Chapter

1

Medical Gases and Equipment in Anaesthesia

In the modern times, the anaesthesia machines are not covered by a single international standards organization. In spite of standard committees like EN740 (Europe), ASTMF-18500-00 (USA) and BNEN740: 1999 (UK) there is no single standards committee globally though extensive reference is made to IEEE1078 for medical devices.

GAS SUPPLY

In major hospitals central gas pipelines are now the major source of gas supply to the machines (60 psi). Oxygen produced by fractional distillation of liquid air is stored at–150°C to –175°C in vacuum. The liquid occupies 1/800 of the gas space, compared with 1/142 for oxygen in a cylinder. The oxygen is warmed to 4°C before entering pipelines. A back up is provided with oxygen cylinders along with an automated alarm system in a liquid tank.

Nitrous oxide (N_2O) is stored at ambient temperature, under a pressure of 3030 mm Hg (404 kPa) before entering pipeline. There is a strict control on labeling of pipelines monitoring panels with audible alarms and emergency shut offs.

Sometimes surgical instruments are powered by air compressors at 404 kPa or 107 kPa. Pipeline is connected to machine by non-interchangeable screw thread, specific for each gas (pin index). There is a pressure gauge at the machine end for each gas. Pressure and flow reducing valves are provided to protect flow meters from a high pressure or flow from the pipeline.

Gas Cylinders

The cylinders are color coded and labeled. In past, different countries have suggested different systems of differentiating their gas cylinders (Table 1.1). In 1981 in Iran, the cylinders were painted black with name of gas written in Persian language. With time, the paint came out and the labels were indistinguishable. So an interchange of N_2O cylinder and oxygen cylinder connected to anesthesia machine lead to mortality.[1] The matter was reported to standards committee UK. In India, however, BOC follows the British Standards and cylinders standards and transport is governed by Ministry of Transport, Government of India as per ISO 3.2 (1977) standards. Cylinders are made up of light weight molybdenum steel for portable cylinders and manganese steel for large cylinders. Some of the portable cylinders (for MRI) are made of aluminum.

Cylinders are identifiable by a stamp on the shoulder, or by a plastic/paper collar. Cylinders are tested following manufacture and regular intervals by visual inspection for outside and inside (endoscopic) and hydraulic testing by a pressure 50% greater than the normal maximum working pressure.

Filling Ratio

In cylinders with liquid gas, a filling ratio (density) is specified, which is the ratio of the total weight of the gas in cylinder to the weight of water that the cylinder can hold at 16°C. For N_2O and CO_2, filling ratio is 0.67 (tropical areas) and 0.75 (temperate areas).

Table 1.1: Color-coding of medical gas cylinders

Gas	*India and UK*	*USA*	*Pin index position*
Oxygen	Blackbody, white shoulder	Green	2,5
Carbon dioxide	Gray	Gray	1,6
Nitrous oxide	Blue	Blue	3,5
Entonox ($N_2O + O_2$)	Blue body, shoulder black/ white quartered	NA	Single central hole
Air	Gray body, shoulder black/ white quartered	Yellow	1,5
Helium	Brown	Brown	–
Vacuum	Yellow	White	–

Safe handling of cylinders: Oxygen and N2O gases support combustion. The presence of oil may ignite the gases in the presence of O_2. The cylinders are stored in a cool, well-ventilated, dried areas away from fire. The valves, regulators, gauges should be kept free of oil and grease in a vertical or tilted position a seal should protect the cylinders, which is opened just before use and valve opened slowly to blow any dust. The slow opening of cylinder after its connection to machine prevents heat generation in yoke, due to a rapid compression. This may ignite any dust or grease if present. Any rapid rise in cylinder pressure gauge or pipeline is prevented.

Cylinder Testing

The cylinder testing is done by tensile test, done in 1:1000 finished cylinders. Stripes are cut longitudinally from the cylinder and stretched till they elongate. The yield point should not be less than 15 tons/sq. inch.

Flattening test: One cylinder is kept in between two compression blocks and the pressure is applied to flatten it ill the distance of blocks becomes 6 times the thickness of walls. There should not be any crack.

Impact test: Three longitudinal and three transverse strips are taken from a cylinder and struck by a mechanical hammer. The mean energy needed to produce a crack should not be less than 5 ft Lb for transverse and 10 ft Lb for longitudinal strips.

Bend test: From one in 100 cylinders, a strip of 25 mm width is cut, equally divided in four strips, which are bent inwards till the inner edges are apart (not greater than the diameter of the strip). The approved cylinder will not develop any cracks.

Pressure test: Apre-OT pressure of 2.36.2 kg f/cm^2 is applied in a water jacket. The change in volume on applying and withdrawal of this pressure is measured by changes in water level in a gauge projecting from the upper end of the water jacket. Secondly there is a non-jacket method, where change in volume in the vessel from which water is drawn up by pump is applying the internal hydraulic pressure is measured. These tests determine any leak in the cylinders. Normally, the permanent stretch should not exceed 10% of the total stretch under pressure.

The cylinders are denoted as A B C D as per their sizes, the size A is smallest, however, AA size is available for army. Size and capacity increase in B C D % E, F, G, and M and may vary with the manufacturers. Commonly used cylinders are D and E type (Tables 1.2 and 1.3).

Oxygen – about 2000 Lb/inch^2 (138 bar)

N2O – 750 Lb/inch^2 (52 bar or Atm)

CO^2 – 720 Lb/inch^2 (50 bar)

Air – 2000 Lb/inch^2 (138 bar)

Entonox – 2000 Lb/inch^2 (118 bar)

Cyclopropane – 75 Lb/inch^2 (5 bar)

Table 1.2: Contents, dimensions of medical gas cylinders

Capacity	*A*	*B*	*C*	*D*	*E*	*F*	*Pressure*
Dimensions	(3″ × 7″)	(3.5″ × 13″)	(4.5″ × 17″)	(4.5″ × 23″)	(4.5″ × 26″)	(5.5″ × 51″)	kPa
Capacity	–	–	1.21 L	2.3L	4.7 L	9.4 L	–
Oxygen	16	–	170	340	680	1360	13650
N_2O	189	378	450	900	1850	3600	4400
CO_2	–	–	450	–	1800	–	5200
Entonox	–	–	500	–	–	2000	13650
Air	–	–	–	–	640	1250	13650

Table 1.3: British Oxygen Company specifications

Type of capacity	*Outside diameter*	*Length*	*Wall thickness*	*Water capacity*	*Weight*
Medical oxygen					
1320 L	140 mm	850 mm	5.8 mm	10 L	17.5 Lb
1246 L	5.5″	27.75″	0.165″	20 L	34 Lb
Boyle's machine					
E 1612 L	40144″	25.25″	0.103″	4.6367 L	12 Lb
D340 L	4.144″	16.75″	0.103″	2.785 L	8 Lb
Nitrous oxide					
E 1650 L	4.144″	25.75″	0.103″	4.637 L	12 Lb
D 995 L	4.144″	16.75″	0.103″	2.785 L	8 L
CO2 B 372 L	3.271″	13″	0.073″	84 in^2	3.75 Lb

While oxygen gauge shows the contents of cylinder in proportion to gauge pressure, nitrous oxide pressure gauge shows a constant pressure of the vapors above the liquid, till later is depleted, after wards it drops suddenly. The empty cylinder produces dull thumps when gently bumped against floor while full cylinder bottom when bumped produces ringing noise.

Following identification marks are stamped on the neck of the shoulder. The weight of cylinder (empty), symbol of gas, pressure of hydraulic test, capacity of the cylinder, serial number and name of owner. The mechanical testing of cylinder must be done every 5 years, the date of which should be stamped on the shoulder and valve block. The mushrooming of so many gas companies has lead to a difficult control over the cylinder inspection and thus safety is the worry of most of the users. There had been reported incidences in media from time to time about the accidents occurring inside the manufacturing units and transport and central pipelines, which are a matter of concern.

Cylinder Valve

The valve is fitted at the top of the cylinder. The chemical formulae of the gas are engraved on it. It can be used to start, regulate or stop the flow of gases from the cylinder (Fig. 1.1). There is an outlet at one side to the master body where it fits with yoke assembly of Boyle's machine, through monitor changeable pinholes. On the other side, there is a conical depression to fit the screw of the yoke. On the

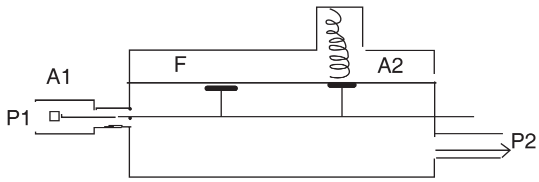


Fig. 1.1: Preset regulator (BOC): High pressure P1 tends to keep small area A2 closed. Opening the flowmeter reduces the pressure in the main chamber, pushes diaphragm down, opening small valve, allowing gas to flow into the main chamber. P2 is factory preset pressure. P1 × A1 = P2 × A2

top, there is a stem or spindle with a packing nut, which in turned with a spanner, allows the gas to go through the outlet.

The cylinder valves are made up of a brass plated with chromium and nickel allowing rapid dissipating of heat of compression. There are two types of valves, flush or diaphragm type valve with an adjustable screw raising or lowering a metal diaphragm for opening or closing it. There is less leakage, so safe. The other type of flush valve as shown in Fig. 1.2, the commonly used valve in Boyle's machine. There are other valves like bull nosed, straight type and angled type.

There should be a safety relieve device in cylinder vale, in case of excessive high pressures (7500 psi) developed in the cylinder. These pressure relief valves also cause leakage sometimes. Any rise of pressure and dirt, dust, oil, grease can lead to explosion.

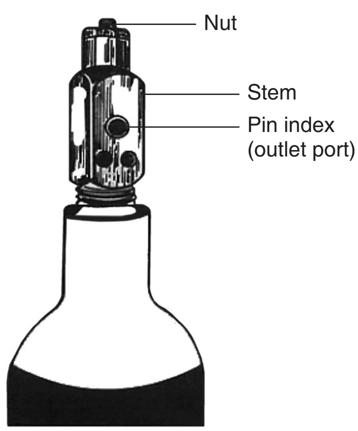


Fig. 1.2: Cylinder valve

Yoke-nipple: Gases enter the machine through the nipple of the yoke, which projects from the yoke and fits into the part of the cylinder. If damaged, nipple cannot provide a tight seal with cylinder valve. Sometimes filler can be provided for any particulate matter to enter the machine.

Pin index system: The cylinders are locked by the positions of two predetermined clockwise pins on the yoke. A line is drawn through the center of the valve outlet at an angle of 30° to the right of valve face. The center of valve outlet and center of pinhole is 14.3 mm and diameter of pinhole is 4.8 +/–0.1 mm. There are a total of 6 pin positions on the yoke and 6 holes in the cylinder valve (Fig. 1.3). This gives ten different combinations using 2 hole positions on the valve and corresponding pin positions on the yoke. The pins are 4 mm in diameter and 6 mm long except for the seventh pin, which is thicker and positioned on the circumference of a circle 9/16-inch radius centered on the port.

A cylinder is fitted with yoke with a sealing washer (Bodok seal) in between to prevent leakage and provide proper fitting (Fig. 1.4). Bodok seal is made of carbon in pregnated

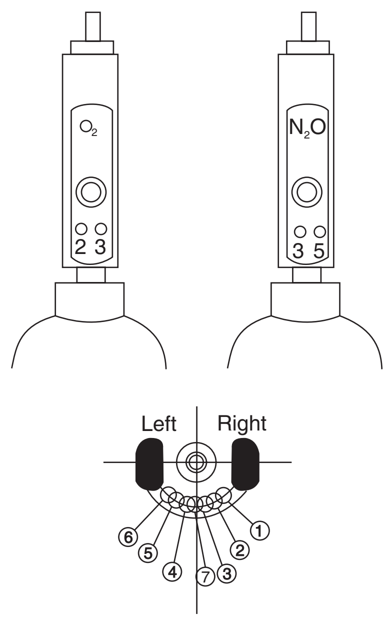


Fig. 1.3: Pin index system

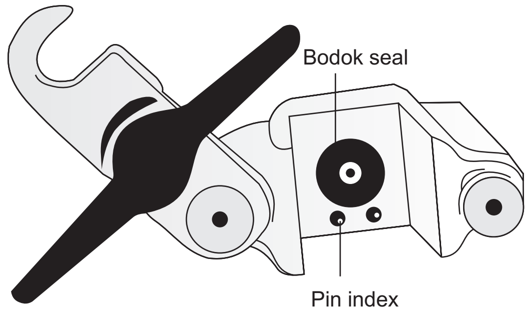


Fig. 1.4: Yoke assembly

material with a metal ring and has a 2.4 mm thickness. Only one seal is allowed in between for proper fitting of valve into the yoke. A tightening of the screw on yoke can damage the washer.

Central Pipeline

In bigger hospitals, the medical gases are supplied by a pipeline system, which consists of a central supply unit, a distributing pipeline and particular outlet points located at the point of use. Usually O_2, N_2O, compressed air and vacuum are supplied (Fig. 1.5).

The pipeline consists of a high quality of copper and outlet point is color coded with matching quick couplers (connect/disconnect probes). There are flexible color-coded pipelines from the outlet to the anesthesia machine.

Central pipeline supply has large bulb cylinders. The delivery of gas is done at 50–60 kg/inch^2. There are audible alarms or warning light when gas pressure becomes too low. Ideally there are 2–4 bulk cylinders, when one exhausts, the other is automatically turned off and the former turns off automatically. The exhausted set is than replaced by fresh cylinders. The central supply system is provided with properly labeled and provided with pressure gauge. Oxygen is stored in gas or in some hospitals in liquid oxygen tank. The later is less expensive and more convenient, takes less place for storage. Liquid oxygen is stored at –165°C at 10.5 bar in a big thermos flask called tank. The later is a vacuum insulated evaporator and some heat from a warming device passed through the insulating layer to evaporate and maintain a constant pressure of O_2 in the pipeline system. In case of extra pressure above 17 bar, the gas runs out through an outlet pipe safety valve. In case of low pressure, there is a slow evaporation of liquid oxygen. In such case, a valve opens to allow more liquid O_2 to enter in the evaporator and more gases pass into pipeline. The tanks are filled with cryogenic flow hose assembly.

Nitrous oxide should be provided from by a bank of bulk cylinders. However, it may cool to low temperature due to latent heat of vaporization and water vapor of the ambient atmosphere may condense and even freeze on

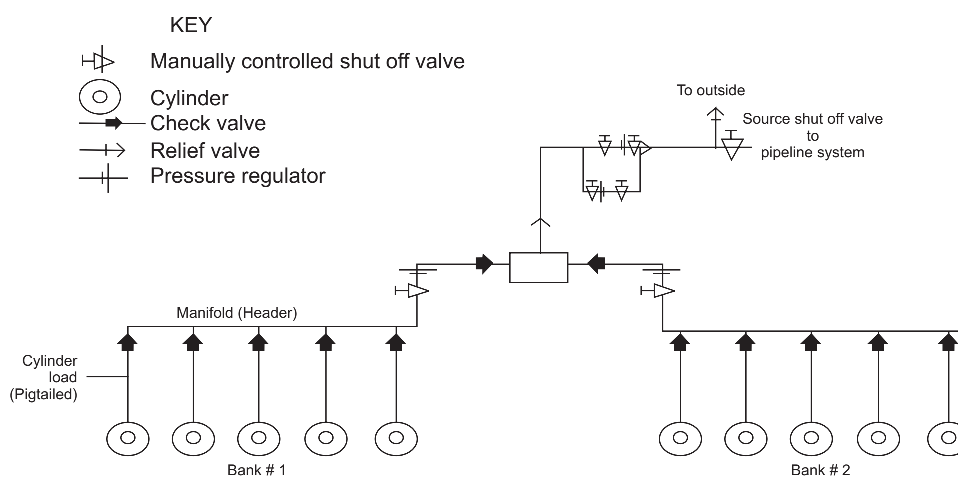


Fig. 1.5: Central pipeline system (manifold changeover device)

the outlet surface of pipeline. This can block the regulation of nitrous contains some water vapor. So a thermostatically controlled heater (at 47°C) may be needed to warm the gas and prevent condensation. Entonox cylinder is always kept horizontal at temperature 0–38°C. Entonox used for larger time may be harmful to patient and hospital personnel so proper scavenging is done. Compressed air is supplied in bulk cylinders driven by motor of 4000 kPa–700 kPa. It can be used for driving ventilators. Piped vacuum service is used for sucking fluids or blood or in anaesthesia suction is used in emergency for oral, gastrosecretions. The lines are provided with high or low-pressure signal and separate pressure gauges and color code (yellow).

The pipelines terminate at station outlet fixed on the wall, provided with non-interchangeable connections (quick couplers), prevent wrong connections. In diameter index safty system connectors, there is a particular diameter of the line to be connected and a thread connection of the nut. But there is a delay in connecting so quick couplers are popular. The outlet is connected through a color-coded flexible tube to the anaesthesia machine using pin index system. The advantage of central pipeline is its ease, convenience, dispensing the frequent change of cylinders, delivery, economy, and transport. There is less explosion hazard in OT and patients safety. It can be used at different locations, e.g. ICU, trauma, wards, etc. high initial costs, which are recoverable and occasional accidents, are only disadvantages. The central supply room should be well ventilated, constructed with fireproof tiles, and well spaced, located on ground floor for easy access to transport trucks. The compressors and central vacuum plant should also be located there.

Oxygen Concentrator

This device extracts oxygen from atmospheric air, by absorbing N_2 by zeolite molecular sieve. Zeolites are hydrated aluminum silicates of alkaline earth metals. The atmospheric air is exposed to a zeolite sieve column series at a certain pressure. The sieve selectively absorbs N2 and other constituents of air, which are released back to the atmosphere, and thus oxygen of about 95% concentration can be produced. Argon is the main remnant. If circle absorber closed system is used, argon accumulates.

High gas flow avoids argon accumulation. The oxygen concentrators used for domestic use, which are light weight and portable and useful in remote locations. Large-scale oxygen concentrators with 2 units can also supply central pipelines. The oxygen concentrators are high initial cost, which is recovered easily by free oxygen later. The disadvantages include fires, device malfunction, and contamination of sieve medium and argon accumulation. Water vapors cause deterioration of the absorbent medium (Fig. 1.6).

Pressure gauge (Bourdon): It is used in anaesthesia machine and central pipelines to measure the gas cylinder and pipeline pressure. The pressure of cylinder allowed to pass through a flexible copper allow tub. A result of transmitted pressure the coiled tube tries to straighten out. This motion is transmitted in a clock-like mechanism and gas pressure is indicated on a scale on a dial. The gauge is color-coded, name and symbol of gas written on it and capable of measuring one-third greater pressure than maximum pressure. In case of a rupture, the escaping gas generally vented from the backside rather than front window. There should not be any oil or grease near the gauge so it is marked "use no OIL". It is used for oxygen, nitrous where it shows pressure of the evaporated vapors only; it is calibrated specifically for a gas (Fig. 1.7).

Pressure regulator: Pressure reducing valve is needed to convert high pressure of cylinder gas to allow, safer pressure. A high pressure may damage the machine or the lungs of the patient. Most popular being Adam's valve, reducing the pressure to 5–10 Lb/inch^2. The principle of this valve (Fig. 1.8) depends upon conversion of a high pressure (P_1) into a central chamber and distending a diaphragm through a coiled ring. Ultimately the diaphragm

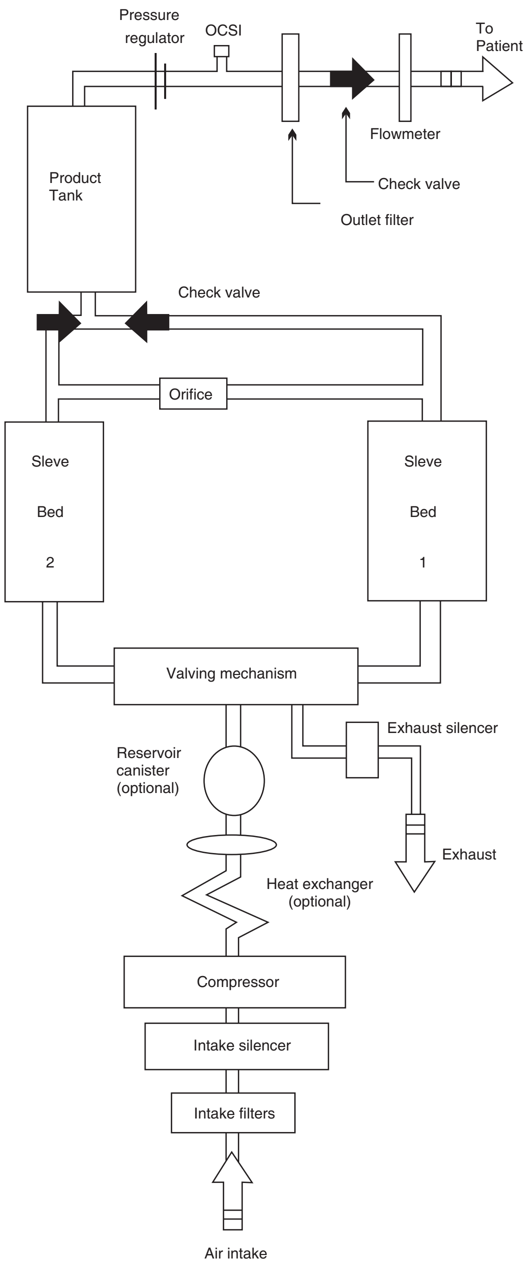


Fig. 1.6: Oxygen concentrator

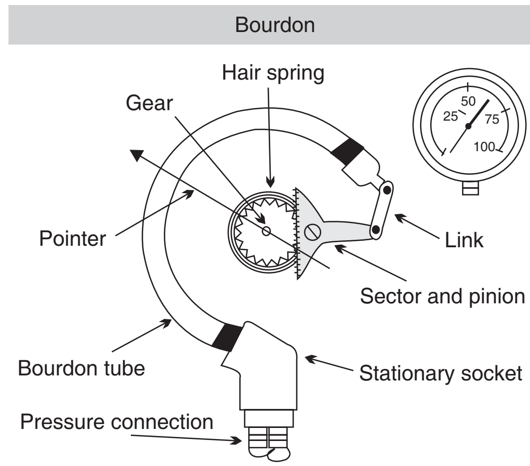


Fig. 1.7: Bourdon pressure gauge

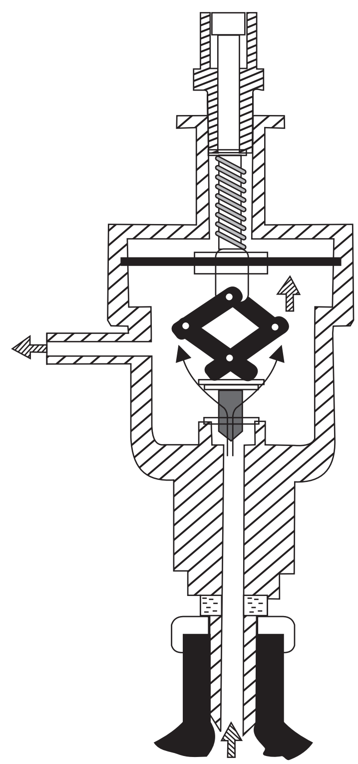


Fig 1.8: Pressure regulating valve — Adam's valve

moves, the end of the rod in the entry port moves and shut the inflow. The gases of the chamber pass through outlet. The pressure may be regulated by turning the screw clockwise or anticlockwise. After the gases escape, the diaphragm moves up again and the pressure falls and inlet valve opens again.

During use, a steady pressure is maintained in the chamber by partial opening of the valve. The pressure regulator is made up of material which does not react with the gas and functions at a temperature range of –18°C to 50°C. The inlet can withstand 4 times the maximum pressure of the gas in the cylinder (up to 400 Lb/inch^2). A filler of 66 mm is placed upstream to filter unwanted material.

There are placed pressure relief valve (700 kPa) and a one-way valve within cylinder supply line to prevent back flow.

There are fins on the N_2O Adam's pressure regulator for heat exchange preventing cooling of the valve due to water vapor deposition it. Some machines have two-one stage regulations for high pressures, first stage provide inlet pressure to second stage. The dirt can damage the valve, which produce a hissing noise. Intermittent change of gas pressure and flow shown in bobbin of flowmeter. The pressure regulators are agent specific and serviced at regular intervals.

Preset pressure regulator (BOC India Limited): In India, British Oxygen Company uses the preset regulators, which is set by adjusting the screw for a pressure of 60 Lb/ inch. The principle of this valve is same as described earlier. The high-pressure gas passes through dust filler into the high-pressure chamber. Through a gap between valve and nozzle, the gas enters a low-pressure chamber, which can be controlled by adjusting the screw. The pressure of the spring presses the diaphragm at the center against a nozzle, creating a gap between the valve nozzles, allowing the gas to flow from high pressure to low pressure. The outlet valve has a relief hole operated where 10 kg/cm^2 (50% greater than maximum supply pressure). The preset gases are agent specific. Maximum inlet maximum pressure allowable is 200 kg/cm^2 with maximum preset down strain pressure of 4.2 kg/cm^2 for a discharge of 100 L/ml gas. The valve is designed for minimum inlet pressure of 9.4 kg/cm. The regulators are serviced at regular intervals and rubber diaphragm is checked and renewed (Fig. 1.9).

In the pipeline pressure gauge, the pressure should be between 45 and 55 psi (310–180 kPa). In pipeline system, there is no pressure regulations on anaesthesia machine. The gas is supplied at 60 Lb/ inch^2. The sudden change in pressure at machine end can be prevented by flow restorers. They are simple constrictions in the pipeline upstream. However, flow restrictors which pressure regulator may cause changes in flow rates, which need readjustment of flow, control vales. Any obstruction at the outlet or anaesthesia machine may damage vaporizers. A blow

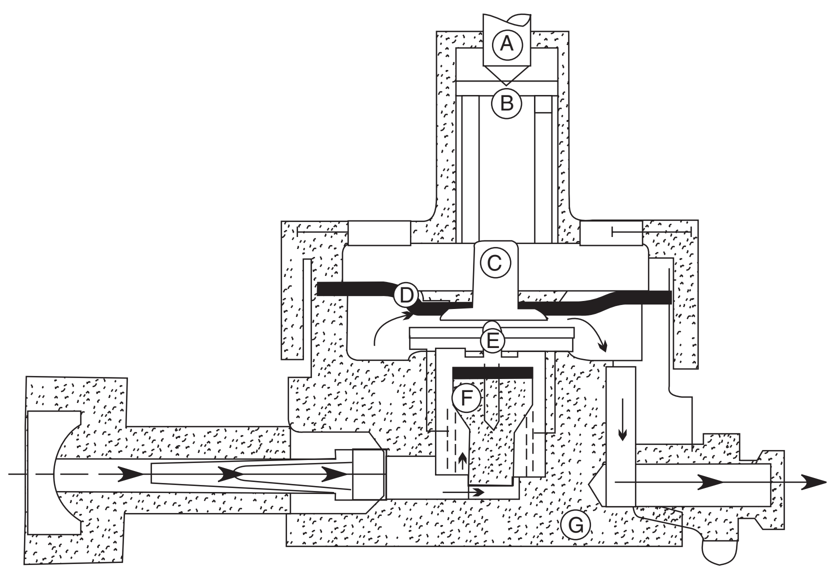


Fig. 1.9: Pressure regulator (BOC) (A . pressure adjusting screw, B. Spring centre, C. Diaphragm carrier, D. Diaphragm, E. Pin, F. Valve assembly, G. Regulator body)

off safety valve in the downstream end of vaporizer reduce the risk of backpressure during controlled ventilation. The pressure regulator safety relief valves allow pressure above 100 Lb/inch^2 to escape to atmosphere, at a working pressure of 60 Lb/inch for the regulator.

Flowmeters (Rotameters)

The rotameter unit consists of a series of flowmeters for oxygen, nitrous and air in a metal frame. In front, there is a transparent window for clear readings and at the back there is a radiolucent plate, which makes the readings possible in case of darkness (OT light goes off or in radiology department). The flow of the gas passing per minute is measured and can be controlled by opening the needle or pin valve 'sitting on a metal seat'. The central knobs of the pin valves are agent specific and color coded, with error of +/–2% (Fig. 1.10).

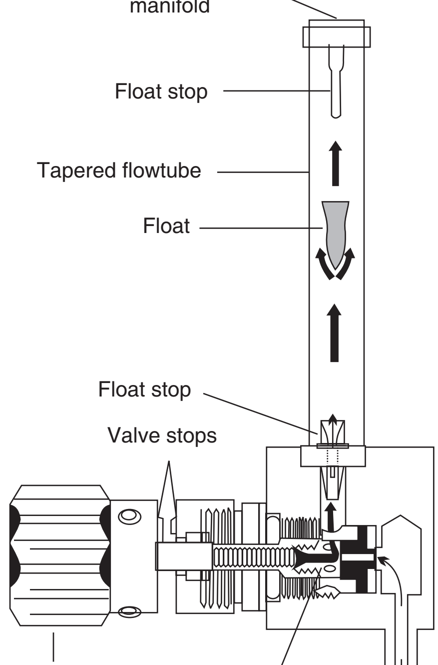


Fig. 1.10: Flowmeter and bobbin

The flowmeter is an accurately tapered glass tube with a lightweight bobbin spinning in the gas flow. The gap between the bobbin and tube wall is called annulus, varies at low and high flow rates (variable oftices). The bobbin is lifted by the flow of the gas until the upward pressure caused by the gas escaping through the spinning bobbin at the upper end and weight of the bobbin is in equilibrium. Higher the bobbin, greater is the flow rate. The pressure difference of gas above and below the bobbin is always constant. The flow is laminar at low flows while it is turbulent at higher flows. The bobbin is always spinning shown by a white radiolucent dot on it, preventing fluctuations and reduce wear and tear. Bobbin is antistatic to prevent its sticking to wall due to friction charges and serviced by anti-static sprays at regular intervals. Bobbins can be of ball, non-rotating, H float, skirted or non-skirted type also but not in use.

The flowmeter tube has a spring stop at the upper end. The flowmeters are individually calibrated for each gas along with the bobbin at room temperature and 760 mm Hg (1 atmp). The error of (+/–2) is greater at low flows in closed circuit. To prevent delivery of hypoxic mixture, a delivery of 50–250 ml/min flow of oxygen, before flow of other gases is preset or an alarm with low oxygen flow is incorporated. In commonly used machines presently, a minimum 25% oxygen ratio is reached and maintained with O_2 and N_2O mixture automatically. Disadvantages include leaks, obstruction, stuck bobbin, improper alignment, wrong gas, etc. Small filler can avoid air entering the flowmeter. The temperature and back pressure cause inaccuracy in case of leakage in any other flowmeters (N_2O, CO_2, air, cyclo-propane), there is a preferential loss of oxygen, so the oxygen flow meter is placed on the right end of the assembly. The control knob of oxygen is of different size and color. A separate block in which oxygen and nitrous are premixed at desired concentration and than flowmeter shows total fresh gas flow, is not suitable at low flows.

Other types of flowmeters: (1) Heidbrink-tapered metal tube with upper calibrated glass tube, inverted float. (2) Connell type – two ball floats with a tapering bore. (3) Foreggar type – differential pressure fixed orifice with a water manometer of two different diameter limbs.

VAPORIZERS

The Boyle's machine is equipped with an ether vaporizer which is a variable bypass flow over or bubble through type. It consists of a vaporizing glass bottle chamber, calibrated up to 300 ml (Fig. 1.11).

There is a control metal top with a lever to regulate the amount of gases inlet. A plunger made up of copper with a hood at end of the delivery tube when depressed provides more contact of the gases with anaesthetic liquid, increasing the evaporation. The evaporation depends on temperature of OT and also usually decreases with water condensation after sometime. The flow rate and surface area of contact also affect evaporation. So temperature in vaporizers depend on vapors pressure have and thermal conductivity latent heat of vaporization and specific heat of the inhalation agent. This leads to improvement over the years to improved designs of vaporizers over the years for various inhalation agents, e.g. halothane, isoflurane, sevoflurane.

Factors Affecting Vaporizer Output

The output of an ideal vaporizer with a fixed dial setting would be constant, regardless of flow rate, temperature, and backpressure and carrier gases. Contemporary vaporizers approach ideal but still have some limitations due to various factors.

Flow rate: The rate of gas flow at low or high rates (< 250 ml/min and >15 L/min) leads to decreased concentration delivered in spite of a fixed dial setting. At low flow, density of agent is high, so insufficient upward movement of the vapors. At very high flows, there is insufficient mixing, the resistance characteristic of the bypass chamber and vaporizing chamber also vary with high flows.

Temperature: The output is almost linear to the wide range of temperatures in modern vaporizers. A bimetallic strip as in Ohmeda Tec 4 (Fig. 1.12) or an expansion element in Drager vapor 19.1 (Fig. 1.13) vaporizers in

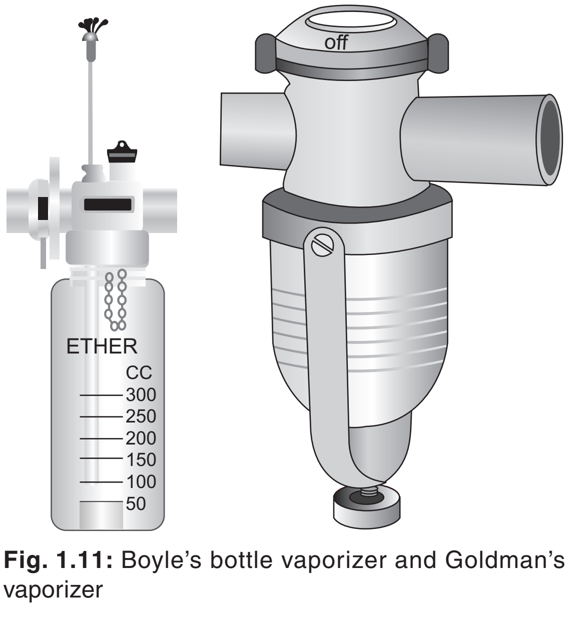


Fig. 1.11: Boyle's bottle vaporizer and Goldman's vaporizer

Fig. 1.12: Tec 4 vaporizer

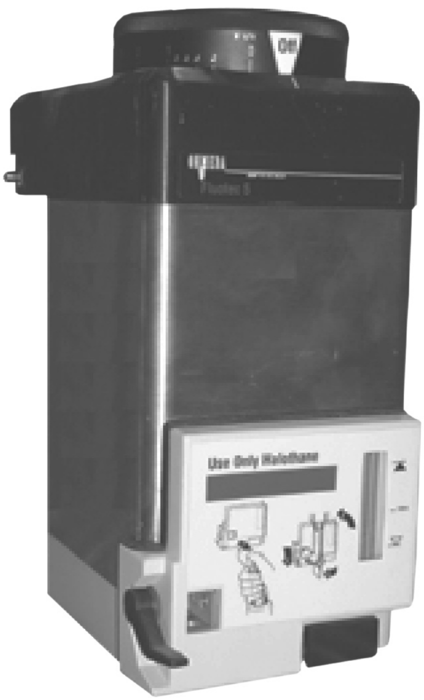


Fig. 1.13: Tec 5 vaporizer

bypass chamber directs a greater proportion of gas flow through the bypass chamber with temperature increases. The risks are placed in direct contact with the metal wall of vaporizer to help replace heat used for vaporization. The metal of vaporizer has a high specific heat and thermal conductivity to minimize heat loss.

Intermittent back pressure: Intermittent back pressure due to oxygen flushing controlled ventilation is produced a pumping effect which is more pronounced with low flows, low dial settings, low levels of liquid in vaporizing chamber, higher respiratory rates, high peak inspired pressure and rapid drops in pressure during expiration. The cause of pumping effect is retrograde pressure transmission from patient circuit to vaporizer during inspiration, during inspiratory part of controlled ventilation. The gas molecules are compressed in bypass and vaporizing chambers. During expiration, the vapors exit from inlet and outlet ports of vaporizing chamber. This effect is offset by having a small vaporizing chamber then the bypass chamber (Tec 4, Dragger 19.1) by a baffle system along spiral tube respectively (Figs 1.14 and 1.15).

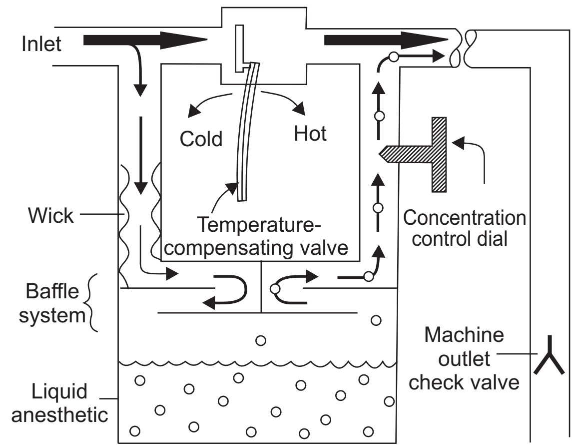


Fig. 1. 14: Simplified schematic of Ohmeda tec 4 vaporizer

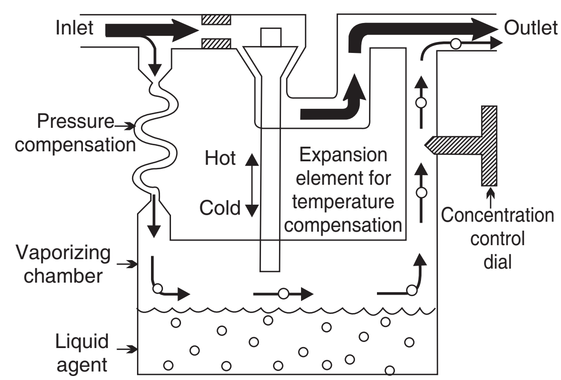


Fig. 1. 15: Schematic of Drager vapor 19.1

Carrier gas composition: Sudden switch from 100% oxygen to 100% nitrous leads to a decreased vaporizer output which only reach a new steady-state value (Fig. 1.16). This is due to a higher solubility of nitrous in halogenated liquid than that of oxygen. Steady state is achieved rapidly with increased flow rates. Viscosity, density and solubility of carrier gas are the agent, the flow splitting characteristics of the specific vaporizer and dial setting are responsible.

Safety factors: The Tec 4 and Tec 5 and Drager 1901 vaporizers have eliminated various

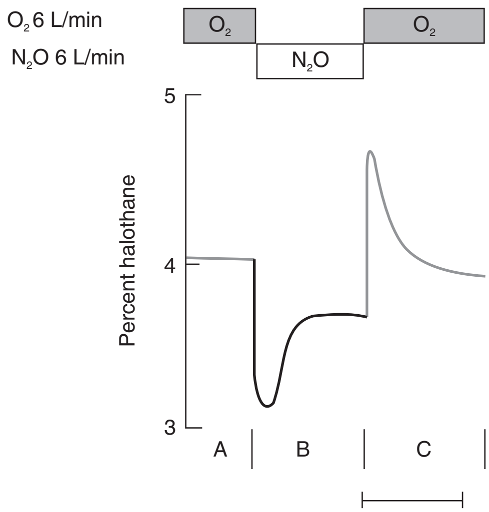


Fig 1.16: Effect of carrier gas on halothane output of Drager vapor 19.1

hazards associated with old models. Agent specific keyed filling devices prevents filling by wrong agent. Overfilling is minimized, tipping is minimized due to fixed vaporizer to the back bar.

Hazards

- Misfiling with wrong agents removed by keyed fillers.
- Contamination due to a contaminated agent.
- Tipping due to moving the vaporizer or incorrectly switched out. The excessive liquid reach bypass chamber and a high output results. A flushing for 20–30 minutes a high flow rate at low concentration can offset the effect of tipping.
- Overfilling leads to excess fluid entering bypass chamber and up to 10 times the intended vapor concentration is delivered.
- Simultaneous inhaled anaesthetic concentration prevented by interlock system when two adjacent vaporizers are in use simultaneously.
- Leaks due to loose filler caps, at O-ring junction between vaporizer and manifold can be detected to conventional positive pressure leak test or by a negative pressure leak-testing device as suggested by Drager and Ohmeda, respectively.

Electrically heated pressurized Tec 6 vaporizer for desflurane: To obtain controlled vaporization of desflurane which boils at 2.8°C and has a vapor pressure 3–4 times of conventional inhaled agents, Tec 6 vaporizer is electrically heated and pressurized (Fig. 1.17). There are two independent circuits for fresh gas and for vaporizer. The former passes through a restrictor (R) and exits through vaporizer outlet. The vapor circuit originates at desflurane sump, which is electrically heated and thermostatically controlled at 37°C with a vapor pressure 1300 mm Hg (2 absolute). A shut off valve allows only after concentration dial is on position. A pressure regulator regulates pressure to 1.1 Atm absolute at a flow of 10 L/min. The operator controls desflurane output by adjusting concentration control valve (R_2). A differential pressure transducer regulates and equalizes both vapor and fresh gas circuit, and resultant goes out through outlet port towards patient (Fig. 1.18).

Fig. 1.17: Tec 6 vaporizer

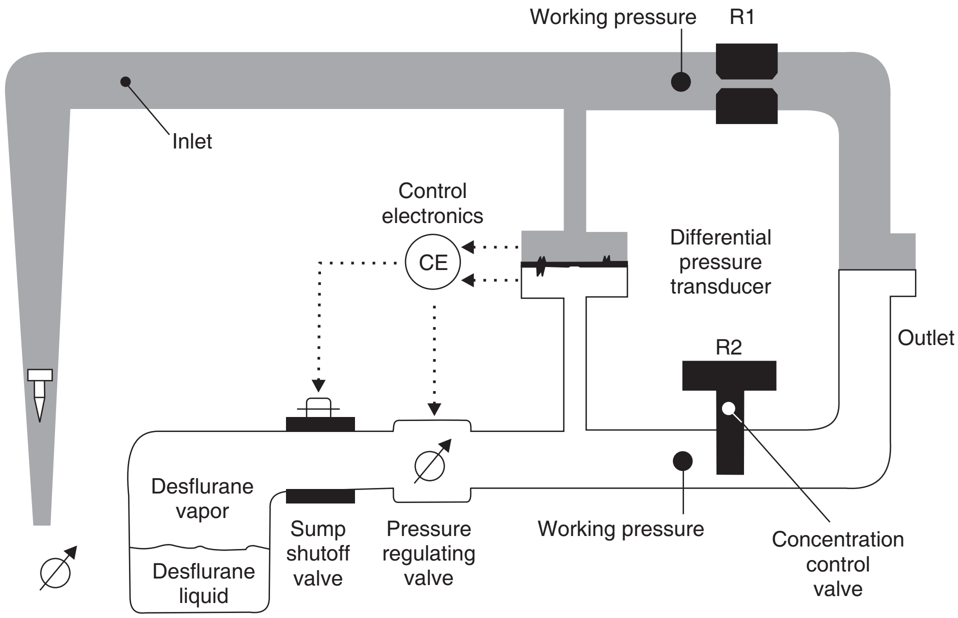


Fig 1.18: Desflurane vaporizer

Datex Ohmeda Aladdin vaporizer consists of an agent specific cassette that is inserted into a port on ASIS anaesthesia machine. The electronic control system recognizes the cassette type and dispense agent into fresh gas stream (Fig. 1.19). They cannot be tipped, are not discharge agent without electrical power and adequate oxygen pressure in the system. The Aladdin desflurane vaporizer works without heating.

Back Bar

Back bar supports the frame of Boyle anaesthesia machine, which supports the rotameter, vaporizers and other accessories. There are two metal rods on which flowmeters and vaporizers are connected with each other and than bolted with the back bar. The flowmeters are on the left hand the temperature compensated vaporizer should be placed next to the flowmeter and should be emptied after each use. The vaporizer with more volatile liquid should be mounted nearer to the flowmeter. At the end of the back bar there may be an angled outlet, with a non-return valve to prevent backpressure. At the extreme right, there is an emergency oxygen bypass with a knob which if turned provide emergency oxygen bypassing the rotameter (up to 35 L/min O_2). The emergency oxygen outlet is provided in current machine near the open/close circuit outlet as an emergency spring loaded press button valve (Fig. 1.20).

From the back bar, the gases and vapor pass to a Magil's circuit at the above mentioned open/close valve. There is a tube leading from this valve to the circle absorber. In current machines, a combined non-return and pressure relief valve is provided at the extreme right end of the back bar. The trilene interlock unit is now not provided in the current machines.

Common gas outlet: This is the exit point for all gases and vapor leaving the machine. It has a 22 mm male outer and 15 mm diameter inner female connection. It is attached to the fresh gas supply tube or bag mount. The other end of the bag mount is connected to the angle piece adaptor corrugated rubber tube (Fig. 1.21). The reservoir bag is connected to the lower end with a valve to cut out the bag, which is ellipsoidal shaped, made up of antistatic rubber with capacity from 0.5 to 2 liters (or 3L).

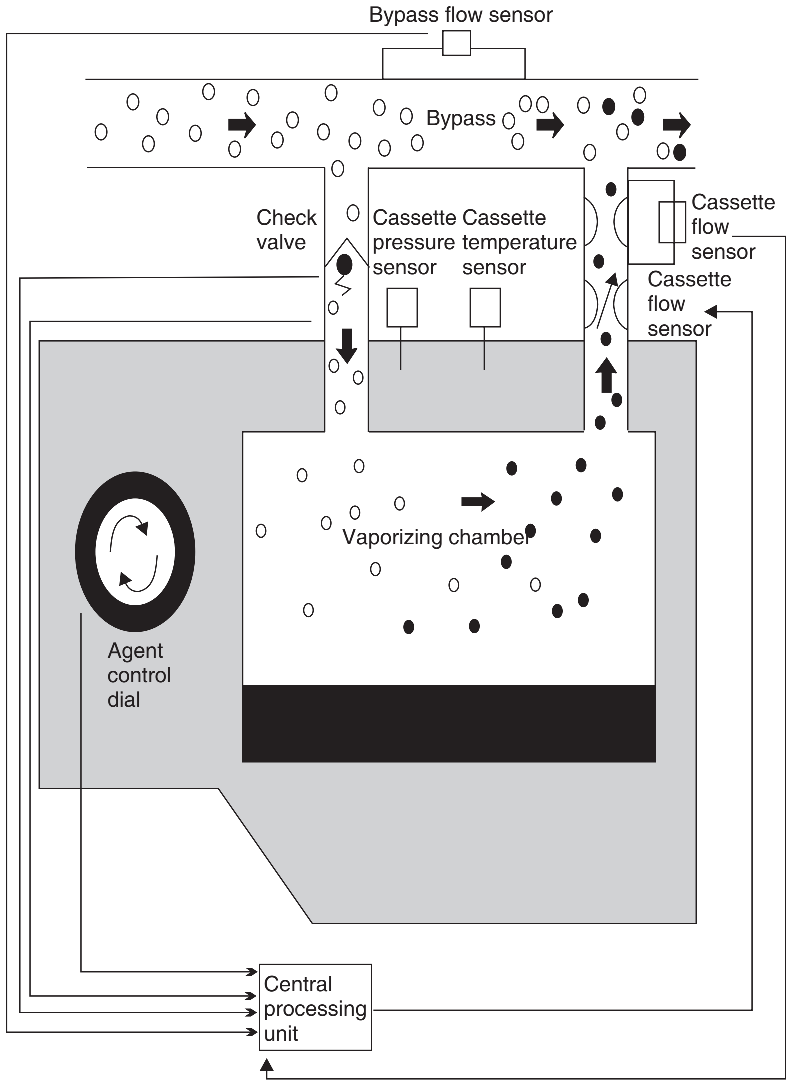


Fig. 1.19: Schematic of Aladdin cassette vaporizer

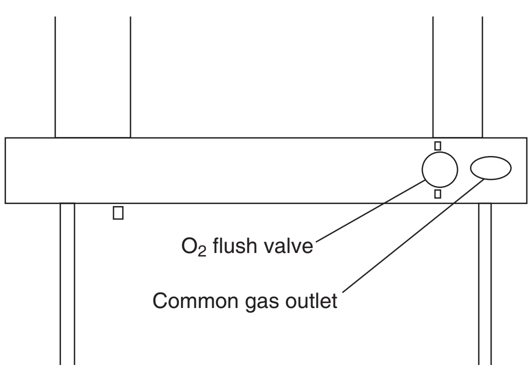


Fig. 1.20: Flush valve

All rubber goods used in anaesthesia machine are made up of conductive, antistatic carbon particles make them black in color. The bag acts a reservoir for gases, which collect during

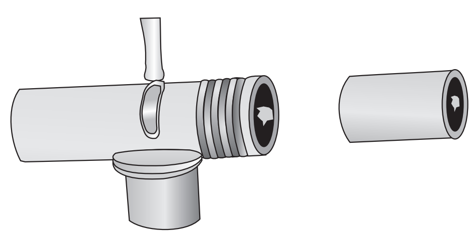


Fig. 1.21: Bag mount

expiration phase, monitors spontaneous respiration. In pediatric bag, there is small distal hole, which act as expiratory port. The ventilator bag is bigger (3L) and stiff with strong wall. Ideally the capacity bag should be more than patient's tidal volume. Larger bags cause difficulty in squeezing, while a small bag will not provide adequate reservoir. The bag should be able to distend 4 times its capacity; the pressure will not exceed 50 cm H_2O pressure so act as a buffer. A loop at the lower end can help it hanging from the knob or lever of bag mount. Thus making the capacity half of the original. A rat tailed rebreathing bag in pediatric circuit is cut open to minimize rebreathing. The open end may contain a stopcock, which can be opened or closed if needed for controlled assisted or spontaneous ventilation.

Corrugated rubber tube is a flexible light weight breathing tube made up of antistatic rubber or polyethylene corrugations allowing acute angulations without kinking. This tube acts as a reservoir in certain system and can be used to connect ventilator to the machine. Capacity of 42– standard hose is about 550 ml. The tube is smooth at both ends for an inch, pointed with 22 mm female connector joining with bag mount or reservoir bag. During automated ventilation, the tube may collapse during inspiration and during expiration returns to normal. Plastic tubes are light weight causing less dragging, absorb less halogenated anaesthetics and have lower compliance. Its rigidity minimizes rebreathing and wasted ventilation and can be sterilized.

The Heidbrink valve is fully opened during spontaneous respiration, placed as near to the patient as possible to avoid rebreathing and dead space. The setting of valve determines the average pressure in the circuit and flow rate through it, the pressure needed to open the valve should be greater than the collapsing pressure of the reservoir bag, with sufficient resistance to prevent the bag from emptying spontaneously. The Heidbrink valve has a light weight valve disc, whose stem rests on a point setting and a delicate spring beneath the valve top (Figs 1.22 and 1.23).

Fig. 1.22: Expiratory valve (Heidbrink type)

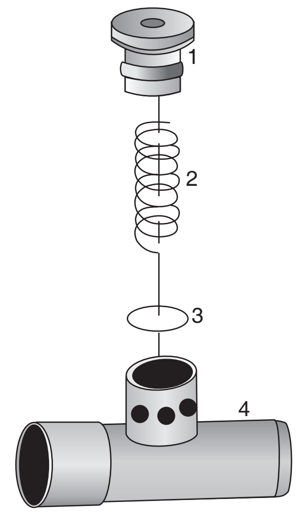


Fig. 1.23: Parts of Heidbrink valve: 1. Cap of expiratory valve, 2. Spring, 3. Valve (pin and disc), 4. Body of Heidbrink valve

The disc is in upright position in the horizontal position and the valve is somewhat open. The oblique position, friction may prevent it from closing. In upside down position, the valve is kept open by gravity. In the absence of spring, there is delay in closing the valve in early inspiration and some air may enter the circuit. Tightening the screw closes the valve fully. In fully opened position, there is a minimum pressure on the disc and during expiration the disc rises and shortens the spring. The expired gas partially escapes through the valve. When the pressure is fully relieved, the valve closes. The increased flow rate increases the opening pressure. Humidity also increases the opening pressure of the valve, due to deposition of surface water film, at the pint of contact between the disc and the seat.

During controlled or assisted ventilation, the valve is either partially or completely closed for adequate lung inflation. During minimal squeezing, the valve is opened due to extra pressure. The valve is periodically partly opened (if closed fully) to release excess gas to allow fresh flow. The valve has a 22-mm male taper at proximal end to be connected to corrugated tube and 22 mm female taper to accept a 15-mm endotracheal connector or catheter mount. Some of the APL valves have marked to show the pressure at which they will once the exhaust port is vented to atmosphere. A small needle inserted through one of the vent holes between the disc and seating, makes valve in efficient, so high flow rates are given as in pediatric patients. Other valves are Magill, McKesson, salt valve (without spring). Filters for dust and microorganisms are used in the breathing tube of the circle system or ventilator hose. The water deposition can clog to the filters, increasing resistance, when they should be cleaned or discarded.

This valve is known as pressure relief valve, blow off, safety valve, exhaust and pressure release valve. This is one-way spring load valve through which gases can be expired to atmosphere, not allowing any air to enter. They are noisy with dead space of 9 cm with minimal resistance, e.g. Reuben's valve, Ambu valve (Fig. 1.24).

Facemask is designed to fit the contour of the face. When applied to face gently, there should not be any air leak. The masks are available for size 1,2,3, and 4 with a dead space of 80–200 ml equal to or more than the anatomical dead space. So mask should be as small as possible. The thumb and index finger are kept on the mask body on opposite side of the mount and middle and ring fingers placed on the mandibular jaw to pull the jaw and extend the back, the little finger placed on angle of the jaw. Avoid excess pressure on eyes and face.

The mask consists of a mount, the body and the edge. Mount is made up of hard rubber and if fits with angle piece adaptor (Fig. 1.25). At the bottom, the edge is provided with an air filled cushioned edge with a cuff to inflate air. The edge used to have a sponge in the past. The facemask can be cleaned with soap and water, autoclaved, boiling or pasteurizing. The facemask can cause contact dermatitis, damage to fifth cranial nerve branches and facial damage to eye and face, and force gas into stomach during assisted or controlled ventilation. A Clausens or Connell's is a Y-shaped rubber strap to keep the facemask in position is not used nowadays.

The anaesthesia machine available mostly is basic Boyle's MK IIIs, a modified version of Boyle's major. It provides pin index yokes for

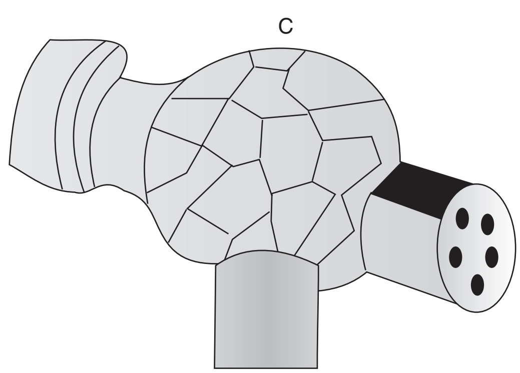


Fig. 1.24: Reuben's valve

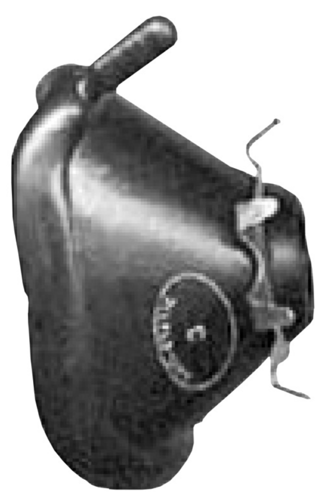


Fig. 1.25: Facemask

2 oxygen and 2 nitrous oxide cylinders with their pressure gauges. It includes a self-sealing chrader type outlet points (4.22 kg/cm^2) for driving ventilators, sprays, cuff inflators, aspirators, etc. (Fig. 1.26). The rotating bobbin flowmeter tubes are long, well calibrated for accuracy from 100 ml to 8 L, O_2 and 200 ml to 12 L/min N_2O. There are two-plunger type ether and trireme vaporizers with built in space for flutech or Tec 5 vaporizer. It is provided with a non-return pressure relief valve in the circuit, to prevent pressure built up beyond 200 cm H_2O, which can be reset. The change over unit is located conveniently along with emergency oxygen valve. The machine can accommodate a Manley Servovent ventilator. A carbon dioxide absorber is also provided with a quick change over system from open to close circuit. The oxygen flowmeter is placed on downstream of other gases and nitrous supply is interlocked with oxygen supply, so nitrous cannot be administered in case the oxygen falls. It is constructed from stainless steel. There are other portable Boyle's version like King's portable apparatus or Boyle's portable. It is simple, light weight compact with a provision for 2 oxygen and 2 nitrous cylinders to be fitted to yoke. There is only one ether vaporizer. The apparatus is kept standing on a stand. The machine should be checked for gas supply in cylinders, vaporizers (clean and refill breathing circuit, closed circuit, ventilators and test for gas leak by a respirometer or monitoring exhaled carbon dioxide. Leaks occur in cylinder valve, yoke, reducing valves, oxygen bypass, flowmeter tubes, connectors, circuits, etc. circuit port for loses, causes a fall in bobbin and a pop at release.

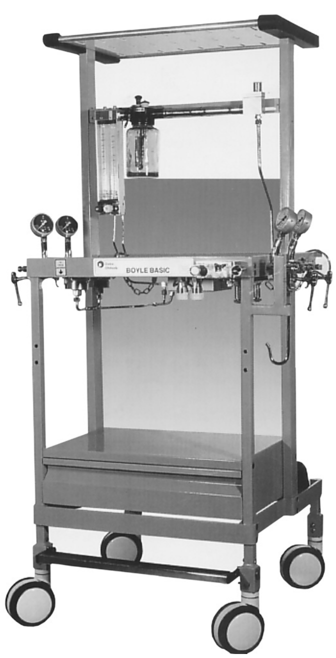


Fig. 1.26: Boyle's mark III anaesthesia machine

Anaesthesia breathing systems: As per ISO, breathing systems are classified as non-rebreathing, partial rebreathing and complete rebreathing. The terms show open and semiopened are not used. All systems fall within the categories of open, semi- closed and closed systems.

Open system: Open systems are valve less systems including the early use of soaked ether in an agent held near the patient's face. Modern example is the fixed flow of gases delivered to the patient via use of facemask, in providing oxygen support therapy during spontaneous breathing. The degree of air entrainment depends on respiratory rate and minute volume. High air flow oxygen enrichment, e.g. venturi, use a high flow of oxygen through a constriction in the delivery system to entrain known concentration of a known proportion of air flow approaching up to 3 L of peak inspiratory flow. The open system used in past was Schimmelbusch mask or the Noseworthy modification for ether (Fig. 1.27).

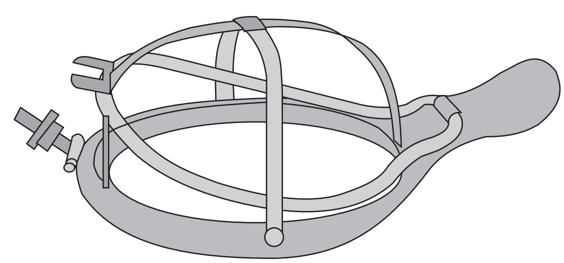


Fig. 1.27: Schimmelbusch ether mask

Mapleson Classification

This combines semi-open and semi-closed systems, are valve less in semi-open and provided with APL valve in semi-closed system and are closely fitted at face, with a reservoir bag in the system to cope with high flow rate. This is also called Magill's system (Fig. 1.28).

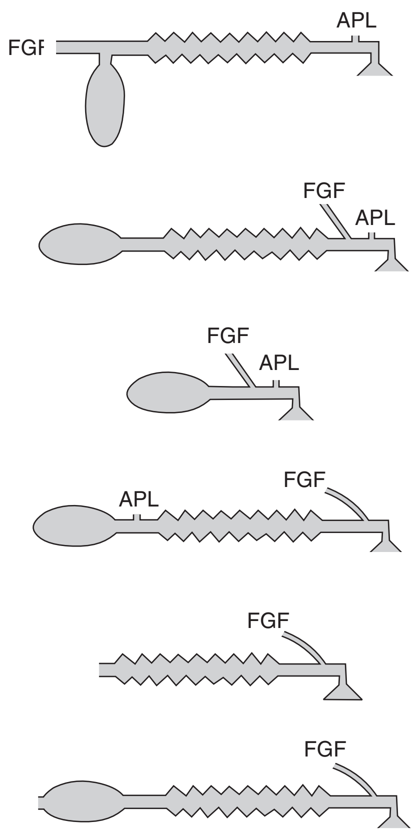
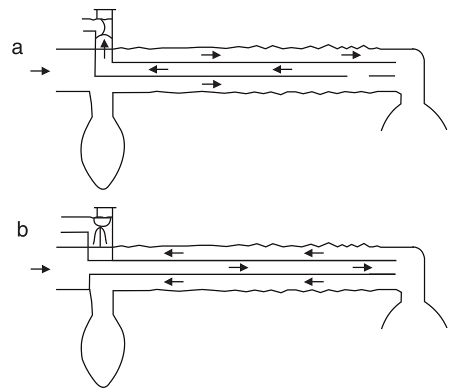


Fig. 1.28: Maplesons classification of breathing systems. VF is the ventilatory flow

Mapleson A: This includes the Magill attachment and the coaxial Lack system (Fig. 1.29).

The reservoir bag is attached to the same limb of the system as that into which fresh flow is introduced and the APL valve is part of the expiratory limb, or directly over the patient's airway. These systems are efficient in spontaneous ventilation as the dead space gas enters the circuit along with alveolar gas following it later goes out through APL into



Figs 1.29a and b: Coaxial anaesthetic breathing systems (a) Lack system (Mapleson A), (b) Bain system (Mapleson D)

the atmosphere, while dead space gas only goes to the patient during next inspiration (Fig. 1.30).

The fresh gas is not higher than alveolar ventilation of the patient as the anatomical dead gas is breathed, while alveolar gas which took part in ventilation goes out through APL valve without a reservoir bag the respiratory flow up to 30 L/ min may be needed. The pressure on APL valve has to be increased during controlled ventilation. A high pressure, 2–3 times the minute volume (tidal volume and respiratory rate), is needed to prevent remixing of fresh gas and alveolar gas.

Mapleson B: The fresh gas inlet is near the patient end, between the APL valve and corrugated tube. The reservoir bag is at one end of the tube. This is used in spontaneous, assisted and control ventilation. It is more efficient during controlled breathing due to high flow and port of the fresh gas entering the inspiratory phase will reach the patient. In spontaneous ventilation, there is more rebreathing, which will read twice the minute volume to prevent it. This circuit is not in use.

Mapleson C: This system is found in recovery areas, used for mechanical ventilation during transfer of the patient. There is always a degree of rebreathing during spontaneous and controlled ventilation, preventable by flows 2–3 times minute ventilation. During