperature. As compressed gases are released to flow meters through cylinder valves, the temperature of gas falls due to adiabatic expansion. This phenomenon can potentially lead to formation of ice crystals if any moisture is left in the gases, leading to interruption of gas flow. Hence, drying the gases before filling cylinders is important.

Medical oxygen is stored as compressed gas in banks of large cylinders (H-type), or LOX bank. A hospital should have at least a 2-day supply of oxygen on-hand, and a backup of at least 1-day supply. Consequently, the system chosen and its capacity will depend on the oxygen demands of the hospital. Even at peak use, the pressure across the network should not result in a larger drop in pressure of more than 5 psig from the source to the outlet.

Liquid Oxygen

Oxygen can be supplied in cryogenic containers containing LOX (Fig. 2.1). LOX, though stored as liquid, is used primarily as a gas. It is less bulky and less costly than the

Fig. 2.1: Liquid Oxygen plant (Linde CryoPlants Ltd.).
Source: https://en.wikipedia.org/wiki/Cryogenic_oxygen_plant

Table 2.1: Physical properties of oxygen.

- Boiling point @ 1 atmosphere: – 183.0°C (90°K)
- Critical temperature: – 118.4°C
- Critical pressure: 729.1 psia (49.6 atm)
- Expansion ratio, liquid to gas, boiling point to 20°C: 1 to 860.

equivalent capacity of high-pressure gaseous storage. One liter of LOX expands to 860 L of gas at 20°C. The physical properties of oxygen, which govern the storage and delivery of LOX, are shown in Table 2.1.

Because the temperature difference between the product and the surrounding environment is substantial (the temperature of LOX has to be maintained below its critical temperature of – 118°C), even in the winter, keeping LOX insulated from the surrounding heat is essential. The product also requires special equipment for handling and storage to prevent cold burns for the workers. A typical storage system consists of:

- A cryogenic storage tank
- One or more vaporizers
- A pressure control and pressure relief system, and
- Piping necessary for the fill, vaporization, and supply functions (Fig. 2.2).

The cryogenic tank is constructed, in principle, like a thermos bottle. There is an inner vessel surrounded by an outer vessel. Between the vessels is an annular space that contains an insulating medium, from which all the air has been removed. This space keeps heat away from the LOX held in the inner vessel.

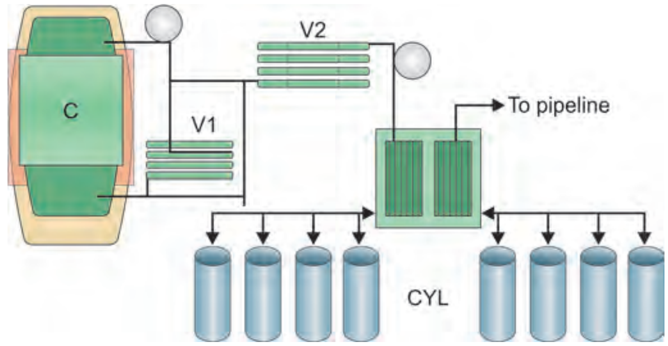


Fig. 2.2: Medical gas supply to pipeline. (C: Cryogenic container; V1 and V2: Vaporizer; CYL: Cylinder bank).

The liquid oxygen is converted into a gaseous state in the vaporizers. A pressure control manifold then controls the gas pressure that is fed to the pipelines. A backup system may comprise of another smaller-sized LOX container or manifold of oxygen cylinders. The backup system should have a separate feedline to the pipeline network to lessen the risk of interrupted supply.

Oxygen Concentrator

Oxygen concentrators are devices, which can be used as a primary source of oxygen in remote locations to feed pipelines. Oxygen is generated onsite using pressure swing adsorber technology. Oxygen in the atmospheric air is concentrated by adsorption of nitrogen by a molecular sieve (zeolite). Oxygen produced by this method has a concentration of only 93% ± 3%. Pressurized air passes through a bed of zeolite contained usually in two containers. As one container adsorbs nitrogen, the other is purged of adsorbed nitrogen and the zeolite is regenerated. The adsorbent has a high affinity for water. Hence, design should include adequate purges, low dead space and heat exchangers. The beds should be sealed so that atmospheric moisture cannot seep into the zeolite. The output concentration of oxygen should be monitored carefully to ensure delivery of adequate oxygen to the pipelines. The size of the adsorption beds determines the output. They must always have a pressurized reservoir that is large enough to cope with peak flows. Portable oxygen concentrators are also available and are quite popular for home oxygen therapy.

Nitrous Oxide

Nitrous oxide is often provided for use as an anesthetic gas. Nitrous oxide is synthesized commercially by heating ammonium nitrate and stored as a liquid at room temperature because the critical temperature of this gas is 36.5°C. Nitrous oxide is usually stored in two banks of large H-cylinders, which are cross-connected via an autoswitching manifold using two-stage pressure regulator (similar to that of oxygen banks). The banks usually have smaller number of cylinders compared with oxygen supply because of the higher content of liquefied gas and lower consumption of nitrous oxide. As nitrous oxide becomes vaporized from a liquid to a gas, heat will be absorbed from the surrounding. This can lead to the formation of frost on the outside of a gas cylinder.

Medical Air

Air is the natural atmosphere of the earth, a nonflammable, colorless, odorless gas that consists of a mixture of gaseous elements (nitrogen, oxygen, water vapor, a small amount of carbon dioxide and traces of many other constituents). Medical air can be provided from a manifold of cylinders or from a central compressor plant. Usually, two compressors are used, which can run alternately or concurrently depending on the demand. This also ensures that during servicing or repairing, the supply is not interrupted. Air from the intake to the compressors is drawn through a filter and silencer. There usually is an air cooler to cool the compressed air. The air then passes through a non-return valve into a large reservoir to maintain a constant air pressure. After leaving the reservoir, the air is cleaned by passing it through baffled separators and filters to remove particulate impurities like oil droplets. The air is then passed through two driers containing a desiccant to remove any excess humidity. Finally, the air is passed through a bacterial filter to ensure removal of any contaminants.

MEDICAL GAS CYLINDERS

Medical gases are stored in metal-alloy cylinders of varying sizes. Tables 2.2 and 2.3 indicate the color codes, state in cylinders, and service pressure for different medical

Table 2.2: Medical gas cylinders.

Gas	*Formula*	*Color (US)*	*Color (international)*	*PSI at 21°C*	*State in cylinder*	*E-cylinder capacity (L)*
Oxygen	O_2	Green	White shoulder and black body	1900–2200	Gas	660
Carbon dioxide	CO_2	Gray	Gray	838	Gas and liquid < 31°C	1590
Nitrous oxide	N_2O	Blue	Blue	745	Gas and liquid < 37°C	1600
Helium	He	Brown	Brown	1600–2000	Gas	500
Nitrogen	N_2	Black	Black	1800–2200	Gas	660
Air		Yellow	White and black shoulder	1800	Gas	600

Table 2.3: Size and capacities of various gases in commonly used cylinders.

		Oxygen		*Nitrous oxide*		*Carbon dioxide*	
Type	*Dimensions (mm)*	*Water capacity*	*Gas content*†	*Tare weight*	*Gas content*†	*Tare weight*	*Gas content*†
C	430 × 89	1.2 L	170 L	2.0 kg	450 L	2.0 kg	450 L
D	535 × 102	2.32 L	340 L	3.4 kg	900 L		
E	865 × 102	4.7 L	680 L	5.4 kg	1800 L	5.4 kg	1800 L
F	930 × 140	9.43 L	1360 L	14.5 kg	3600 L		
G/M*	1320 × 178	23.6 L	3400 L	34.5 kg	9000 L		
J/H*	1520 × 229	47.2 L	6800 L	68.9 kg	18000 L		

(*: Alternate nomenclature. The valves may be different, and the contents are slightly different; †:Gas content when full).

gases. Cylinders are made of aluminum or steel alloys. The parts of cylinder are body, shoulder, neck and head (valve). Each cylinder is tested by visual inspection and with hydraulic stretch test to assess its integrity when subjected to test pressures 1.66 times the service pressure. Each cylinder should be permanently stamped on the shoulder to indicate the contents, the service pressure, serial number, manufacturer's symbol, owner's symbol and the test date (original test date and retest date) and the mark of the testing facility.

Filling the Cylinder

The pressure inside a cylinder may vary with ambient temperature. In order to prevent build-up of excessive pressure, a cylinder should not be filled above the service pressure stamped on the cylinder for compressed gases. The filling limit on the cylinders containing liquefied gases is based on the filling ratio or filling density, which is the percent ratio of weight of a gas in cylinder to the weight of water the cylinder would hold at 60°F. The filling density of nitrous oxide and carbon dioxide is 68%.

Safety Pressure Release

Every cylinder is fitted with a safety pressure release device to vent the contents into atmosphere if inside pressure increases to a dangerous level. There are several relief valve models used for this purpose:

- The venting orifice is closed with a disk that ruptures at a given pressure.
- A fusible plug (woods metal), which melts at high temperatures
- A spring-loaded pressure relief valve.

In "pin-indexed" valves, this device is present just below the conical depression for the screw clamp and hence care should be taken to prevent any inadvertent damage while mounting the cylinder on the anesthesia machine.

Devices to Open or Close a Cylinder

Large cylinders are fitted with "hand-wheel" to open or close the valves. Small cylinders come with a spindle valve and the spindle can be opened or closed with a wrench or a handle. This wrench is usually fixed to the anesthesia machine to prevent misplacement. While using these wrenches, one must be careful not to handle the hexagonal gland nut that fixes the spindle valve to the cylinder.

Contents of a Cylinder

The contents of a cylinder containing compressed gases like oxygen can be calculated by using Boyle's law; using the pressure inside the cylinder and the water capacity of the cylinder.

$$P1 \times V1 = P2 \times V2;\ V1 - \frac{P2 \times V2}{P1}$$

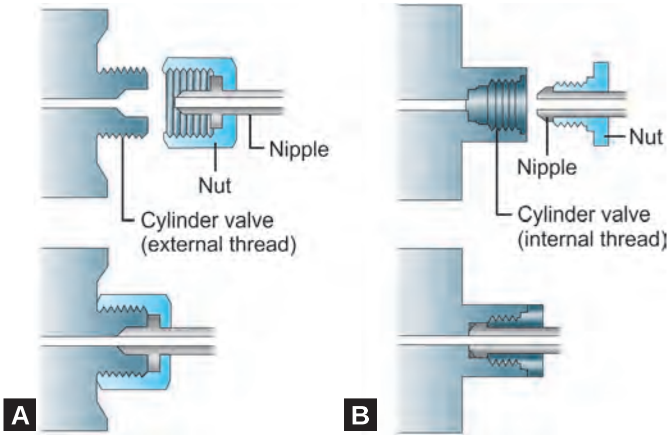
(P1: Atmospheric Pressure; V1: Volume of oxygen available at atmospheric pressure; P2: Pressure in the cylinder; V2: Water capacity of the cylinder or volume of oxygen in compressed state)

In Type "E" cylinder with a water capacity of 4.7 liters, if the pressure gauge reads 100 atmospheres (1470 psig) then approximate amount of oxygen available (V1) to be used at 1 atmosphere will be:

$$V1 = \frac{100 \times 4.7}{1} = 470\text{ L} \text{ or } V1 = \frac{1470 \times 4.7}{14.7} = 470\text{ L}$$

For all practical purposes, if one learns to read the pressure in the cylinder in atmospheric pressures (the number labeled as kPa × 100), then multiplying this with 4.7 (or even with 5 for approximate values) will give an estimate of the contents of type "E" cylinder for compressed gases. Similarly, the water capacity of type "H" bulk cylinder is 47.2 liters. If cylinder pressure reads 100 atmospheres then each cylinder would contain 4720 L.

The contents of a cylinder containing liquefied gases (nitrous oxide and carbon dioxide) cannot be estimated by measuring the pressure inside the cylinder, since the pressure remains nearly constant till all the liquid is evaporated. However, they can be estimated using Avogadro's principle. Molecular weight of nitrous oxide and carbon dioxide is same and is 44. As per Avogadro's hypothesis, 44 grams would occupy a volume of 24 liters at room temperature and pressure (RTP) (20°C, 1 atm; corrected for temperature as per Charles' law). Hence, a liter of nitrous oxide weighs about 1.8 g. The actual weight of the gas in the cylinder should be estimated by the difference between the actual weight and the tare weight of the cylinder. This weight in grams divided with 1.8 (one may use 2 for approximation and ease of calculation) would give us an estimate of the contents of the cylinder. This aspect is particularly useful for the laparoscopic surgeons and their teams to have an idea of the contents of carbon dioxide cylinders prior to starting the surgery.



Figs. 2.3A and B: Valve outlet connections for large cylinders. The threads of the valve outlet must match with the threads on the nut. When the nut is tightened, the nipple seats against the valve outlet. (A) The threads are on the outside of the cylinder valve outlet and the nut screws over the valve outlet; (B) The valve outlet thread is internal so that the nut screws into the outlet.

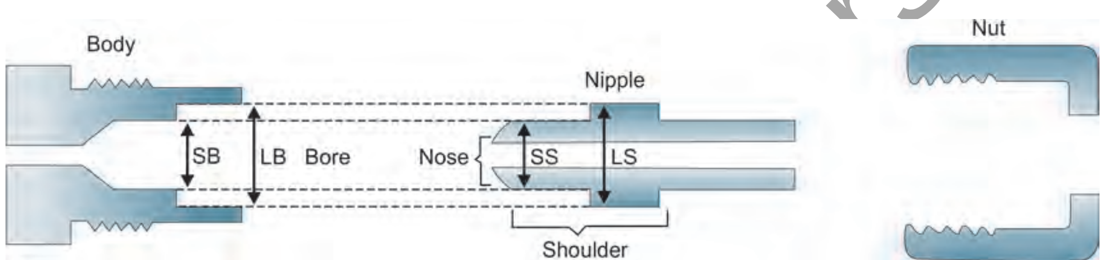


Fig. 2.4: Diameter index safety system. (SB: Small bore; LB: Large bore; SS: Small shoulder; LS: Large shoulder).
Source: Dorsch JA, Dorsch SE. Understanding Anesthesia Equipment, 5th edition. Philadelphia: Lippincot Williams & Wilkins; 2008.

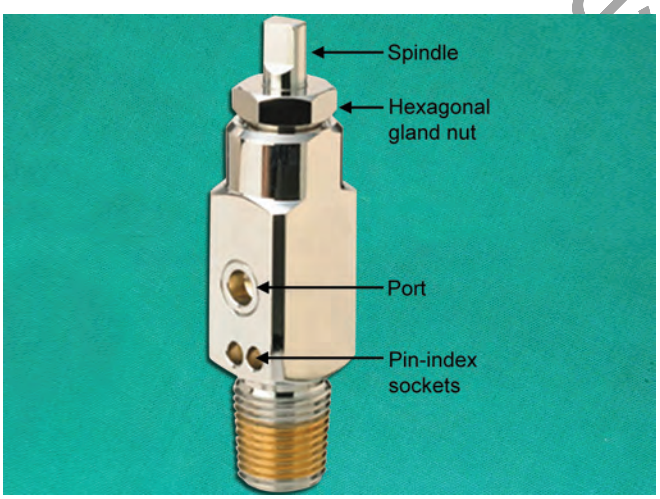


Fig. 2.5: Parts of spindle valve.

Valves

The bulk cylinders supplying the pipelines are fitted with bullnose valves with noninterchangeable screw thread system. In order to prevent use of wrong gas the threads on the cylinder should match the threads on the nut. These threads can be either outside or inside the cylinder outlet (Figs. 2.3A and B). This is different from diameter index safety system (DISS) discussed below (Fig. 2.4). The Type "E" or other type cylinders that fit as backup on anesthesia machine are fitted with pin indexed, spindle valve (Figs. 2.5 and 2.6).

MANIFOLD AND PIPELINE NETWORK

Normally, the main gas supply to the anesthesia machine is the hospital pipeline system, delivered at approximately 50–55 pounds per square inch gauge. The oxygen supply to the pipeline supply may be from one of the following sources:

- Primary LOX tank with smaller secondary LOX tank as a backup
- Primary LOX tank with a manifold of compressed gas cylinders as backup
- Two banks of compressed gas cylinders with a backup of smaller bank of compressed gas cylinders.

The high-pressure source is connected to the pipeline through a two-stage pressure regulator. Where a manifold of cylinders is used, only one of the two banks supplies

Fig. 2.6: Pin index safety system for different gases. Two pins in the hanger yoke of anesthesia machine are aligned with two corresponding holes on the cylinder head in order to prevent mounting of a wrong cylinder. Exception being entonox which has one pin on yoke and corresponding hole on cylinder.

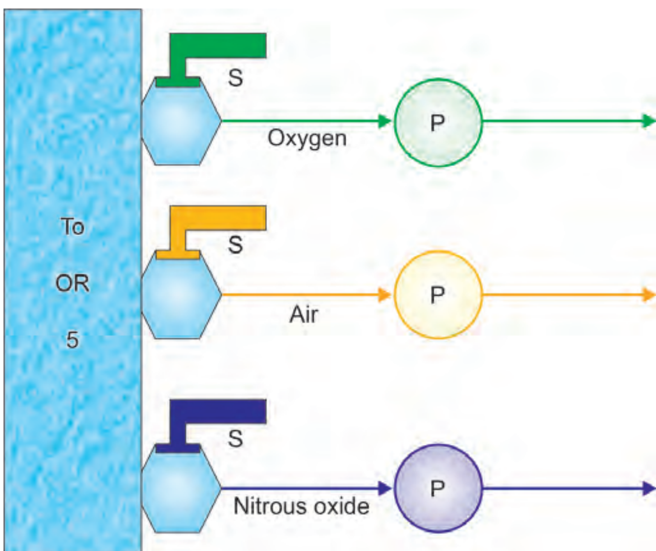


Fig. 2.7: Pipeline shut off system.

Fig. 2.8: Quick coupler on the left. Diameter index safety system connectors on right.
Courtesy: Prof M Ravishankar, modified by Mr Muralidhar Areti.

the pipeline at any time. When this bank reaches exhaustion, the second bank automatically kicks in. The status of the banks is indicated by visual indicators at the source as well as at a manned control station to enable a prompt change of empty cylinders.

The supply and the manifolds are usually located outside the hospital or free ventilated area. From the manifold, the gases are carried to various points of care through network of pipelines. The pipelines are made of copper. These pipelines should be clearly marked with the label of the gas, color coding, and the direction of gas flow. The pipeline network consists of main pipes, risers (to transport gases from floor to floor) and branches (transport across the floor) to individual areas of the hospital. Each area should have pressure monitors and shut off valves to conduct repairs and maintenance without having to shut down the entire system (Fig. 2.7).

Outlets

The pipelines end in terminal wall outlets with color-coded plates. These outlets may be either noninterchangeable quick coupling outlets or DISS outlets.

Quick Connectors (Fig. 2.8)

Quick connectors (automatic quick couplers valves, quick connects, quick-connect fittings, quick couplers) allow apparatus (hoses, flow meters, etc.) to be connected or disconnected by a single action by using one or both hands without the use of tools or undue force. Quick connectors are more convenient than DISS fittings but tend to leak more. Each quick connector consists of a pair of gas-specific male and female components. A releasable spring mechanism locks the components together. Hoses and other equipment are prevented from being inserted into an incorrect outlet by using different shapes and/or different spacing of mating portions.

The Diameter Index Safety System

The DISS was developed to provide noninterchangeable connections for medical gas lines at pressures of 1380 kPa (200 psi) or less. Each DISS connector consists of a body, nipple, and nut combination (Figs. 2.4 and 2.8). There are two concentric and specific bores in the body and two concentric and specific shoulders on the nipple. The small bore (SB) mates with the small shoulder (SS), and the large bore (LB) mates with the large shoulder (LS). To achieve non-interchangeability between different connectors, the two diameters on each part vary in opposite directions so that as one diameter (LS and LB) increases, the other (SS and SB) decreases. These dimensions are unique for each gas and only properly mated parts will fit together and allow the threads to engage.

Safe Use of Cylinders

- The personnel handling the cylinders should be trained adequately.
- In order to prevent injury, gas cylinders must always be properly secured and stored in a cool environment that is protected from fire and open flame. They should not be subjected to temperatures above 54°C or below – 7°C.
- Care should be taken to ensure that cylinders are never dropped or rolled, since damage to a pressurized cylinder can lead to the creation of a fatal projectile.
- They should not be transfilled by the user.
- The cylinders should be kept closed and covered at all times except when they are in use.
- They should never be draped.
- They should be labeled full or empty and stored separately.
- A cylinder should always be opened slowly, in order to prevent rapid raise in temperature due to adiabatic expansion.

OTHER MEDICAL GASES OF INTEREST TO ANESTHESIOLOGIST

Entonox

Entonox is a mixture of 50% oxygen and 50% nitrous oxide, stored in cylinders at a pressure around 2,000 psig. Though the critical temperature of nitrous oxide is 36.5° C, in a mixture of gases such as entonox, nitrous oxide remains in gaseous phase. This is sometimes referred to as pseudo critical temperature, or poynting effect. However at a temperature below – 5.5° C, a liquid phase containing 20% oxygen and 80% nitrous oxide may form below the gas. In order to prevent delivery of hypoxic mixture it is recommended that Entonox cylinders be stored at temperatures above 10° C Entonox is used mostly for obstetric analgesia, and dental analgesia. It is also used for wound dressings and during transport of patients with long bone fractures without any other injuries. It is usually self-administered under supervision of medical or paramedical personnel through a two-stage pressure regulator and a demand valve.

Nitric Oxide

The role of inhaled nitric oxide (iNO) for clinical use has increased remarkably over the last decade. The discovery of iNO's role in pulmonary vascular tone led to a flood of research from basic science to large randomized clinical trials in patients of all ages, resulting in thousands of publications. In 1992, the journal Science named nitric oxide the "Molecule of the Year". Several researchers received a Nobel Prize in medicine and physiology for their work with nitric oxide in 1998. The only Food and Drug Administration-approved indication for iNO is for the treatment of term neonates with hypoxic respiratory failure associated with pulmonary hypertension as a means to improve oxygenation.

Nitric oxide is supplied as a gaseous blend of nitric oxide (800 ppm) and nitrogen. It is supplied in a non-liquefied form at a cylinder pressure of 2,000 psig at 21°C. Cylinders are constructed of an aluminum or steel alloy. It is administered into the ventilator breathing circuit through a monitoring unit (NOx Box, Nodomo unit, iNO-vent) which operates at 55–60 psig. The most commonly used initial dose is 5–20 ppm by inhalation. Monitoring the levels of inspired nitric oxide, nitrogen dioxide levels and methemoglobin levels is essential. Weaning should be achieved gradually in decrements of 5 ppm over 6–8 hours.

Heliox

Helium and oxygen mixtures (heliox) have been used for medicinal purposes since 1934. Heliox has been studied and reported to be effective in a variety of respiratory conditions, such as upper airway obstruction, status asthmaticus, decompression sickness, postextubation stridor, bronchiolitis, and acute respiratory distress syndrome. Helium, an inert gas, is odorless and tasteless, and it does not support combustion or react with biologic membranes. Helium is 86% less dense (0.179 g/L) than room air (1.293 g/L). It is seven times lighter than nitrogen, and eight times less dense than oxygen. The lower density of helium reduces the Reynolds number associated with flow through the airways.

Heliox converts areas of extreme turbulence and makes these areas less turbulent. Additionally, heliox converts some areas of turbulence to areas of more efficient laminar flow. Hence, heliox mixtures have the potential to decrease work of breathing in patients with increased airway resistance. However, heliox does not "treat" airway resistance. Heliox also increases the deposition of inhaled particles to the distal airways in patients with severe asthma.

Heliox is commercially available and supplied at the point of care as compressed medical gas cylinders in sizes H, G and E. Helium and oxygen typically are blended to percentage concentrations of 80/20, 70/30 and 60/40, respectively. Gas regulators manufactured specifically for helium must be used to deliver the gas safely and accurately. The mixture can be administered to the patient via either an endotracheal tube or face mask with reservoir bag.

Xenon

Xenon is a chemical element with symbol Xe and atomic number 54. It is a colorless, dense, odorless noble gas, inert gas that occurs in the Earth's atmosphere in trace amounts. Xenon has been used as a general anesthetic. Although it is expensive, anesthesia machines that can deliver xenon are about to appear on the European market, because advances in recovery and recycling of xenon have made it economically viable.

Xenon is a high-affinity glycine-site N-methyl D-aspartate (NMDA) receptor antagonist. However, it lacks neurotoxicity of ketamine and nitrous oxide. Xenon inhibits nicotinic acetylcholine alpha-4 beta-2 receptors which contribute to spinally mediated analgesia.

Xenon is a competitive inhibitor of the serotonin 5-HT3 receptor. This action reduces anesthesia-emergent nausea and vomiting.

Xenon gives rapid induction and recovery, due to its low blood/gas partition coefficient (0.15). Xenon has a minimum alveolar concentration of 72% at age 40, making it 44% more potent than N_2O as an anesthetic. Xenon is not a greenhouse gas and so it is also viewed as environmentally friendly. Xenon vented into the atmosphere is being returned to its original source, so no environmental impact is likely.

Xenon induces robust cardioprotection and neuroprotection. It was added as an ingredient of the ventilation mix for a newborn baby, whose life chances were otherwise much compromised.

VACUUM

A vacuum is a volume of space that is essentially empty of matter, such that its gaseous pressure is much less than atmospheric pressure (negative pressure). Vacuums are commonly used to produce suction. Suctioning is an important part of anesthesia practice to remove and/or collect solids, gases, and liquids from the patient, airway devices, and the patient's environment.

The most common source of vacuum in healthcare facilities is the pipeline system (Fig. 2.9). The system must be capable of maintaining a vacuum of approximately 40 kPa (300 mm Hg) at the user end (Fig. 2.10). The suctioning apparatus is connected to a wall inlet through a noninterchangeable coupler, similar to those used for medical gas pipelines. The pipelines are connected to a central vacuum source. These pipelines are constructed of copper and are slightly larger than the medical gas pipelines. Vacuum is created by two pumps connected in parallel. These pumps are essentially air compressors mounted in reverse to create vacuum. There is a reservoir between the pumps and the pipeline to even out the vacuum and collect any fluids or debris that may enter the system.

SCAVENGING SYSTEMS (FIGS. 2.11 AND 2.12)

The anesthetic gases and vapors that leak into the surrounding room during medical procedures are considered waste anesthetic gases (WAGs). It is estimated that more than 250,000 healthcare professionals in US, who work in hospitals, operating rooms, dental offices and veterinary clinics, are potentially exposed to WAGs. The relationship between exposure to trace concentrations of WAGs in the operating room and the possible development of adverse health effects has concerned healthcare professionals for

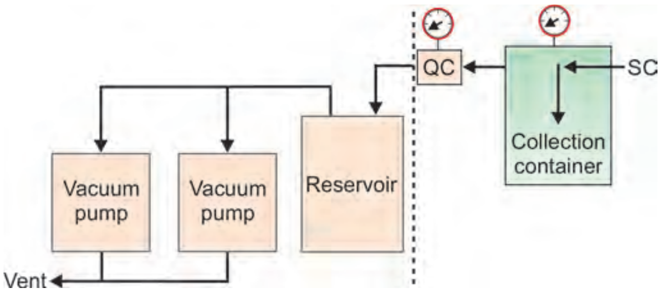


Fig. 2.9: Complete suction system. Normally, liquids and solids do not move any further than the collection container.
(SC: Suction catheter; QC: Quick coupler in operating room).

Fig. 2.10: Testing vacuum in operating room using vacuum gauge.

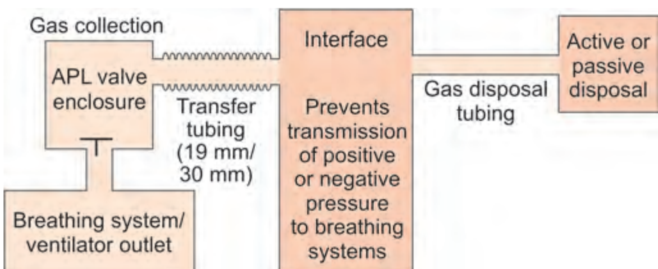


Fig. 2.11: Schematic representation of the components of scavenging system.

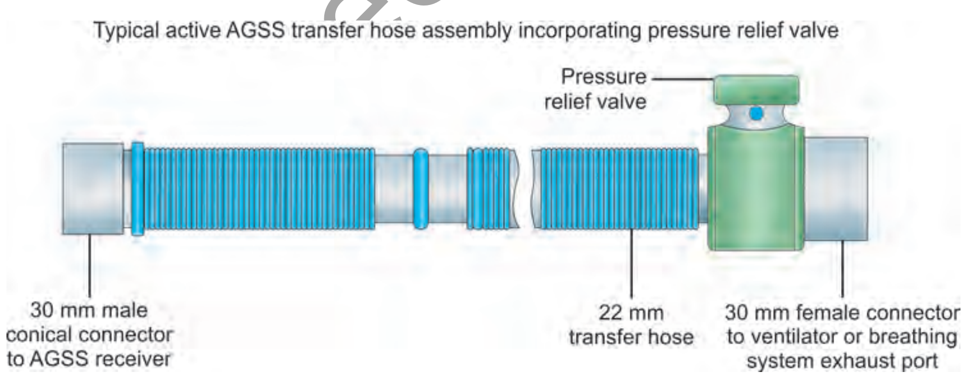


Fig. 2.12: Gas disposal in active scavenging.

numerous years. Some potential effects of exposure to WAGs are nausea, dizziness, headaches, fatigue, and irritability, as well as sterility, miscarriages, birth defects, cancer, and liver and kidney disease, among operating room staff or their spouses (in the case of miscarriages and birth defects). The reports on the effects of exposure to WAGs are controversial. The evidence that trace anesthetic gases are harmful is at present suggestive rather than conclusive. However, scavenging of WAGs is recommended for all areas, and work practices to reduce contamination. The maximum recommended trace gas levels are recommended as particles per million (ppm), and varies between different countries (Table 2.4). In addition, there should be a program for management of WAGs, with a documented maintenance schedule for all anesthesia machines and the ventilation system in the operating room and postanesthesia care units.

Table 2.4: Recommended trace concentrations of waste anesthetic gases (WAGs).

The recommended maximum accepted concentrations over a time-weighted average

	UK (8 hours)	*US (1 hour)*
Nitrous oxide (ppm)	100	25
Isoflurane (ppm)	50	2
Halothane (ppm)	10	2
Other halogenated agents (ppm)		2

Factors contributing to operating room pollution:

- Use of breathing systems with high flow techniques
- Poorly fitting masks
- Failure to turn off gases at the end of anesthetic
- Filling anesthetic vaporizers without key systems
- Liquid agent spills
- Leaks in the machine and breathing systems
- Improper scavenging.

The components of scavenging system are as shown in Figure 2.11. The waste gases are collected by suitable modification of adjustable pressure-limiting (APL) valves and ventilator relief valves and are transferred via special tubing to the scavenging interface. These tubes are of different size and appearance to prevent misconnection or direct connection to breathing systems (19 mm/30 mm—corrugated tubes used in breathing systems are 22 mm size). The interface protects the breathing systems from excessive positive or negative pressure. From the interface, the gases are conducted through collapse-proof tubing to the gas disposal assembly, which eliminates excess waste gas.

There are two types of gas disposable systems:

1. *Active:* This is the most common system and uses central vacuum. It provides for high flows but only slight negative pressure (*see* Fig. 2.12).
2. *Passive:* The pressure of the waste gas itself produces flow through the system and no vacuum is used.

Occlusion of scavenging systems can produce high levels of positive pressure in the breathing systems leading to barotrauma. In active systems, failure of the interface can transmit excess negative pressures to the patient.

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