International Journal of Science, Environment and Technology, Vol. 5, No 5, 2016, 2752 – 2764

ISSN 2278-3687 (O)
2277-663X (P)

Review Article

ANAESTHETIC DELIVERY SYSTEM

Rukmani Dewangan* and S.K. Tiwari
Department of Veterinary Surgery and Radiology
College of Veterinay Science and A.H. Anjora Durg (C.G.)
E-mail: dewanganrukmani@gmail.com (**Corresponding Author*)

Abstract: This paper describes the basic components of anaesthetic machine which delivery oxygen and precise amount of inhalant anaesthetic to the patient, removal of carbon dioxide and assisted ventilation carried out by breathing system.
Keywords: Anaesthetic Machine, Breathing system, Vaporizer.

Introduction

The first continuous flow anaesthetic machine was named as Boyle's machine in the honour of anaesthetic H E G Boyle. Modern anaesthetic machine are developed from this Boyle's machine.The anaesthetic delivery system consists of four parts: 1) Gas source (Gas cylinder) 2) Anaesthetic machine 3) Breathing system and 4) Waste Gas Scavenging system. The functions of the anaesthetic delivery system are to deliver oxygen and precise amount of anesthetic gas to the patient, to remove CO_2 from the breathing system, to allow for ventilation (manual or mechanical) and to scavenge waste gases.

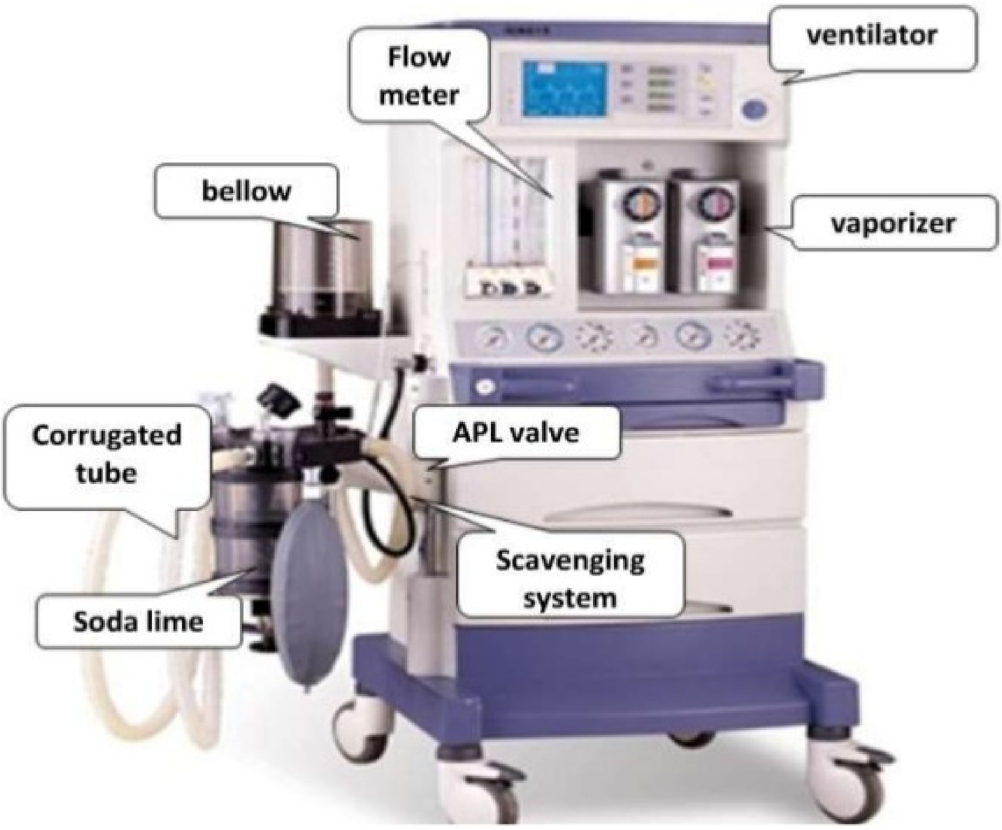
BASIC COMPONENTS OF THE ANESTHETIC MACHINE

Gas Source (Gas Cylinder)- Compressed Oxygen

Anaesthetic gas cylinders are usually made of molybdenum steel. Cylinder sizes are designated according to letter, with size A (smallest) to H (largest). Size E is the most commonly used cylinder in anaesthesia machines. The pressure and volume of these cylinders varies for each type of gas being used. The two most common gases are oxygen and N_2O. The standard E size oxygen cylinder contains about 700 liters and H size cylinder contains about 7000 liters. Both have a pressure of 2200 psi when they are full. The pressure of the oxygen cylinders is proportional to its volume, i.e. an E size cylinder with a pressure of 1100 psi contains about 350 liters. One can estimate the liters of oxygen remaining in a cylinder by multiplying the pressure in the cylinder by a factor 0.3 for E size cylinder and 1.7 for H size cylinder. The pressure in a full N_2O cylinder at room temperature is about 750 psi.

*Received July 24, 2016 * Published Oct 2, 2016 * www.ijset.net*

An E size N_2O cylinder contains about 1600 liters and a full H N_2O cylinder contains 16,000 liters of nitrous oxide. Pressure of gases in an anaesthetic machine varies at different location in an anaesthetic machine. High pressure areas (about 2200 psi) includes cylinder to



regulator. Intermediate pressure areas (37-50 psi) consist of just after regulator to flowmeter. Low pressure areas (0-30 cm of water) from flowmeter to common gas oulet. Cylinders are colour coded according to the gas of the cylinder contains. Tag label indicates whether the cylinder is full, part full or empty.

COLOUR CODE SYSTEM FOR GAS CYLINDER

S.No.	GAS NAME	COLOUR CODE
1	Oxygen	Green
2	Carbon dioxide	Gray
3	Nitrous oxide	Blue
4	Cyclopropane	Orange
5	Helium	Brown
6	Ethylene	Red
7	Nitrogen	Black
8	Medical air	Yellow

Pin Index System- In order to ensure that the correct cylinder is attached to the yoke of the anaesthetic machine. This is a system which has been devised to prevent inhalation of the wrong gas. This is known as "American Standard Connection No. 860 pin index safety system". This system consists of two pins protruding from yoke of the inhalant anaesthetic machine which must fix into the matching holes of specific gas (O_2, CO_2 and N_2O) cylinder. This prevents the wrong gas from being attached to the wrong flowmeter, thus insuring that the correct gas at the correct flow is delivered to the patient. Cylinders should be regularly checked for faults before refilling. As the gas leaves the cylinders it passes through a **pressure gauge and regulator.** The **pressure gauge** is utilized to indicate the pressure on the cylinder side and attached to the regulator.

Pressure Regulator

The **pressure regulator** is utilized to decrease and maintain the gases at a safe operating level, as oxygen moves from the high-pressure tank (at up to 2200 psi) into the anesthetic machine. The pressure is lowered by regulator usually about 50 psi to provide a safe operating pressure which maintains constant flow to the flowmeter. Two stages regulators are more useful as the first stage regulates the pressure from the cylinder and second regulator regulates the pressure that goes into the pipe line or machine. They provide more stable flow of gas than single stage regulators.

Flowmeter/ Rotameter

The gases from cylinders flow through a norrow steel tubing to the flowmeter or rotameter. A **flowmeter/ rotameter** measures and indicates the rate of flow of gases to the vaporizer. This flow rate is expressed in liters/ minute and is adjusted by the anaesthetist. Flowmeters are calibrated at 760 mm Hg and 20°C. There are various designs of flowmeters with different type of indicators to indicate the flow. Flowmeters with aluminum balls should be read from the middle of the ball whereas bobbin type indicators should be read from top of the bobbin. Flowmeter knobs are colour coded for gas they measures (green for oxygen and blue for nitrous oxide). Flowmeters allow anaesthetist to provide measured amount of oxygen/gas to the patient. Recommended oxygen flow rates for patients on a non-rebreathing system are at least 200-300 ml/kg/min., with the minimum flow rate being 1 L/mim. Patients on semi-closed (circle) system are maintained on flow rate of 20-50 ml/kg/min with a maximum of 2 L.min. in general, an oxygen flow rate of 1.5-2.5 L/min is appropriate for most large patients when low flow technique is employed. The flowmeter should be turned off when not in use to prevent the sudden build up of pressure in the glass tube and indicator when the gas flow is turned on.

Vaporizer

Volatile anaesthetic agents are supplied as liquids, and need to be vaporized into gas before being mixed with anaesthetic gases. A vaporizer is therefore, designed to convert a liquid anaesthetic into vapours and mix the specified amount of the vapour with gases being delivered to the patient. The percent of agent delivered is determined by the settings on the dial on the vaporizer that is set by the anaesthetist. Vaporizers deliver know concentration of anaesthetic. Vaporizers are constructed of highly conductive metal so that heat from the surrounding is transferred to the volatile agent in order to supply the lastent heat of vaporization. An indicator window at the base of the vaporizer indicates the amount of liquid anaesthetic remaining. The machine should be refilled if the level is below the half mark. Vaporizers should be serviced as recommended by the manufacture or any time you suspect it is not functioning properly. Also be careful not to overfill or fill with the incorrect agent. There are two types of vaporizers, precision and non-precision.

1. A **precision vaporizer** delivers an exact concentration of the anaesthetic agent. These vaporizers are temperature, flow, and back flow compensated. The disadvantage of this type of vaporizer is that they are expensive and are calibrated for a specific anaesthetic agent. Examples of precision vaporizers are the Tec, Ohio, and Vapor type vaporizers.
2. A **non-precision vaporizer** is used for agents with low vapor pressures. The concentration anesthetic agent is not exactly known. These vaporizers are not flow, temperature, and backpressure compensated. Examples of non-precision vaporizers are the Ohio NO 8 and Stephens vaporizers.

Common Gas Outlet

A tube running from the oulet side of the vaporizer attaches to the brething circuit, which can be either a rebreathing or non-rebreathing system.

Pressure Relief Valves

Some anaesthetic machine are fitted with pressure relief valves on the back bar distal to the vaporizers. The valves are designed to protect the machine and vaporizers against high pressures.

Oxygen Flush Valve

The **oxygen flush valve** is used to bypass the vaporizer and delivers oxygen only to the common gas outlet then to the breathing circuit. The O_2 flush valve delivers a high flow of about 30 or more liters per minute depending on the machine. Do not use the oxygen flush valve to fill the breathing circuit with oxygen while connected to a patient. This may cause damage to patient's lungs due to the sudden increase in volume pressure. Turn the flow on the flowmeter to fill the system when a patient is connected to the breathing circuit.

Patient Breathing Circuits/Systems

Breathing systems are attached between the anaesthetic machine (at the common gas outlet) and the patient (endotracheal tube). The functions of the breathing systems are to deliver oxygen and anaesthetic vapour to the patient, to remove exhaled carbon dioxide and to provide method for intermittent positive pressure ventilation (IPPV). The basic components of all breathing systems include connection to the anaesthetic machine, patient and scavenging system, reserviour or rebreathing bag, various lengths of tubing, pop-off and one way valves and soda lime. However, their arrangement is different in different systems and some of the components may not be present in all the systems. There are six common breathing systems used in veterinary practice. Four common systems do not contain soda lime; they are the T-piece and its numerous modifications like Bain, Mapleson, and Magill etc. There are two systems which containd soda lime they are To and Fro and circle systemtion of breathing system. Circle system may be used with a vaporizer out of circle or vaporizer in circuit. The breathing systems can be classified as non-breathing systems and rebreathing system (circle) based on the absensce or presence of soda lime respectively.

NON-REBREATHING SYSTEM

In non-rebreathing circuit, fresh gases from the anaesthetic machine pass in to reservoir and patient breaths from that reservoir; it means oxygen flows through a flowmeter into a vaporizer. In a **non-rebreathing system** little to no exhaled gases are recirculated. The gases are evacuated by the scavenge system. The components of a non-rebreathing system differ from a rebreathing system as that there are no unidirectional valves, manometer, or absorber circuit. The use of a reservoir bag allows for bagging when needed and a buffer between the scavenging systems.

These systems are recommended for patients weighing less than 10 kg as small dogs, cats and small exotic animals because rebreathing system components (inhalation and exhalation one way valves, carbon dioxide absorption canister and the pressure relief valve) in small animals may increase resistance to breathing.

Advantages and disadvantages of non-rebreathing systems.

Advantages	Disadvantages
1. Economical purchase price 2. Simple construction 3. Rapid changes in concentration of inspired volatile agents possible 4. The concentration of anaesthetic breathed by the patient will be the same as that delivered by the vaporizer 5. Soda lime not required 6. Suitable for a large range of patients 7. Nitrous oxide may be used safely 8. Denitrogenation not necessary 9. Low resistance to breathing	1. High fresh gas flows required, cost is increased 2. Increased use of volatile agents as result of this cost is increased. 3. Increased potential for contamination of atmosphere by waste anaesthetic gases 4. Dry, cold gases delivered to patient

Non-rebreathing system with Ayers Tpiece, Magill system, Bain coaxial system and Stephen-slatter valve apparatus are used. There is minimum resistance to breathing.

- **Ayer's T-Piece**

This is simple non-rebreathing system has no valves and so has very little resistance. It consists of expiratory corrugated tube, reservoir bag and T-piece. The T piece is a T shaped tube with an internal diameter of 1 cm. During spontaneous ventilation, fresh gas flows towards the patient during inspiration and gas flows towards the reservoir during expiration and to the next inspiration.

- **Magill System**

This system utilizes a constant flow of anaesthetic mixture, a reservoir bag, corrugated tubing between the bag and the endotracheal tube, exhalation valve located as close to the animal as possible. The system is good for patients under spontaneous ventilation. The volume of the reservoir bag and corrugated tube should be equal to the patient's tidal volume.

- **Stephen Slatter System**

This system is not used (obsolete) in veterinary practice. The inspired and expired gases are separated by a valve as close to the patient. The recommended total fresh gas flow is equal to the patient's minute volume.

- **Bain Coaxial System**

Bain coaxial system is designed as tube within a tube and fresh gas travelling down the inner tube and the reservoir bag situated on the expiratory (outer) limb. This system is designed to be used with IPPV, but requires a very high fresh gas flow if used during spontaneous respiration in larger patients. Recommendation for total fresh gas flow into a bain coaxial system depends on minute voule, body weight and body surface area. Attach the Bain breathing system to the fresh gas outlet of the anaesthetic machine. Set the oxygen fl owmeter to 2 – 6 litres. Occlude the inner tube of the Bain. If the inner tube connections are intact the oxygen fl owmeter bobbin will dip briefly. Immediately remove occlusion from inner tube.

REBREATHING (CIRCLE) SYSTEM

The **rebreathing or circle system, after removal of** CO_2 by soda lime allows for the rebreathing of the all exhaled gases to the patient. It means fresh gas mixture is continually added. Usually used for patients that weigh greater than 7kgs (15lbs).

- **Advantages and disadvantages of Rebreathing Systems**

Advantages	Disadvantages
1. Economical because gas flow are less as expired oxygen and anesthetic vapor are re-circulated and reused. 2. Warms and humidifies inspired gases as preserving heat and moisture of the patient 3. Reduced contamination of atmosphere by waste anaesthetic gases	1. Initial purchase price high 2. Denitrogenation required 3. Slow changes anaesthetic depth due to lower flow rate of inspired volatile agents in closed and low-flow systems 4. Valves increase resistance to breathing 5. Soda lime is irritant to tissues 6. Soda lime canister increases resistance and contributes to mechanical dead space

There are two types of rebreathing systems. It may be either To and Fro system and circle system.

a. **To and Fro system** is a simple and absorbent canister is located between the endotracheal tube and a reservoir bag. The fresh gas inlet and pop off valve between endotreacheal tube and sodalime canister. This system is suitable for both small and large animals, if proper canister available. The system is protable and easy to disas esemble for cleaning. Heat produced during carbon dioxide absorption may be transferred to the patient.

b. **Circle system-** Cicle system is most complex in common veterinary usage as shown in figure. In this system, gases are exhaled by the patient travels through the expiratory hose and enter the carbon dioxide canister. This system divided into two based on the position of vaporizer in the circle either Circle system with vaporizer inside circle (VIC) or circle system with vaporizer outside circle (VOC). The advantages of circle system are more efficient absorption of CO_2 by sodalime, constant dead space, soda lime canister distant to patient reducing drag and potential for inhalation of irritant soda lime dust and suitable for IPPV. Their disadvantages are complex construction prone to malfunction, bulky system and expensive to purchase

Comparison of vaporizer ouside (VOC) and inside (VIC) the breathing circuit

Parameters	**VOC**	**VIC**
Ventilation	1. Changes in ventilation do not affect the output of the vaporizer 2. An increase in ventilation reduces inspired concentration because of an increased uptake of anaesthetic agent by the animal and a constant output of the vaporizer. 3. Assisted or controlled ventilation can be used with a greater degree of safety.	1. An increase in ventilation due to light anaesthesia automatically increases the inspired concentration. 2. Sudden changes in ventilation can produce dangerously high inspired concentration. 3. Assisted or controlled ventilation at any given setting greatly increases inspired concentration.
Fresh gas flow	1. For any setting, the lower the fresh gas flow the lower is the amount of anaesthetic inspired. 2. The lower the fresh gas flow, the greater the economy. 3. Economy doesnot introduce the risk of high concentrations.	1. For any setting, the lower the fresh gas flow the higher the inspired concentration. 2. The lower the fresh gas flow, the greater the ecomony. 3. Economy is at the expense of potentially high inspired concentrations.
Vaporizer	1. High efficieny vaporizers are essential. 2. Known concentrations can be delivered to the breathing circuit and the inspired concentration can be estimated with no difficulty.	1. Low efficiency vaporizers can be used. 2. Caliberated vaporizers are meaningless because ventilation affects the inspired concentration to a marked degree.

The components of a rebreathing system are fresh gas inlet, absorber circuit, manometer, rebreathing bag (reservoir bag), hoses, Y piece, unidirectional valves (inspiration & expiration), pressure relief valve (pop off valve) and a scavenger system. These components of the rebreathing system increase the resistance to the movement of the gas mixture in the system comparatively to a non-rebreathing. Thus smaller patients may have more difficulty inhaling the gas mixture.

Fresh gas inlet is where the gas enters the breathing system. The inlet is usually located on the absorbent canister near the inspiratory one way valve of a rebreathing circle system. This minimizes the dilution of the fresh gas with the expired gases, absorption of dust and the loss of fresh gas through the pop-off valve.

Unidirectional Valves (inspiratory or expiratory valves) prevent expired gases from being recirculated as result these valves directs the flow of anaesthetic gases towards the patient on inspiration and away from the patient from expiration. Upon inspiration, the inspiratory valve will open and allow the gas mixture to flow toward the patient. At expiration, the inspiratory valve will close and the expiratory valve will open to allow the expired gases to pass into the absorber circuit. These valves allow rebreathing of exhaled gases only after the absorption of the carbon dioxide. Valves should be checked time to time because they contribute to the resistance of breathing.

Breathing tubes (hoses) and Y-piece connect the patient to the absorber circuit. The Y-piece is connected to the endotracheal tube and the other ends of the hoses are connected at the expiratory and inspiratory valves. These tubes are made up of rubber or plastic and are corrugated to reduce the chance of kinking and subsequent obstruction.

Rebreathing Bag (Reservior bag)

The rebreathing (reservoir) bag is an important component of most breathing systems. It is made of antistatic rubber or plastic. The rebreathing bag is used to store gases, observation of respirations and to manually ventilate a patient.

This bag allows controlled ventilation i.e. respiratory rate and tidal volume can be assessed.

Volumes of 0.5, 1, 2, 3 and 5 liters are commonly used for small animals, and 15, 20 and 30 liters are used for large animals. The size of the bag should be at least 6 times the patient's tidal volume. The typical size for a 20 kg dog is 2 liter bag, 500 ml for small dogs and cats, and 30 L for adult horses and cattle.

It accommodates fresh gas flow during expiration acting as a reservoir available for use of the following inspiration and it prevents dilution with room air in non-rebreathing system. Spontaneous deep breath should not empty the bag. The bag should be about ¾ full of anaesthetic gases for optimum condition. Because of its compliance the rebreathing bag can accommodate rises in pressure in the breathing system better than other parts. When grossly over-inflated the reservoir bag can limit the pressure in the breathing system to about 40 cmH_2O. A small bag may not be large enough to provide a sufficient reservoir for a large tidal volume. Too large a bag makes it difficult to act as a respiratory monitor.

Absorber canister is where CO_2 is removed from the expired gases. As the absorber is used the granules will change to a blue color as it becomes exhausted. The granules will return back to a normal color when not in use after sometime has passed. Fresh granules will be soft and easily crushed while exhausted granules will be hard and brittle.

Manometer measures the amount of pressure in the breathing circuit. The manometer is usually located on top of the absorber for assessment of inspiratory pressure (in cm of water) during controlled ventilation. Over pressurization of the system can cause damage to the lungs of the patient.

Pop off valve or APL (Adjustable Pressure Limiting) valve is used to allow the exhaled waste gases to be vented to a scavenging system and fresh gas flows to leave the breathing system when the pressure within the breathing system exceeds the valve's opening pressure. Also called as; Pop-off valve, Exhaust valve, Scavenger valve, Relief valve, Expiratory valve, Over-spill valve etc. It is a one way, adjustable, spring-loaded valve. The spring adjusts the pressure required to open the valve. These valves allow rapid elimination of anaesthetic gases from the circle when 100% oxygen is indicated and are safety features of the closed or semiclosed circle system. The pop off valve is usually left open when the patient is spontaneously breathing and closed for manual or mechanical ventilation. The valve can be adjusted as needed to accommodate the appropriate pressure needed for that particular patient.

FLOW OF GAS THROUGH THE MACHINE TO ANAESTHETIZED A PATEINT

The fresh gas mixture enters the breathing system at the fresh gas inlet. Upon inspiration the gas mixture is delivered to the patient through the inspiratory valve into the breathing tube and Y- piece then to the patient via the endotracheal tube.. When the patient expires the expired gases enter the Y- piece and flow through the breathing tube to the expiratory valve. As the patient inhales the reservoir bag will deflate and at expiration the reservoir bag will inflate. The gas mixture may enter the reservoir bag before or after it has passed through the absorber circuit. These components are arranged to allow movement of the gas mixture in one direction. The expired gas mixture will always pass thorough the absorber circuit before inhalation by the patient.

Waste Gas Scavenging System

For halogenated hydrocarbon anesthetic agents (isoflurane, halothane, sevofurane and desflurane), 2 ppm is the allowed concentration, and 25 ppm for nitrous oxide. When the halogenated hydrocarbon anesthetic agent is used with nitrous oxide the maximum permissible concentration is reduced to 0.5 ppm. The **scavenging system** removes the waste anaesthetic gases from the anaesthetic breathing system and reduces the contamination of the working place. For removal of carbon dioxide from the system usually a gas scavenger canister is incorporated in the anaesthetic machine. The canister contains either soda lime or baralyme. Sodalime consists of 90% calcium hydroxide, 5% sodium hydroxide, plus 5% silicate and contains 10-15% water to prevent powdering. Baralyme is a mixture of 80%

calcium hydroxide and 20% barium hydroxide.Indicators are added to show when it is fully used (but **do not trust** them; they can get leached out by water vapor, and most change color a little too late, and also reverts to its original color when not in use). Calcium hydroxide in the absorbent removes carbon dioxide from the gases that percolate through canister. The absorption of CO_2 by these is exothermic (ie, the soda lime gets hot). In the canister carbon dioxide combines with water to form carbonic acid, which is neutralized by the base.The chemical reaction is as follows:

$$CO_2 + H_2O \longleftrightarrow H_2CO_3$$

Then $2\ NaOH + Ca(OH)_2 + 2\ H_2CO_3 \longleftrightarrow CaCO_3 + Na_2CO_3 + 4\ H_2O$ + heat energy

In most efficient system, 1 gm of soda lime absorbs 175 ml of carbon dioxide. The single canister scavenging system, 1 gm of soda lime absorbs 100-125 ml of carbon dioxide. Soda lime or baralyme granules become exhausted after several hours of use and will no longer absorbs carbon dioxide. Exahaustion of sodalime granules can be indicated by colour chage to pink or violet, but changes of colour may not be a reliable indicator always as colour may return to the original when sodalime is not in use.

Conversions of soft and crushable granules are converted to hard and a non-crushable granule (calcium hydroxide changes to calcium carbonate - limestone) is the best indicator of exhaustion of sodalime. Increased inspired fractional concentrations of CO_2 detected by the capnography indicate exhausted sodalime. There are many scavenging devices suitable for veterinary purposes but care must be taken to ensure that their use does not have an adverse effect on the patient. The **passive system** uses the positive pressure of the anesthetic machine to push the gas into the system. The other is an **active system,** which uses suction created by a vacuum pump or fan to draw the gas into the system. Both systems are effective when correctly assembled, operated, and maintained properly. However, the active system appears to be the most efficient in removing waste gases.

Passive scavenging system

Tubes from the expiratory of the patient circuit lead to outside. Its advantage is cheap to install and disadvantage are ineffective, high expiratory resistance, can obstruct expiration and not acceptable now. **Passive scavenging with adsorption** The tube from the expiratory valve now goes to a canister of activated carbon. Their advantages are effective adsorption of halogenated hydrocarbon anesthetics and simple and portable; fills the gap when moving the machine with the patient connected. Its disadvantage are high resistance, needs frequent changing (weighed to detect when capacity full) and will not adsorb N_2O.

Active scavenging

A central vacuum draws the gases away from the expiratory valve. The suction flow must be at least 30 L/min. Its advantages are very effective (now really the only acceptable method) and minimal resistance to breathing (although need a method of also drawing in room air or else it would suck so hard that animal could not breath in). Its disadvantage is fairly expensive to install **Active scavenging with adsorption** is the best method of all.

All of the components of the anaesthetic delivery system, especially the anaesthetic machine and breathing system, should be tested prior to use to ensure that they are functioning properly. This will help prevent anaesthetic complications associated with the anaesthetic machine and breathing systems during the procedure. Preventative maintenance and cleaning of the anesthetic delivery system is extremely important to its longevity and proper function.

Performing Anaesthetic Machine Check

1. Connect oxygen hose to oxygen source or turn on local oxygen source.
2. Attach appropriate bag and tubing to be used.
3. Check vaporizer for adequate level of liquid anaesthetic.
4. Securely occlude Y-piece with thumb or palm of hand.
5. Completely close pop-off valve.
6. Adjust oxygen flowmeter to 2 L/min.
7. As the rebreathing bag fills with oxygen, the needle gauge on pressure manometer will rise. When the needle reaches 20 cm H_2O readjust oxygen flow to 200 ml/min.
8. If the system is leak free, the pressure manometer should maintain a reading of 20 cm H_2O for 20 seconds with the oxygen flowmeter set at 200 ml/min.
9. If the needle gauge declines, there is a leak. Consult the text of machine manual for possible locations of leak and correct.
10. After 20 seconds of a steady needle at 20cm H_2O, maintain the occlusion on the Y-piece and open the pop-off valve. The rebreathing bag should deflate.
11. Remove thumb from Y-piece.
12. Check scavenging system to ensure connections are intact.
13. Completely open the pop-off valve.

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