Republic of Yemen
Ministry of high education &
Scientific research
Alrazy University
Faculty of Medical Sciences
Departement of Applied Sciences

الجمهورية اليمنية
وزارة التعليم العالي والبحث العلمي
جامعة الرازي
كلية العلوم الطبية
قسم العلوم الطبية التطبيقية

Title of the study:

Anesthesiologists' knowledge Toword anesthesia machine checkout

Submitted by

مرسل عبد القوي احمد النجار
ايوب احمد قايد الحرازي
خالد محمد احمد المقرمي
عبد الكريم صباح
عبدالله محمد الابهر
احمد المصباحي
سلطان قاسم الوجيه
فواد عبد الوارث الخليدي
مجاهد إبراهيم صغير راجح
محمد علي محمدعقيل
مطهر علي صالح الصايدي
وجدي محمد راجح
ماجد امين قايد
عبد الملك علي حاج الهبيط
شبيب غيلان المعمري
محمد حسن تاج الدين
محمد علي محمد الصغير
عبد العزيز محمد غالب
جلال محمد قايد احمد
عبد القوي محمد قحطان
نبيل احمد قاسم مسعودي
محمد علي محمد الوصابي
ماجد محمد ناجي
بشير ناجي محسن عسكر
ناصر صالح غالب قيراط
صدام احمد عثمان
مطهر علي احمد حيدر
علي علي حسن رسام
رضوان سالم
رافت محمد علي قاسم
طلال عبدالفتاح حسان الصوفي

تحت اشراف

د. وائل العزاوى
د. عبدالحميد الذيفانى

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معارف المخدرين تجاه الفحص الدورى

لجهاز التخدير

مرسل عبد القوي احمد النجار
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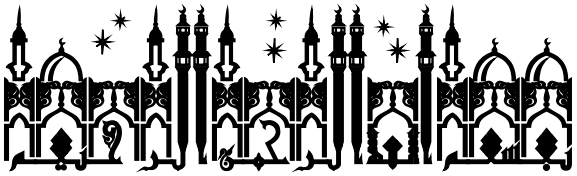


قال تعالى:

Dedication

I dedicate this work

To

My Mother ,My Father

And my family

&

To

AL-Razi University

ACKNOWLEDGMENT

Thank to Allah who have lightened our path to accomplish this work. The few words we wrote here can never and can't adequately express the feelings of gratitude; we have for our supervisors and the persons, who helped us to achieve this work. If we are to vote the heartiest thanks, it is to **Dr. Wael Al-Azawy, and Dr. Abdulhameed Althaifani** for their prompt and thought provoking responses to our questions and for allowing us the freedom to work independently yet keeping us focused on the task at hand, we greatly acknowledge his continuous encouragement and moral support.

It was really an honor working under his wonderful supervision and for all his valuable efforts to produce this thesis. we cannot possibility convey words of our great appreciation for his great faithful effort in supervision during the progress of this work without his valuable instructions this work would never have been done.

The people who actually made this research possible are, of course, the anesthetist who chose to be participants in the study. We sincerely thank them for being willing to share their time. We would like to express our deepest thanks to all who helped me by time, effort and spirit in fulfilling this work.

We are very grateful to our parents, our wife's and our kids for their help every time we needed them. we would not be able to go through our work without their help.

Table of Contents

List of figures

List of tables

List of abbreviations

Abbreviation	Explanation
MRI	Magnetic Resonance Imaging
DISS	Diameter Index Safety Systems
psig	Pounds Per Square Inch On The Gauge
psi	Pounds Per Square Inch
OFPD	Oxygen Failure Protection Device
SVP	Saturated Vapor Pressure
CPU	Central Processing Unit
OR	Operating Room
ICU	Intensive Care Unit
PRV	Pressure Relief Valve
PEEP	Positive End Expiratory Pressure
CMV	Controlled Mechanical Ventilation
AMBU bag	Artificial Manual Breathing Unit Bag
APL	Adjustable Pressure Limiting
PRV	Ventilator Pressure Relief Valve
CO	Carbon Monoxide

Abstract

Anesthesiologists' knowledge about anesthesia machines checkout

Background: The anesthetist has a primary responsibility to understand the function of the anesthetic equipment and to check it before use.

Objective: The aim of this study was to assess the anesthesiologists' knowledge about anesthesia machines checkout in Sana'a city, Yemen.

Methodology: A cross-sectional descriptive design was utilized in the current study. Study populations composed 57 anesthesiologists working at Sana'a city Hospitals, Yemen. A self-administered questionnaire adopted from FDA 1993, was used to collect necessary data, after obtaining verbal consents.

Result: Regarding emergency ventilation equipment checkout, 93% of the anesthesiologists verify the equipment for availability, and 84.2% checked them for functioning, and 73.7% checked oxygen cylinder supply. About three quarters (75.4%) of them adjusted the flow of all gases through their full range, and more than two thirds (68.4%) ensured proper connections between the scavenging system and both APL (pop-off) valve and ventilator relief valve. In final status check of machine, 56.1%, of the participants recognized APL valve open, and two thirds of them incorrectly reported setting vaporizers off.

Conclusion: The anesthesiologists indicated generally inadequate checkout of the anesthesia machines, scavenging system, and machine master switch and flow control valves, which indicates possibility of leak. Lack of compete checkout may put the patient at risk for intra-operative malfunctions as well increase operating room pollution and exposure of operating room personnel to anesthetic gases.

Chapter one:
INTRODUCTION

Chapter 1: INTRODUCTION

1.1 Background and problem statements

The anesthesia machine has evolved to incorporate various mechanical, electrical and electronic components to be more appropriately called anesthesia workstation (Dorsch and Dorsch, 2007). Modern machines have overcome many drawbacks associated with the older machines. However, addition of several mechanical, electronic and electric components has contributed to recurrence of some of the older problems such as leak or obstruction attributable to newer gadgets and development of newer problems (Goneppanavar and Prabhu, 2013).

The scope of medical errors is a major concern to patients and healthcare workers alike. While anesthesiologists have done much to improve the reporting and reduction of errors, much work remains to be done (Demaria And Neustein, 2010). it makes sense to adopt policies which support the anesthesiologist in the completion of essential tasks. A pre-anesthesia timeout which addresses the presence of key safety components and which is separate from the surgical timeout used commonly in most OR's seems a logical step (Demaria and Neustein, 2010).

The anesthetist has a primary responsibility to understand the function of the anesthetic equipment and to check it before use. Anesthetists must not use equipment unless they have been trained to use it and are competent to do so (Hartle et al 2012). A pre-use check to ensure the correct functioning of anesthetic equipment is essential to patient safety. It must be emphasized that failure to check the anesthetic machine and⁄ or the breathing system features as a major contributory factor in many anesthetic misadventures, including some that have resulted in hypoxic brain damage or death.

1.2 Justification of the study

In anesthesia, human factors have contributed to greater complications than machine faults. Therefore, better understanding of the basics of anesthesia machine and checking each component of the machine for proper functioning prior to use is essential to minimize these hazards. Clear documentation of regular and appropriate servicing of the anesthesia machine, its components and their satisfactory functioning following servicing and repair is also equally important (Goneppanavar, and Prabhu, 2013).

The issue of anesthetic mishaps during surgery; human error and insufficient pre-anesthetic checking of the anesthesia machine are a recurring theme. Clinical studies(Craig and Wilson, 1981) also found that human error was responsible for 65% of the incidents "with failure to perform a pre-anesthetic check, the most common associated factor." Another study (Buffington, et al., 1984) noted that 31% of equipment problems involved the anesthesia machine and breathing circuit, with the main cause of human error being insufficient checking of the anesthesia machine before use, especially between cases. They stated, "In our study, human error was the main contributing factor in one-quarter of cases and most of these involved the anesthesia machine. The main cause was insufficient checking of the anesthesia machine before use, especially between cases." The possibility for error and cause for concern regarding anesthesia machine checks are very clear (Al Suhaibani et al 2014).

1.3 Research question

What is anesthesiologists' knowledge about anesthesia machines checkout?

1.4 Research objective

1.4.1. General objective:

The general objective of this study was to assess the anesthesiologists' knowledge about anesthesia machines checkout in Sana'a city, Yemen.

1.4.2. Specific Objectives:

1 To identify the anesthesiologists' knowledge about pressure system checkout
2 To assess the anesthesiologists' knowledge about scavenging system checkout
3 To identify the anesthesiologists' knowledge about breathing system checkout
4 To assess the anesthesiologists' knowledge about manual and automatic ventilation systems checkout
5 To identify the anesthesiologists' knowledge about final position checkout

Chapter two:

REVIEW OF LITERATURE

Chapter 2: Review of literature

2.1. Introduction

In its most basic form, the anesthesia machine receives medical gases from a gas supply, controls the flow and reduces the pressure of desired gases to a safe level, vaporizes volatile anesthetics into the final gas mixture, and delivers the gases to a breathing circuit connected to the patient's airway (Figure, 1) (Tinker & Morgan, 2003).

A mechanical ventilator attaches to the breathing circuit but can be excluded with a switch during spontaneous or manual (bag) ventilation. An auxiliary oxygen supply and suction regulator are also usually built into the workstation. In addition to standard safety features (Table, 1) (Morgan & Mikhail, 2013).

Top-of-the-line anesthesia machines have additional safety features, enhancements, and built-in computer processors that integrate and monitor all components, perform automated machine checkouts, and provide options such as automated recordkeeping and networking external monitors and hospital information systems. Some machines are designed specifically for mobility, magnetic resonance imaging (MRI) compatibility or compact (Morgan & Mikhail, 2013).

Table 2–1. Essential Safety Features on a Modern Anesthesia Workstation

Essential Features	**Purpose**
Non interchangeable gas-specific connections to pipeline inlets Diameter Index Safety Systems (DISS) with pressure gauges, filter, and check valve	Prevent incorrect pipeline attachments; detect failure, depletion, or fluctuation
Pin index safety system for cylinders with pressure gauges, and at least one oxygen cylinder	Prevent incorrect cylinder attachments; provide backup gas supply; detect depletion
Low oxygen pressure alarm	Detect oxygen supply failure at the common gas inlet
Minimum oxygen/nitrous oxide ratio controller device (hypoxic guard)	Prevent delivery of less than 21% oxygen

Oxygen failure safety device (shut-off or proportioning device)	Prevent administration of nitrous oxide or other gases when the oxygen supply fails
Oxygen must enter the common manifold downstream to other gases	Prevent hypoxia in event of proximal gas leak
Oxygen concentration monitor and alarm	Prevent administration of hypoxic gas mixtures in event of a low-pressure system leak; precisely regulate oxygen concentration
Automatically enabled essential alarms and monitors (eg, oxygen concentration)	Prevent use of the machine without essential monitors
Vaporizer interlock device	Prevent simultaneous administration of more than one volatile agent
Capnography and anesthetic gas measurement	Guide ventilation; prevent anesthetic overdose; help reduce awareness
Oxygen flush mechanism that does not pass through vaporizers	Rapidly refill or flush the breathing circuit
Breathing circuit pressure monitor and alarm	Prevent pulmonary barotrauma and detect sustained positive, high peak, and negative airway pressures
Exhaled volume monitor	Assess ventilation and prevent hypo- or hyperventilation
Pulse oximetry, blood pressure, and ECG monitoring	Provide minimal standard monitoring
Mechanical ventilator	Control alveolar ventilation more accurately and during muscle paralysis for prolonged periods
Backup battery	Provide temporary electrical power (> 30 min) to monitors and alarms in event of power failure
Scavenger system	Prevent contamination of operating room with waste anesthetic gases
(Morgan & Mikhail, 2013)	

2.2. Functions Of Anesthesia Machine

The machine performs four essential functions:

1. Provides O_2,
2. Accurately mixes anesthetic gases and vapors,
3. Enables patient ventilation ,

4. Minimizes anesthesia related risks to patients and staff (Moyle et al., 2000).

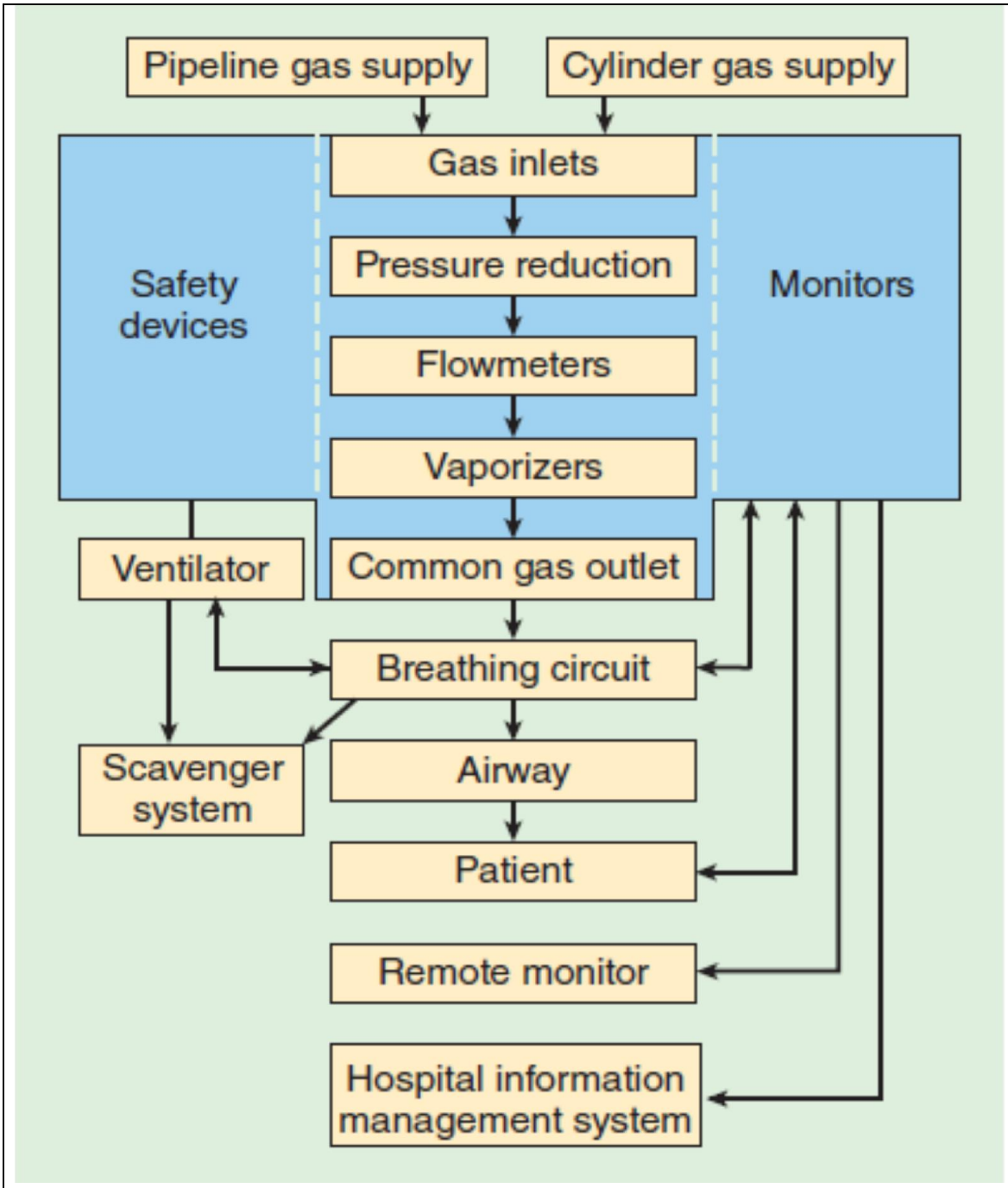


Figure (1): Schematic function anesthesia workstation

2.3. **Anesthesia work station** (Morgan & Mikhail, 2013)

1. Anesthesia machine
2. Gas supply
3. Flow meter

4. Vaporizer
5. Anesthesia machine ventilators
6. Breathing circuit &carbon dioxide absorber
7. Anesthesia machine checkout

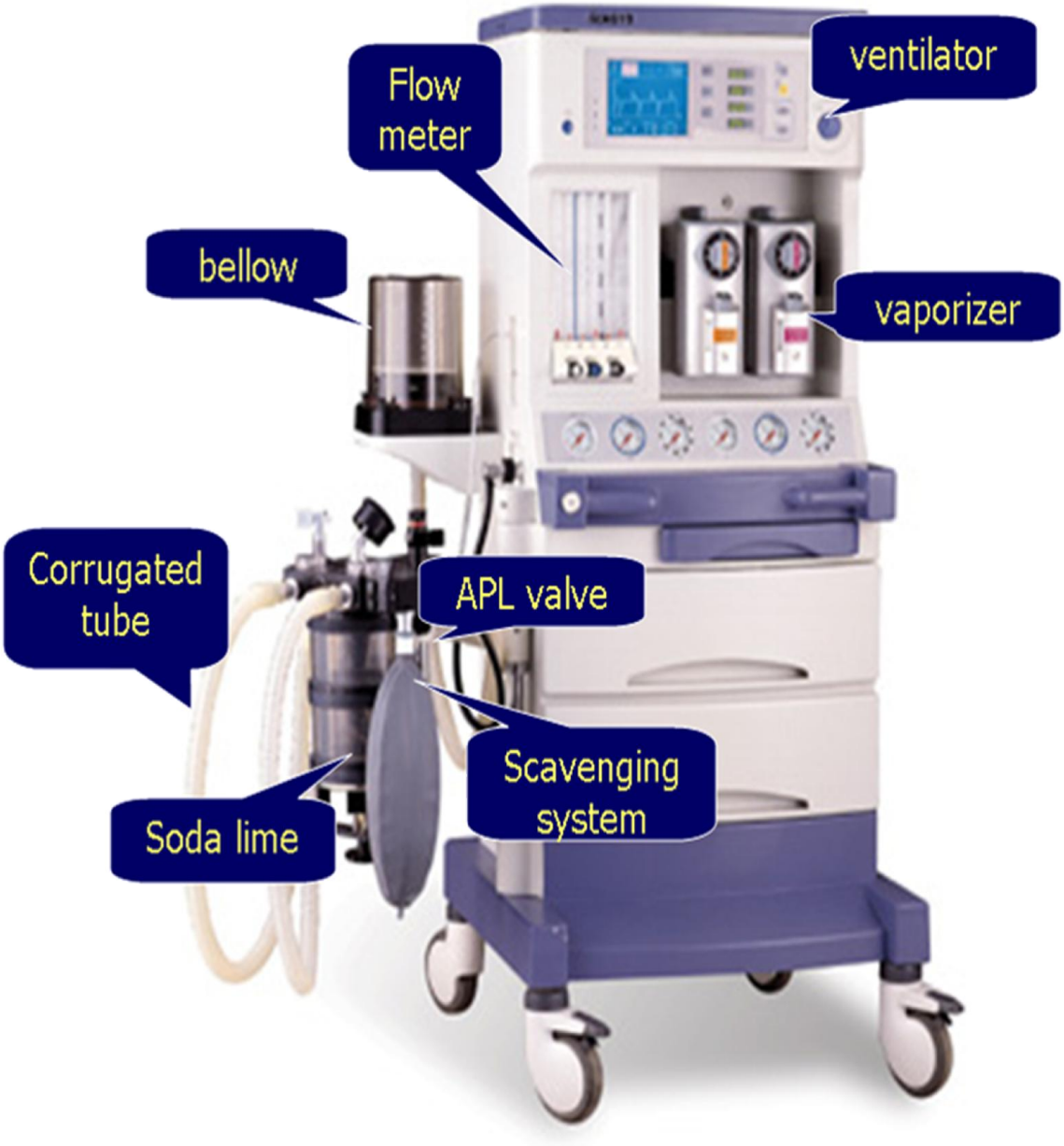
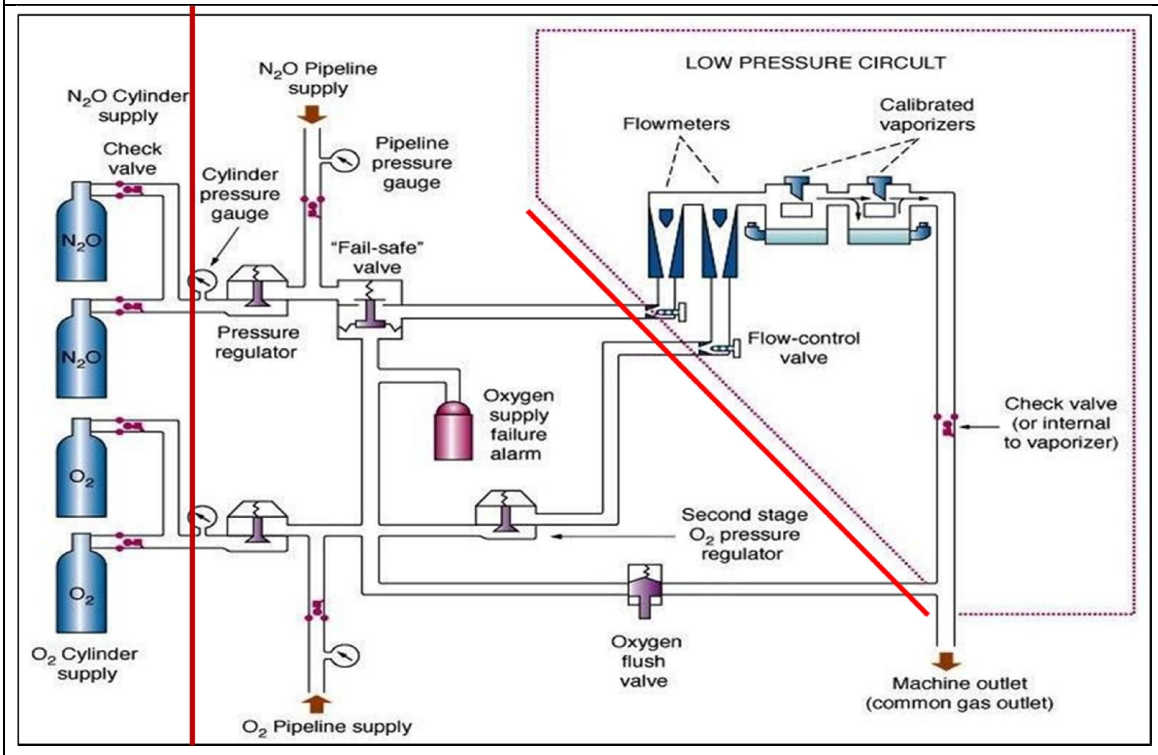


Figure (2): The Anesthesia Machine

(Wiliams & Wikins, 2006)

High Intermediate Low Pressure Circuit



Figures (3): The Anesthesia Machine

2.4. **Component of anesthesia machine** (Davis et al., 2000)

1. Gas supply source (pipe line and cylinder)
2. Check valve – for cylinder yolks
3. Pressure gauge –(pipe line and cylinder)
4. Pressure regulators (pressure reducing valve)
5. Oxygen supply pressure failure safety device
    - Pressure sensor shut off or "fail- safe "valve
    - Oxygen failure protection device (open)
    - Second stage pressure regulator
    - Oxygen supply failure alarm
6. Oxygen flush valve
7. Flow meters
8. Flow control valve
9. Oxygen ratio monitoring (flow proportioning) system
10. Check valve

Anesthesia machine components

Gas Delivery System:-

The anesthesia machine receives the two basic gases "O2" and"N2O" from tow supply sources :

A-Pipeline source

B-Cylinder source

A. Pipeline Supply Source

- Primary gas source for the anesthesia machine
- Gas enters anesthesia machine through the pipeline inlet connections
- Pipeline inlet fittings are gas specific Diameter Index Safety Systems (DISS) threaded body fittings (Tinker & Morgan, 2003).
- DISS provides threaded non interchangeable connections for medical gas lines which minimizes risk of misconnection Check valve:
  - located downstream from the inlet
  - prevents reverse flow of gases from machine to pipeline or the atmosphere Pipeline pressure gauge:
  - located on pipeline side rather than machine side of check valve
  - measured pressure truly reflects pipeline pressure instead of pressure within the machine “Quick connectors”:
  - Non interchangeable operating room wall pipeline connectors
  - gas specific
  - manufacturer specific (Davis et al., 2000)

B. Cylinder supply source

Medical gas cylinders are used to store compressed gases

Cylinder sizes are designated according to letters with size a being the smallest

Size E cylinders are most commonly used on anesthesia machines

Cylinders are color coded according to the gas they contain

Cylinders are attached to the anesthesia machine through the hanger yoke assembly Each hanger yoke is equipped with the Pin Index Safety System (PISS) – Figure 6 PISS discourages incorrect cylinder attachments

A check valve is located downstream from each cylinder

Check valve

Minimizes gas transfer from a cylinder at high pressure to one with lower pressure Allows an empty cylinder to be exchanged for a full one while gas flow continues from the other cylinder into the machine with minimal loss of gas Minimizes leakage from an open cylinder one to the atmosphere if cylinder is absent **O_2 cylinder – pressure reduced from 2200 psig to approx. 45 psig - N_2O cylinder – pressure reduced from745 psig to approx. 45 psig** (Morgan & Mikhail, 2013)

psig = pounds per square inch on the gauge (psig) [sometimes used for pounds per square inch (psi)]

Gauges record pressure above or below existing atmospheric pressure

Absolute pressure is designated psia (pounds per square inch absolute)

Thus 1 atmosphere = 760 mmHg = 14.7 psia = O psig (Morgan & Mikhail, 2013).

A-High Pressure System:

- Receives gasses from the high pressure E cylinders attached to the back of the anesthesia machine (2200 psig for O2, 745 psig for N2O).
- Consists of:
  - Hanger Yolk (reserve gas cylinder holder).
  - Check valve (prevent reverse flow of gas).
  - Cylinder Pressure Indicator (Gauge).
  - Pressure Reducing Device (Regulator).
- Usually not used, unless pipeline gas supply is off (Steolting & Miller, 2000).

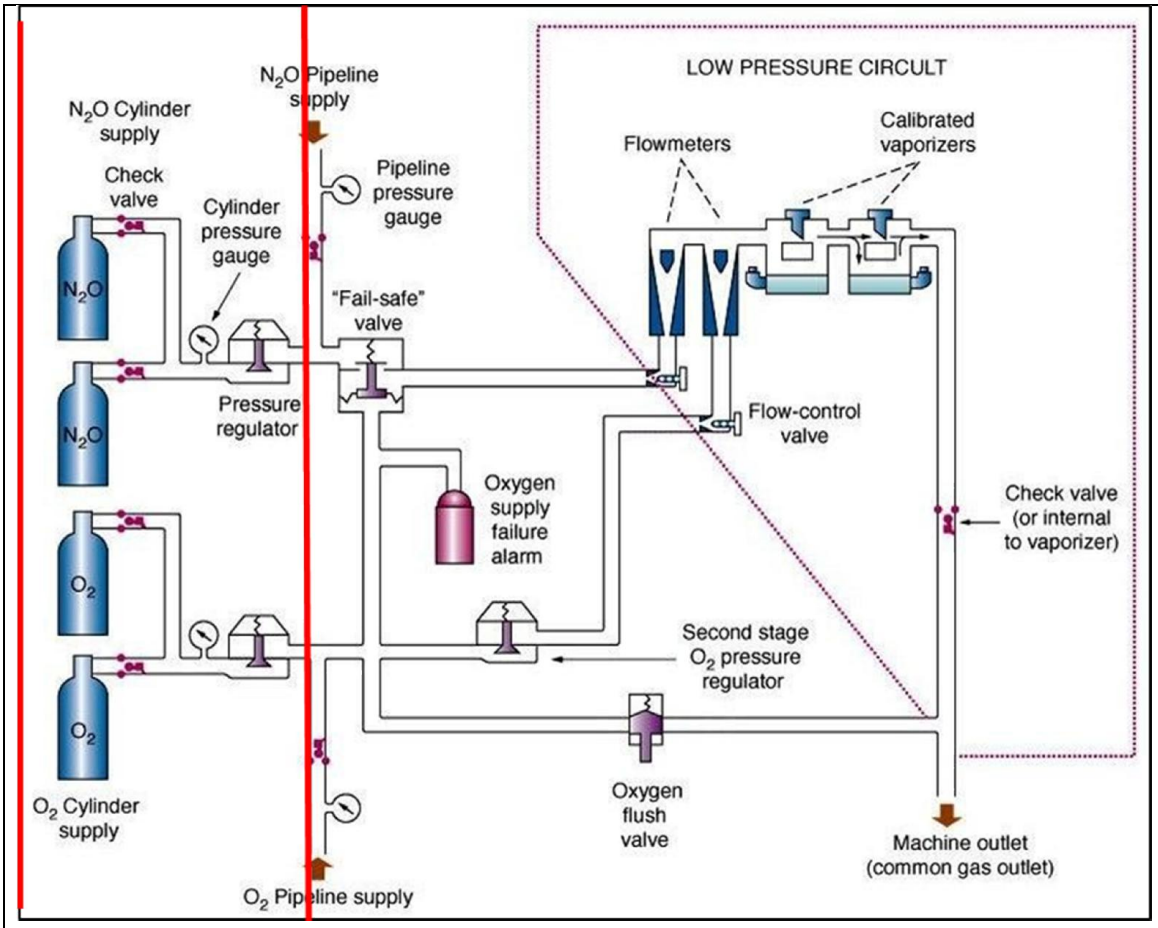


Figure (4): High pressure system

(Davis et al., 2000)

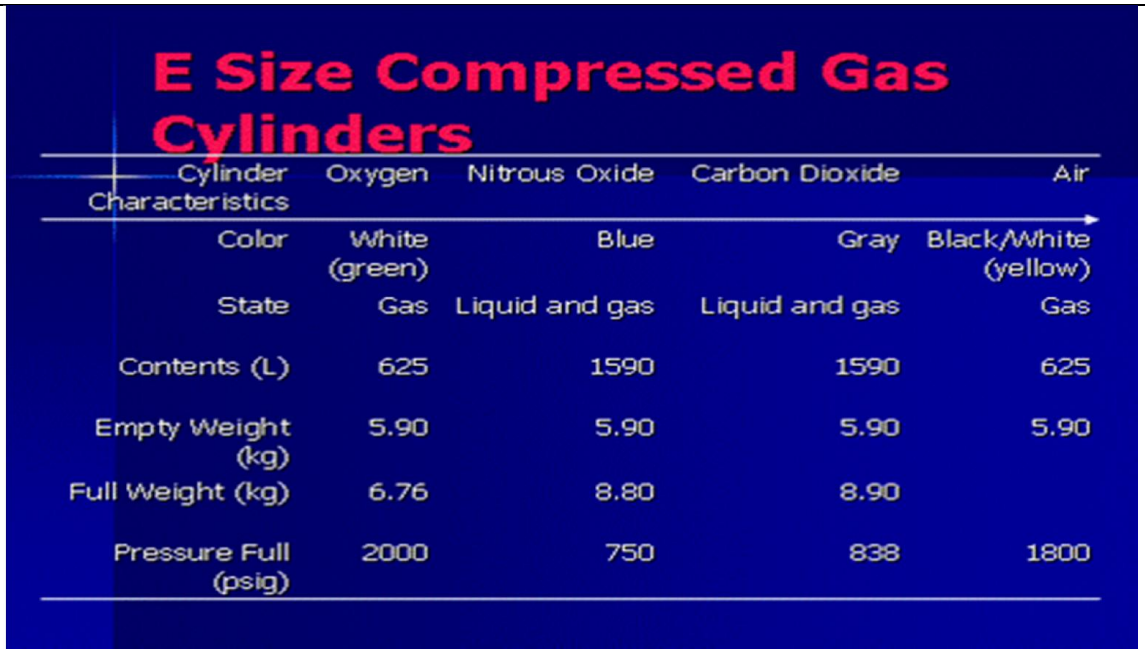


Figure (5): E Size compressed Gas Cylinder

(Davis et al., 2000)

High Pressure System:

1-Hanger Yolk

- Hanger Yolk: orients and supports the cylinder, providing a gas-tight seal and ensuring a unidirectional gas flow into the machine.
- Index pins: Pin Index Safety System (PISS) is gas specific prevents accidental rearrangement of cylinders (e.g.. switching O2 and N2O) (Morgan & Mikhail, 2006).

	**Figure (6): Hanger Yolk**

Cylinder yolk 2-

- Located downstream from each cylinder if a double-yoke assembly is use. Allows gas to enter the machine but does not allow gas to exit the yoke (Morgan & Mikhail, 2013).

<u>Functions</u>:

1. Minimizes gas transfer from a cylinder at high pressure to one with lower pressure .
2. Allows an empty cylinder to be exchanged for a full one while gas flow continues from the other cylinder into the machine with minimal loss of gas .
3. It minimizes leakage from an open cylinder to the atmosphere if one cylinder is absent .

3- Pressure gauges (Figures -7-.) – Cylinder and Pipeline

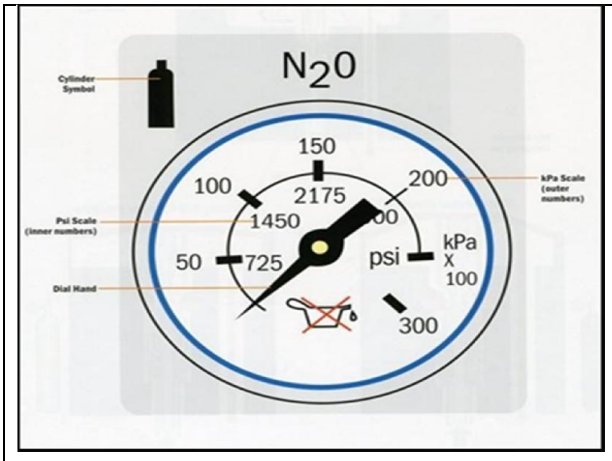


Figure (7): Cylinder and Pipeline Pressure gauges

Pipeline gauge – must be located on the pipeline side rather on the machine side of the check valve to truly reflect pipeline pressure instead of pressure within the machine .

Cylinder gauge – located downstream from the check valves.

When two reserve cylinders of the same gas are opened at the same time, it indicates the pressure in the cylinder with the higher pressure (Davis et al., 2000).

1 atm = 760 mm hg = 14.7 psia = 0 psig

Pressure gauges

NB this prevent gas use form the cylinder even if the cylinder is left open (saves the cylinder for backup if wall gas pipeline failure).

4-Pressure Regulator (a.k.a Pressure reducing valve) – Figures -8-.

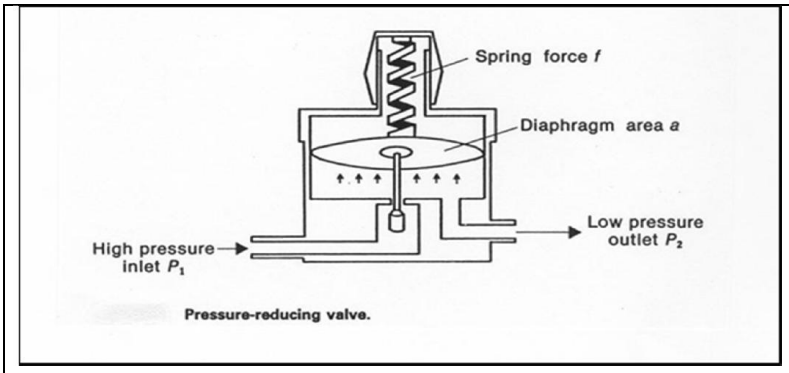


Figure (8): Pressure reducing valve

- Present in the cylinder supply source.
- It reduces the high and variable storage pressure in a cylinder to a lower, more constant pressure suitable for use in the anesthesia machine (Davis et al., 2000).

Oxygen: reduced from 2200 psig to 45 psig

N_2O: reduced from 745 psig to = 45 ps

Pipeline pressure is pre-regulated to 50 psig

B-Intermediate Pressure System: (Stoelting & Miller, 2000)

- Receives gasses from the regulator or the hospital pipeline at pressures of 40-55 psig
- Consists of:
  1. Pipeline inlet connections
  2. Pipeline pressure indicators
  3. Piping
  4. Gas power outlet
  5. Master switch
  6. Oxygen pressure failure devices
  7. Oxygen flush
  8. Additional reducing devices
  9. Flow control valves

Intermediate

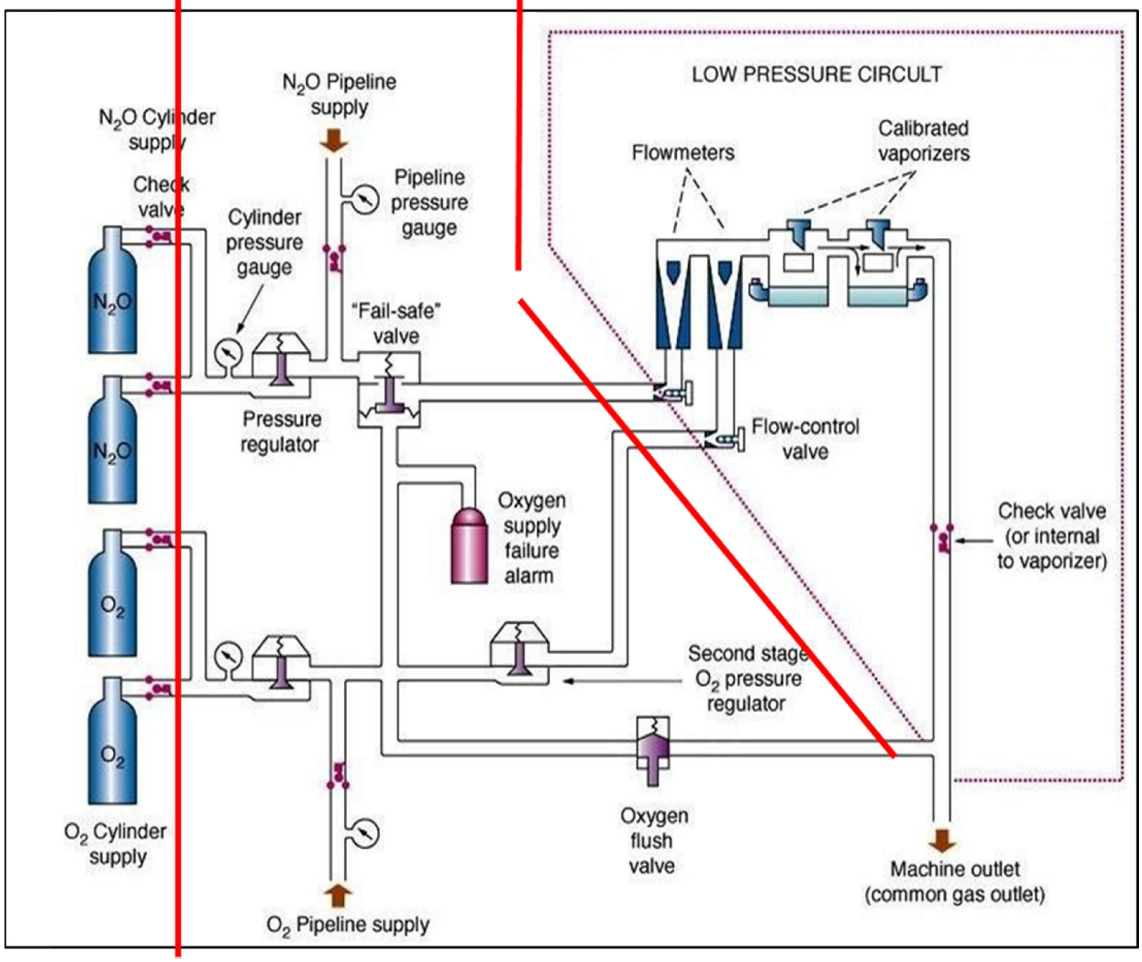


Figure (9): Intermediate Pressure System

Intermediate pressure content;

1- Pipeline Inlet Connections

- Mandatory N2O and O2, usually have air and suction too
- Inlets are no interchangeable due to specific threading as per the Diameter Index Safety System (DISS)
- Each inlet must contain a check valve to prevent reverse flow (similar to the cylinder yolk) (Davis et al., 2000)

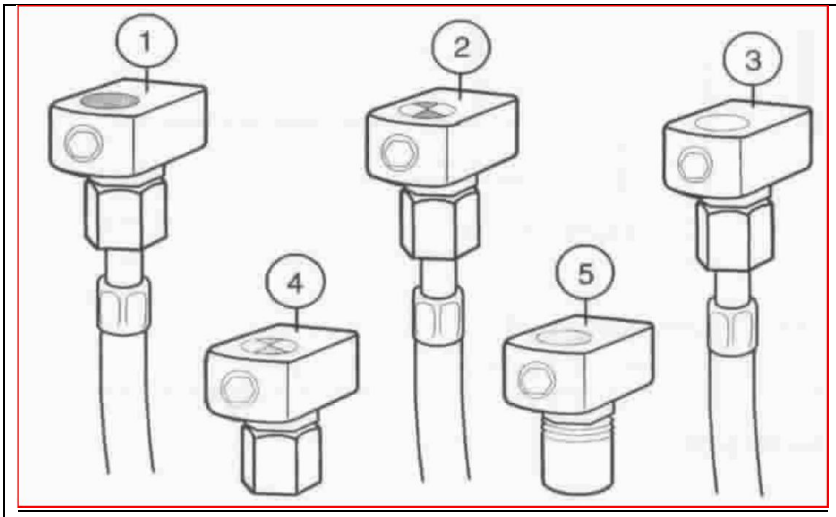


Figure (10 A): **Pipeline inlet connection**

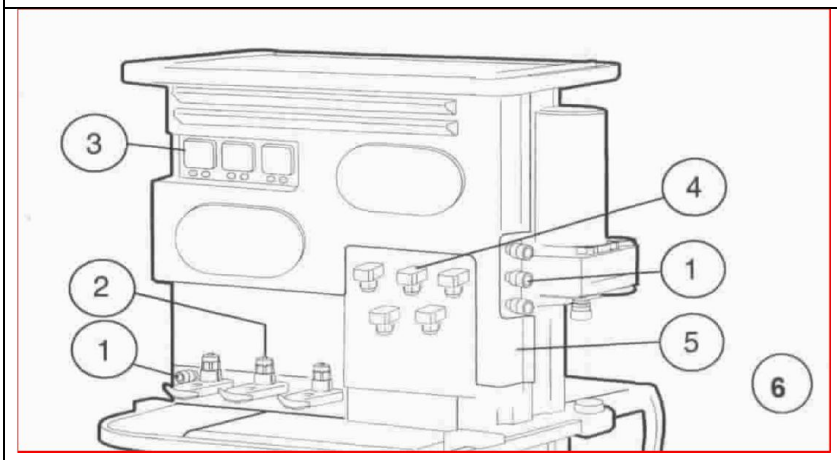


Figure (10 B): **Pipeline inlet connection**

2- Oxygen Supply Pressure Failure Safety Devices

A. **"Fail-safe" valve (Pressure-sensor shut off Valve)** – Ohmeda (Madison, USA 2003)

B. **Oxygen Failure Protection Device (OFPD)** – Dräger (Davis et al., 2000)

A) "Fail-safe" valve (Pressure-sensor shut off Valve)

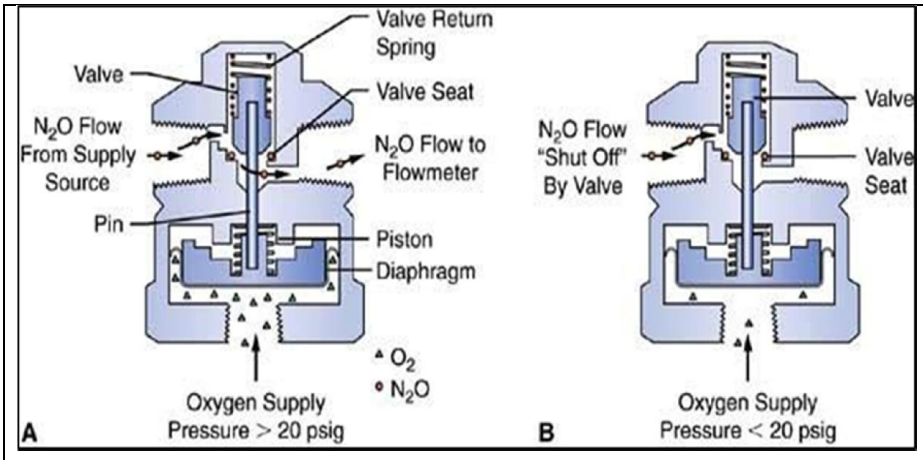


Figure (11): **Pressure-sensor shut off Valve**

Misnomer – not fail-safe .

- Present in gas line supplying each of the flowmeters except oxygen .
- **Controlled by oxygen supply pressure** .
- Interrupts the supplies of N_2O and other gases to their flowmeters if the O_2 supply pressure to the machine is reduced .
- It does not prevent delivery of a hypoxic mixture to the common gas outlet .
- Machines not equipped with a flow proportioning system can deliver a hypoxic mixture under normal working conditions.
    - Pressure sensor shut-off valve in the Ohmeda machine is an “all or nothing” or threshold arrangement that is open at O_2 pressures greater than 20-25 psig and closed at lower pressures (Morgan & Mikhail, 2013)

B) Oxygen Failure Protection Device (OFPD)

- Based on a proportioning principle rather than a shut-off principle
- Pressure of all gases controlled by the (OFPD)

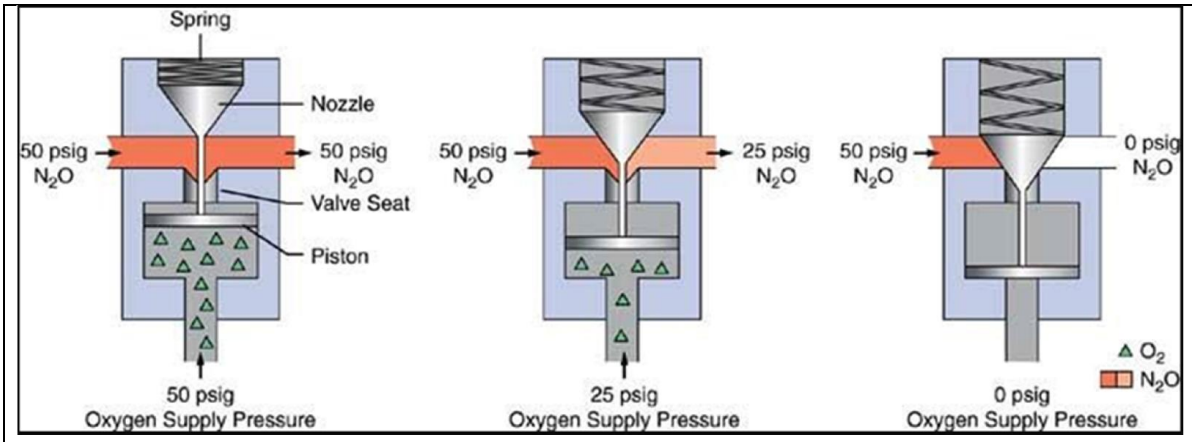


Figure (12): Oxygen Failure Protection Device

- Present in North American Dräger machines
- There is one for each gas supplied to the machine
- in the high pressure system for N_2O and any other gas supplied to the machine

- A decrease in O_2 pressure causes a proportionate decrease in the supply pressure of each of the other gases to their flowmeters
- Proportionally reduce and ultimately interrupt the supplies of N_2O and other gases to their flowmeters if O_2 supply pressure is reduced
- The supply of N_2O and other gases is completely interrupted when the pressure in the O_2 high pressure system falls below 24 psig (Davis et al., 2000).

2nd stage pressure regulator: Figures -13-.(A-B)

**** located : located just upstream of the (flow control valve)**

**** received : received gas from a pipeline or the cylinder reducing device and reduce it further to 26 psig for N2O &14 psig for O2.**

PURPOSE ; is to eliminate fluctuations in the pressure supplied to the flow indication caused by fluctuation in pipeline pressure (Madison, USA 2003).

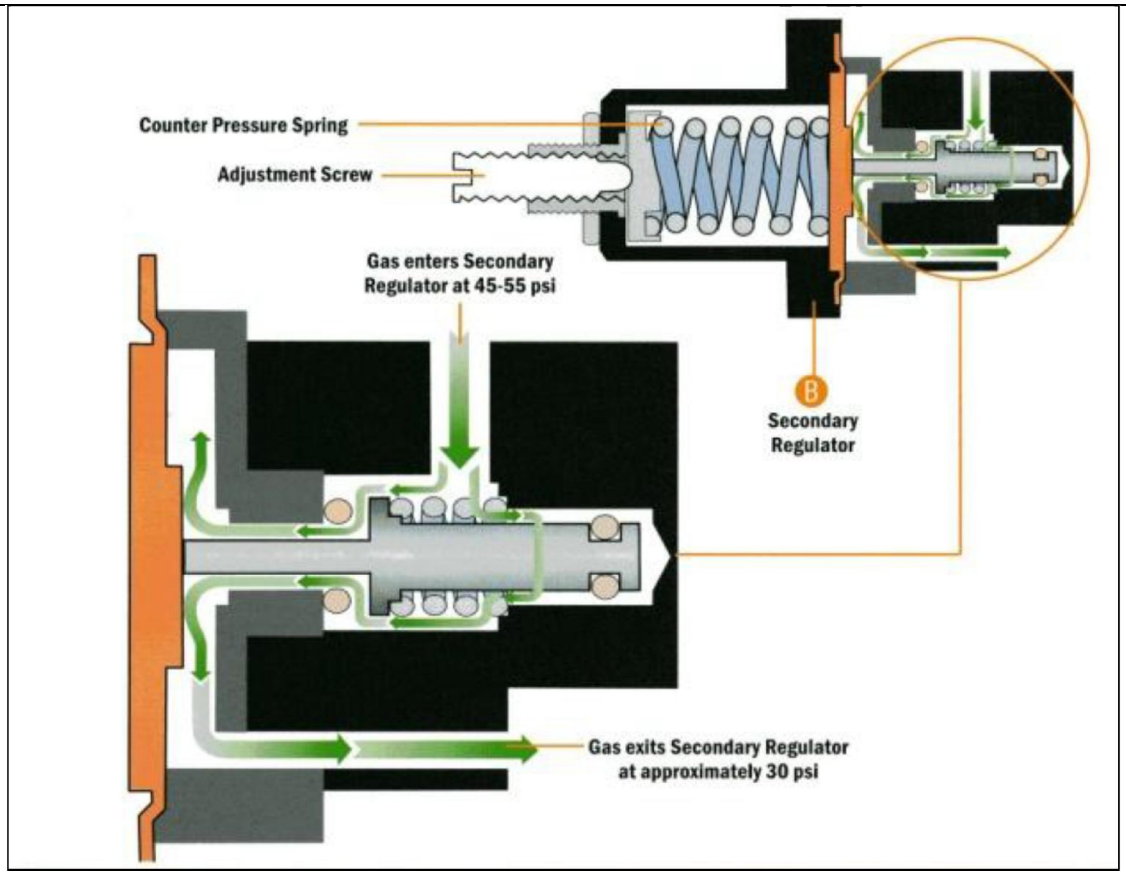
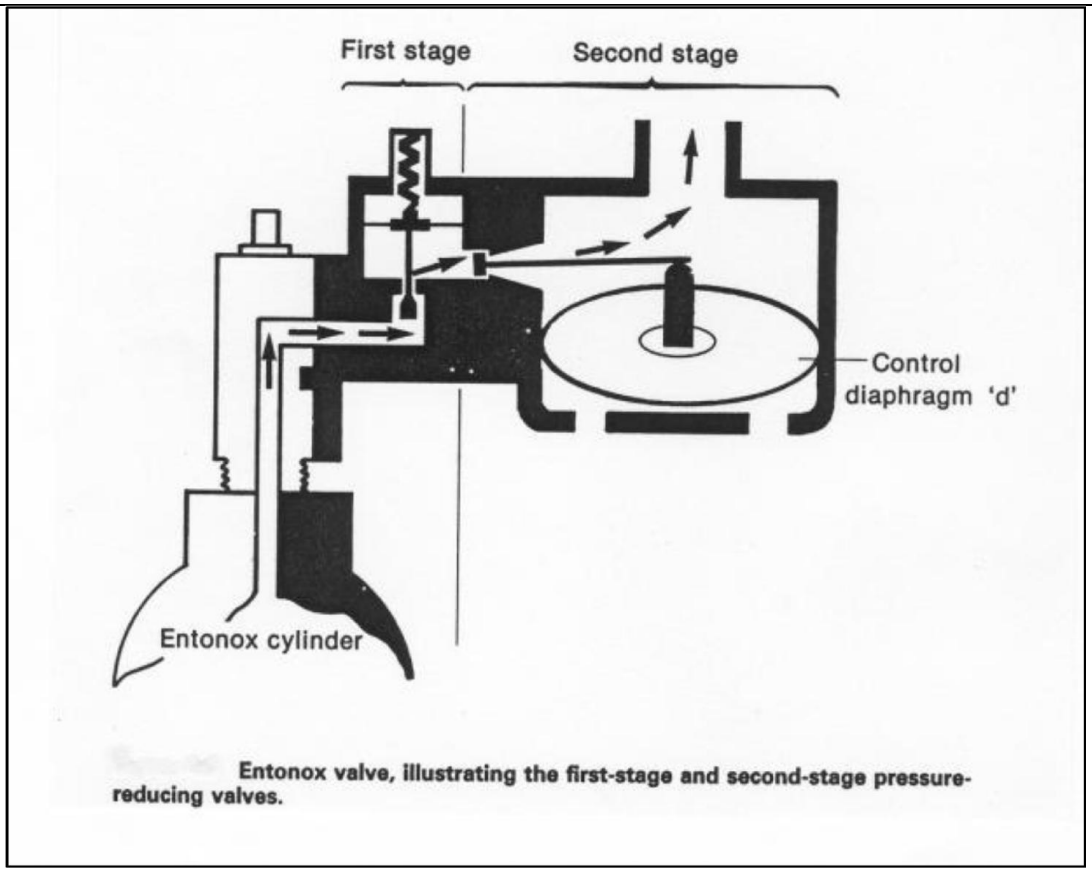


Figure 13 (A): pressure regulator



Entonox valve, illustrating the first-stage and second-stage pressure-reducing valves.

Figure 13 (B): **pressure regulator**

2nd stage pressure regulator – Figures -13-.(A-B)

- Present in contemporary Ohmeda machines .
- Regulates the O2 supply pressure to the flowmeter to **14 psig** .
- Regulates the N2O supply pressure to the flowmeter to **26 psig** .
- This ensures a constant supply pressure to the Ohmeda O2 flowmeter .
- Thus if the O2 supply pressure to the machine decreases below 45-50 psig, as long as it exceeds 14 psig, the flow set on the flowmeter is maintained (Madison, USA 2003).

Not present in the North American Dräger machine because the OFPD performs this function

3- O_2 supply failure alarm Figures -14-

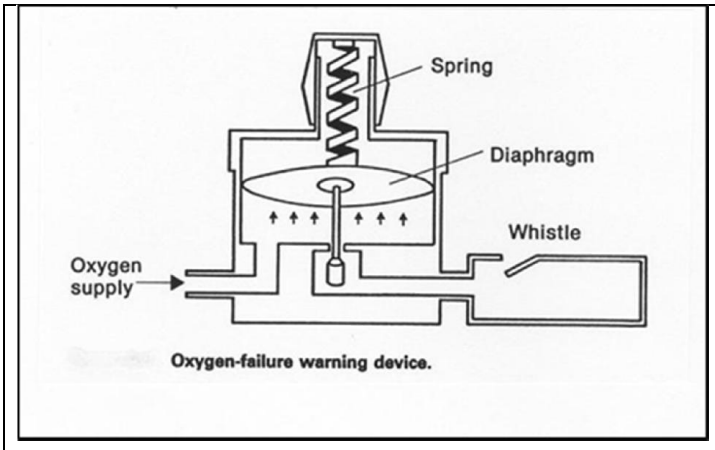


Figure (14): **O_2 supply failure alarm**

- O_2 pressurizes an O_2 failure alarm system .
- If O_2 supply pressure falls (usually below 30 psig) an alarm sounds .
- Emits an audible alarm for at least 7 seconds when the pressure falls bellow threshold In some machines, a pressure-operated electrical switch ensures a continuous audible alarm whenever the O_2supply pressure falls below the threshold setting (Davis et al., 2000).

4- OXYGEN FLUSH VALVE :-

☒ Receives O2 from pipeline inlet or cylinder reducing device and directs high, unmetered flow directly to the common gas outlet (downstream of the vaporizer) .

☒ Machine standard requires that the flow be between 35 and 75 L/min .

☒ The ability to provide jet ventilation .

☒ Hazards :-

- May cause barotrauma .
- Dilution of inhaled anesthetic .

<u>Oxygen Flush Valve</u> Figures -15-(A+B)

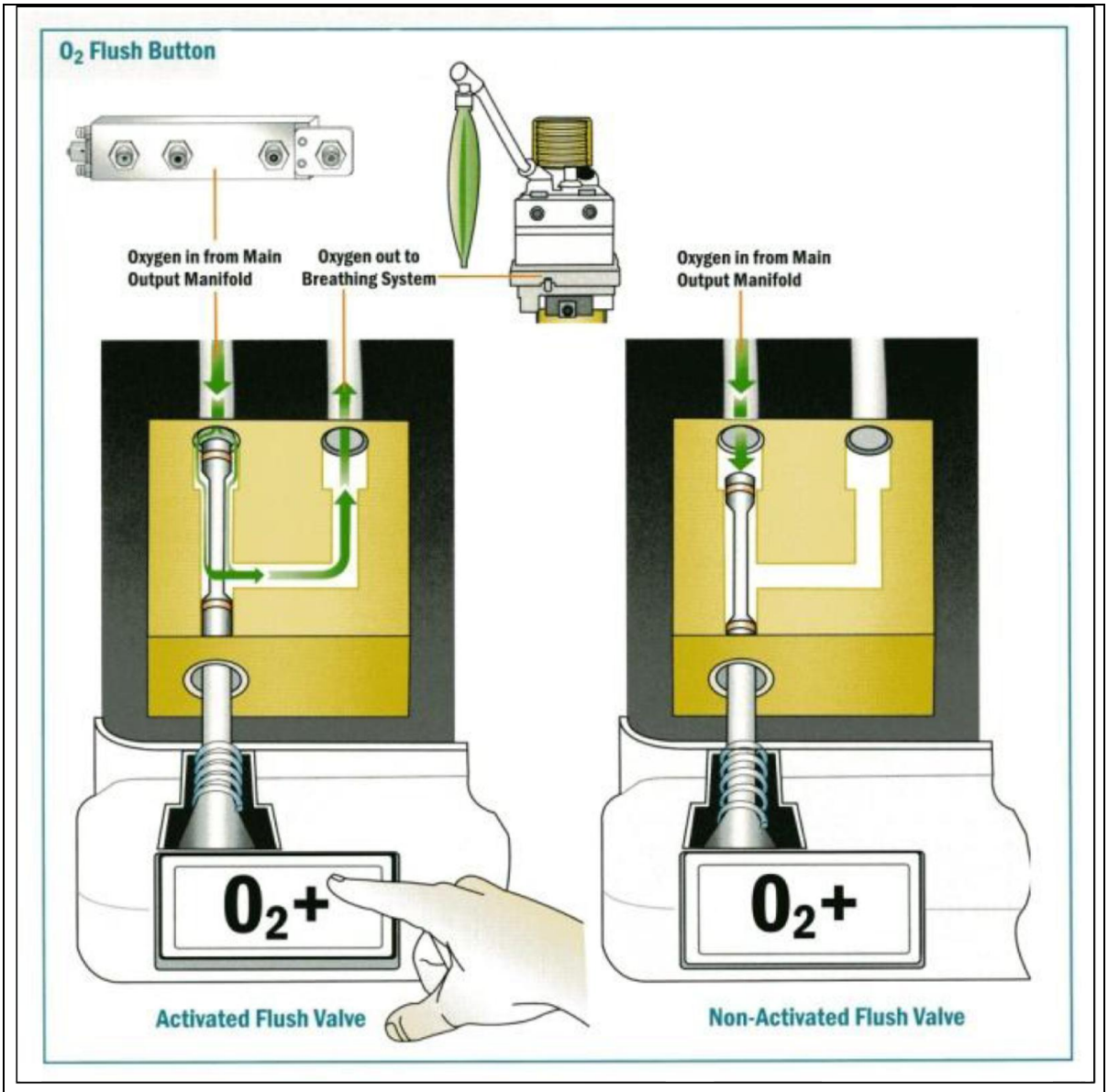


Figure (15 - A): Oxygen Flush Valve

(Morgan & Mikhail, 2013)

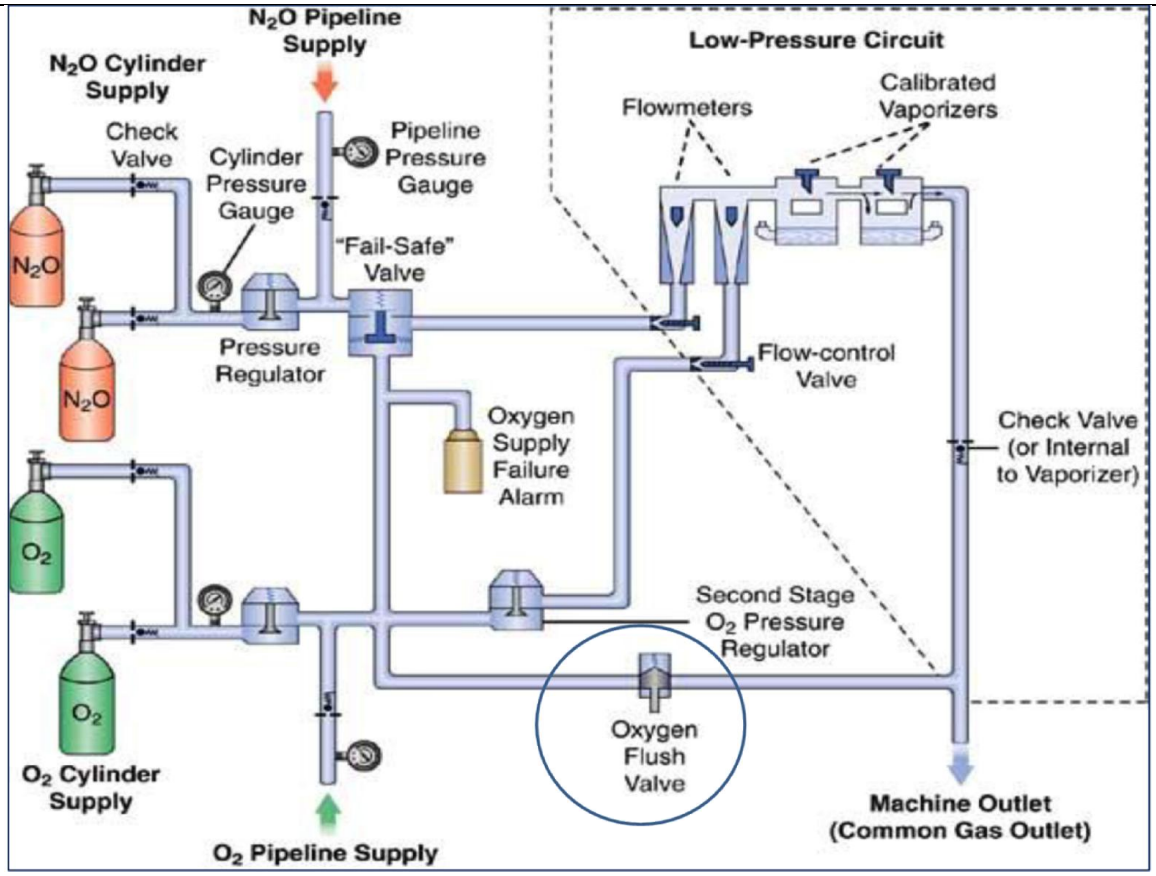


Figure (15 - B): Oxygen Flush Valve

(Davis et al., 2000)

OXYGEN FLUSH VALVE

- Provides a high flow (35-75 L/min) of oxygen directly to the common gas outlet .
- Bypasses the flow meters and vaporizers .
- Exposes the patient circuit to the line pressure of 45-55 psig – potential for barotrauma especially during inspiration delivered by anesthesia ventilator .
- A protective rim reduces the possibility of unintentional activation . Cases of awareness have been reported (Morgan et al., 2006)

C- Low Pressure System

- Extends from the flow control valves to the common gas outlet
- Consists of:

1. Flow meters
2. Vaporizer mounting device
3. Check valve
4. Common gas outlet

Low Pressure System

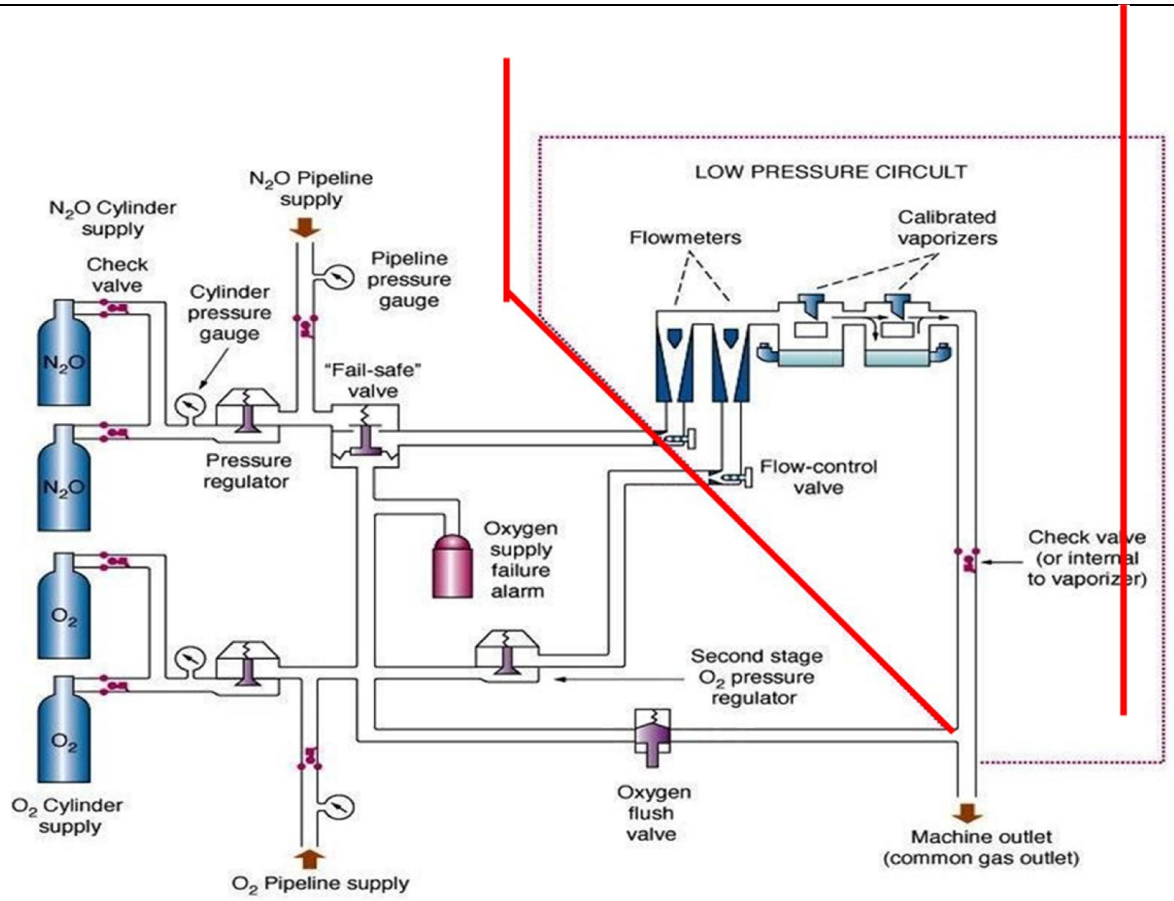


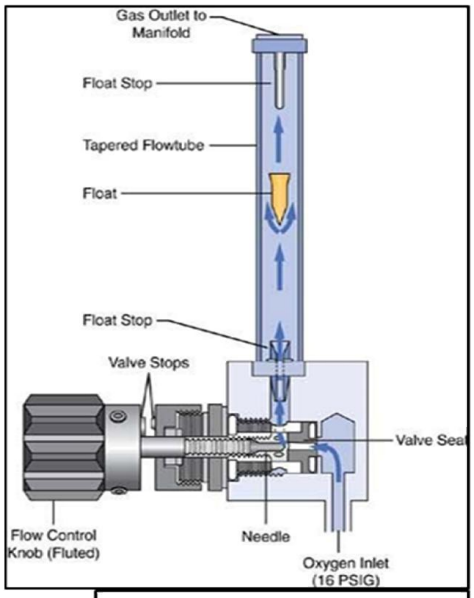
Figure (16): Low Pressure System

(Davis et al., 2000)

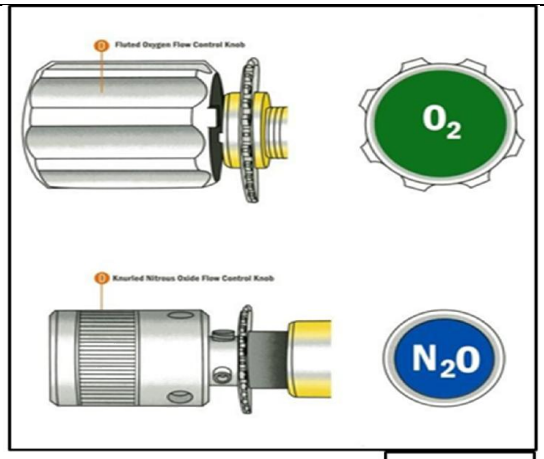
1- Flow meters

Figures -17-(A+B+C+D)

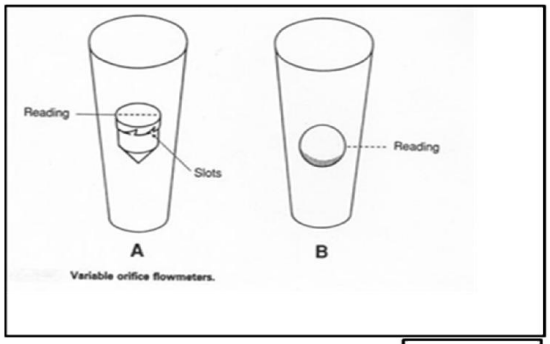
- Flow meters adjust the proportions of medical gases controlled by the anesthesia machine as well as the total gas flows delivered to the patient circuit
- Most flow meters measure the drop in pressure that occurs when a gas passes through a resistance and correlates this pressure drop to flow



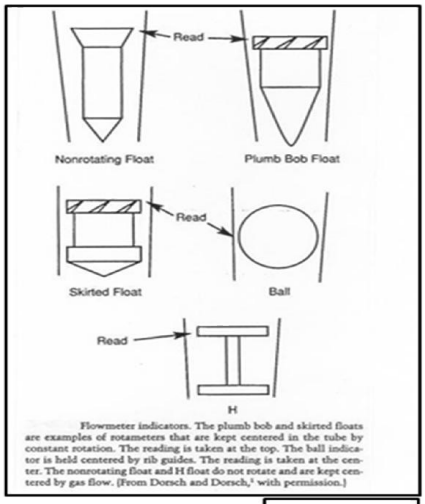
Figures -17 A



Figures -17 B



Figures -17 C



Figures -17 D

Figure 17: A: needle valve; B: knob of flow control valve; C: glass tube with bobbin; D: differential bobbin float

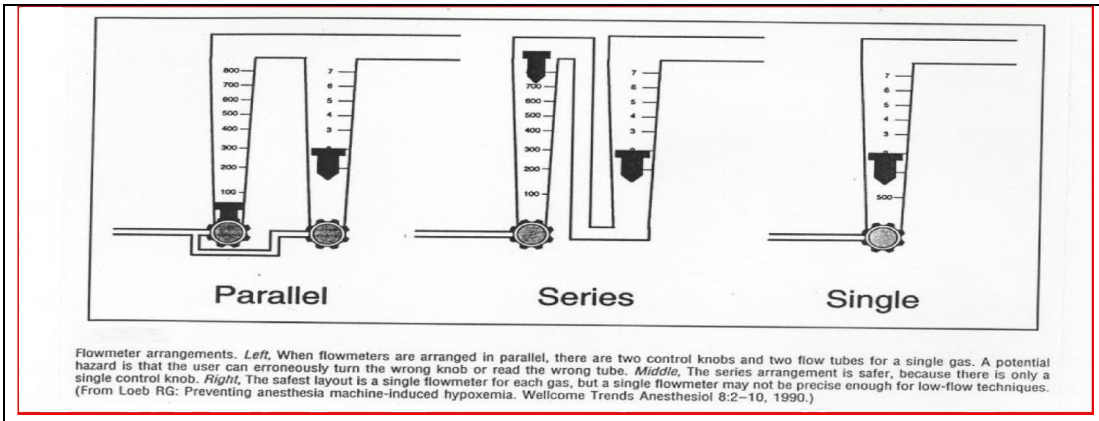


Figure 17 E: Arrangement of the Flow-Indicator Tubes

(Al-Sheikh & Stacey, 2002)

Types of flowmeters

1. Variable orifice flow meters (fixed pressure difference)
2. Fixed orifice flow meters (variable pressure difference)

Variable orifice flowmeters (fixed pressure difference) – [Synonym Rota meter] (Dorsch & Dorsch, 1999)

- This is the type used today in modern machines
- Adjusts gas flow by means of flow control needle valves and flow tubes
- Gas is led to the base of a glass tube, slightly smaller on cross-section at bottom than at top (tapered tube)
- light metal float (bobbin) rides the gas jet
- As the bobbin rises with increased flow, the size of the annulus between it and the glass tube increases. In other words, there is a variable orifice around the bobbin which depends on the gas flow
- The pressure across the bobbin remains constant because it gives rise to a force which balances the force of gravity on the bobbin
- The increase in the area of the annular orifice as the bobbin rises reduces flow resistance at higher flows and so the pressure across the bobbin stays constant, despite the flow increase
- Small notches are placed around the top of the bobbin causing it to rotate centrally in the gas flow
- Readings are made from the upper surface of the bobbin (or in the middle of a ball)
- The glass tubes must be vertical, clean and the float should rotate freely
- A wire stop keeps the float in sight at the top
- The area between the outside of the bobbin and the inside of the tapered glass tube represents a variable orifice (**Figures -18-B**)
- A certain pressure difference across the bobbin is required to “float” the bobbin

- As the orifice widens, greater flows are required to create the same pressure difference across the bobbin, which floats higher in the tapered glass tube

<u>Design Principles</u> Figures -18-A

Calibration of the glass tubes takes into account both the **density** and the **viscosity** of the gases passing through them

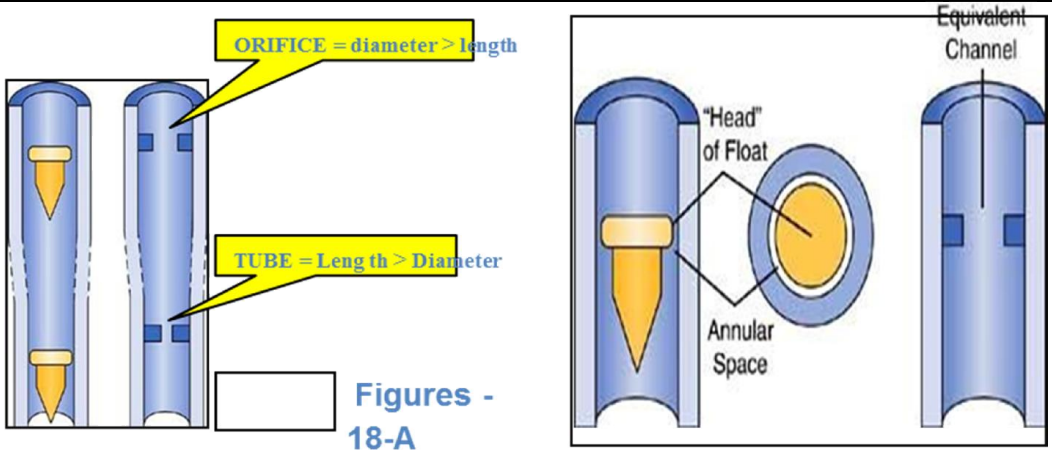
At low flows:

- viscosity is important because gas flow around the bobbin approximates to tubular flow (diameter of channel less than length)
- gas flow is laminar .

At high flows:

- density is important because gas is flowing around the bobbin through an orifice (diameter of channel greater than length) .
- gas flow is turbulent.

Tube = Length > Diameter /// Orifice = Diameter > Length



Figures -18 A & B: design principle tube and orifice

(Davis et al., 2000)

Arrangement of the Flow-Indicator Tubes (Fig. 17 E)

- There may be one or two rota meters for each gas
- If two are present for any gas, the first permits accurate measurement of low flows (usually up to 1 L/min) and the other, of flows up to 10-12 L/min
- Flow indicator tubes for different gases are grouped side by side
- The various gas flows meet at the common manifold (mixing chamber) at the top
- In such a case, the tubes may be arranged either in parallel or in series (Al-Sheikh & Stacey, 2000).

Parallel arrangement:

- Two complete flow indicator assemblies with a flow control valve for each assembly
- The total flow of the gas to the common manifold is the sum of the flows on both flow indicators
- **Not presently available because accidental use of low-flow oxygen flow indicator when a high flow is intended is a hazard whenever two oxygen flow control knobs are present**

Series (tandem) arrangement:

- One flow control valve for the two flow indicator tubes
- Gas from the flow control valve first passes through a tube calibrated up to 1 liter per minute, then passes to a second tube that is calibrated for higher flows
- Total flow is not the sum of the two tubes but that shown in the higher flow tube
- Tandem flow tubes increase accuracy at all flow rates (Al-Sheikh & Stacey, 2000).

Flow Control Needle Valve;

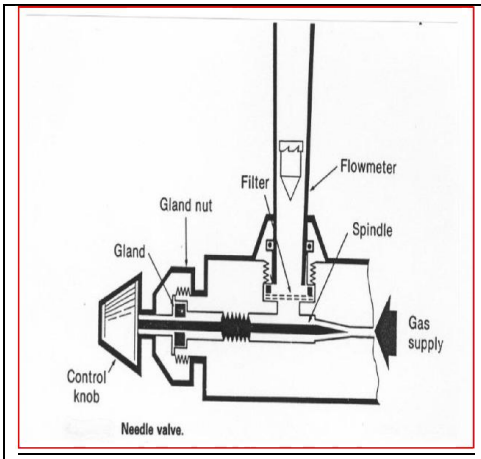


figure-17- F

In the needle valve there is a spindle, attached to a control knob which screws into the seating of the inlet to turn off the gas supply to the flow meter above

Leakage of gas around the spindle is prevented by a gland with its gland nut

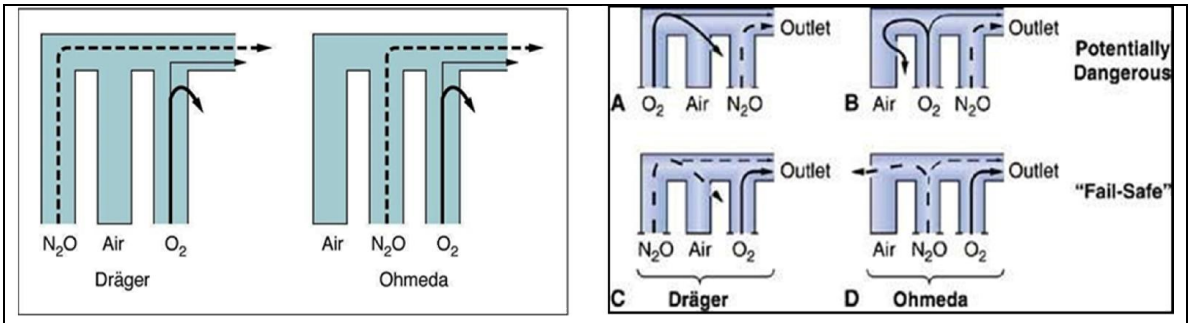
A gland is a washer of compressible material

At the bottom of each flow meter a dust filter of sintered metal is also present

The flow control valves on contemporary North American Dräger Machines are supplied by 50 psig

Flow control valves on Ohmeda machines are supplied by precision second-stage pressure regulators (Oxygen 14 psig; N2O 26 psig)

FLOW METER SEQUENCE – Figures -19-A and B



Figures -19-A and B: Flow Meter Sequence

(Morgan & Mikhail, 2013)

- The O_2 flow meter is positioned on the right side **(most distally)** of the rot meter bank, downstream from the other flow meters and closest to the common gas outlet
- In the event of a leak in one of the other flow meter tubes, this position is the one least likely to result in a hypoxic mixture
- In the presence of a flow meter leak (either at the "O" ring or the glass of the flow tube) a hypoxic mixture is less likely to occur if the O2 flow meter is downstream of all other flow meters
- In A and B a hypoxic mixture can result because a substantial portion of oxygen flow passes through the leak, and all nitrous oxide is directed to the common gas outlet (Davis et al., 2000).

  ** **Note** that a leak in the oxygen flow meter tube can cause a hypoxic mixture, even when oxygen is located in the downstream position*

<u>Oxygen ratio monitoring & Proportioning Systems</u> (Morgan & Mikhail, 2013)

- Protection against hypoxic mixture at the Flow meter level
- Prevention of delivery of a hypoxic gas mixture is a major consideration in the design of contemporary anesthesia machines
- In modern anesthesia machines, N_2O and O_2 flow controls are physically interlinked so that a fresh gas mixture containing at least 25% O_2 is delivered at the flow meters when only N_2O and O_2 are used

Ohmeda = mechanical interlink (Link–25)

North American Dräger = mechanical + pneumatic interlink

Ohmeda Link – 25 Proportioning System Figures -20-

The "fail-safe" system (previously discussed) only serves to interrupt *(Ohmeda: Pressure Sensor Shut-off valve)* or proportionally reduce and ultimately interrupt. *(North American Dräger: OFPD)* the supplies of N_2O and other gases to their flow meters if the O_2 supply to the machine is reduced. It does not prevent the delivery of a hypoxic mixture to the common gas outlet

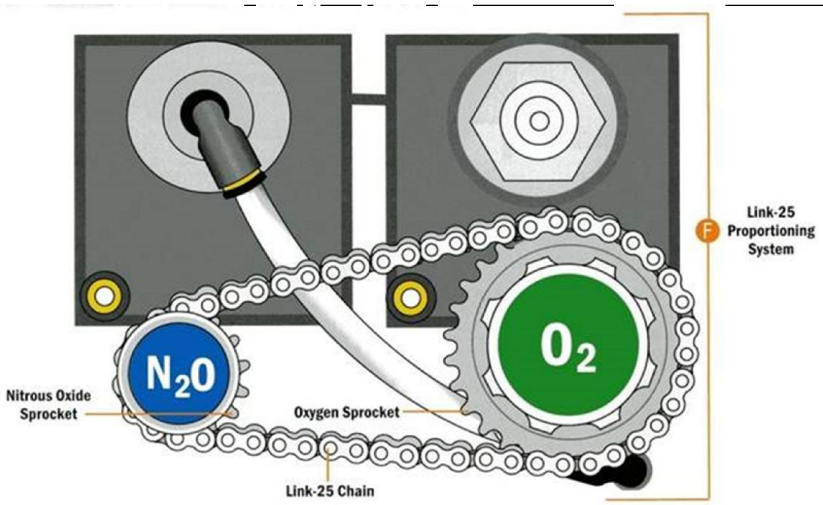


Figure 20: Ohmeda Link – 25 Proportioning System
(14 Gear N2O)
(29 Gear O2)

- A gear with 14 teeth is integral with the N_2O flow control spindle.
- A gear with 29 teeth "floats" on a threaded O_2 flow control valve spindle .
- The two gears are connected by a precision link chain .
- For every 2.07 revolutions of the N_2O flow control spindle, an O_2 flow control, set to the lowest O_2 flow, rotates once because of the 14:29 ratio of the gear teeth
- O_2 flow control spindle gear is thread-mounted so it can rotate on the control valve spindle like a nut and bolt (rather than being integral

with the spindle), therefore O_2 flow can be increased independently of N_2O

- Regardless, of the O_2 flow set, if the flow of N_2O is increased sufficiently, the gear on O_2 spindle will engage with the O_2 flow control knob causing it to rotate and thereby causing O_2 flow to increase **Figures -21-A& B**

- If N_2O flow is reduced, the O_2 flow remains high unless it is deliberately reduced by the user
- The Link-25 system permits the N_2O and O_2 flow control valves to be set independently of one another, but whenever N_2O concentration of more than 75% is accidentally set, the O_2 flow is automatically increased to maintain at least 25% O_2 in the resulting mixture (Morgan & Mikhail, 2013).

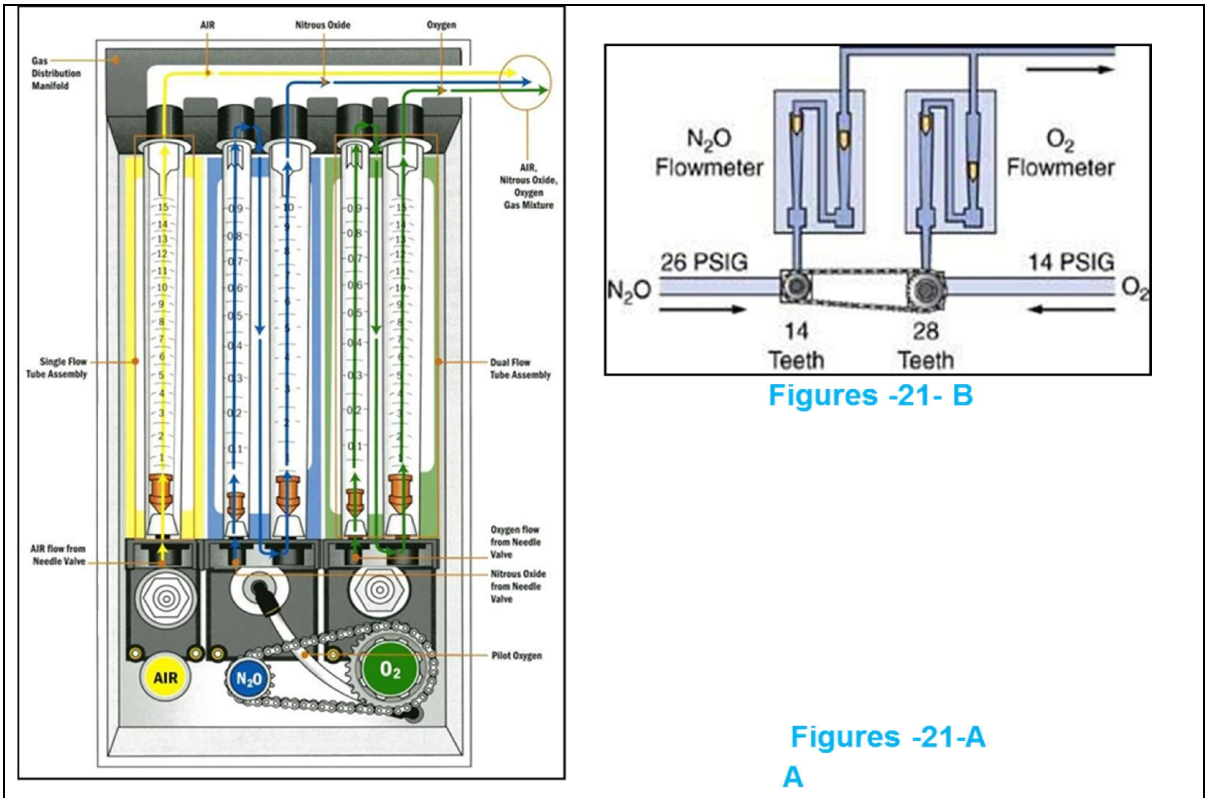


Figure 21 A&B: A: design of Ohmeda Flowmeter Link 25; B: simple design of proportional System

If the anesthesia machine has flow controls for other gases (e.g., helium, air), a gas mixture containing less than 25% O_2 could be potentially set at the flow meters

Summary:-

Proportioning Systems function

- *Mechanical* integration of the N2O and O2 flow-control valves .
- Automatically intercedes to maintain a minimum 25% concentration of oxygen with a maximum N2O:O2 ratio of 3:1 .
- Limitation of proportioning system
- Machines equipped with proportioning systems can still deliver a hypoxic mixture under the following conditions: -
    - Wrong supply gas .
    - Defective pneumatics or mechanics (e.g.. The Link-25 depends on a properly functioning second stage regulator).
    - Leak downstream (e.g.. Broken oxygen flow tube) .
    - Inert gas administration: Proportioning systems generally link only N2O and O2

Flowmeter Problems

Temperature and Pressure Effects

- Changes in temperature and pressure alter both viscosity and density of gases, thereby affecting accuracy of the indicator on the flow meters which are calibrated at atmospheric pressure (760 mmHg) and room temperature (20 C^0).
- Temperature effects are slight and do not cause significant changes .
- As altitude increases, barometric pressure decreases resulting in increased flow .

- At low flow rates, flow is laminar and dependent on gas viscosity, a property not affected by altitude .
- At high flow rates flow becomes turbulent, and flow becomes a function of density, a property that is influenced by altitude .
- The resulting decreases in density will increase the actual flow rate so the flow meter will read lower than the actual flow rate .
- At increased pressure, as in a hyperbaric chamber, the reverse is seen; the delivered flow rate is slightly less than the set flow rate .

Back Pressure

- In machines without an outlet check valve, if pressure at the common gas outlet increases, this is transmitted back to the flow meters, compressing the gas above the float Pressure above the indicator rises forcing the float down, causing the flow meter to be read lower than the actual gas flow rate.

Static Electriciyt

- Static electricity causes the float to stick to the side of the tube causing reading inaccuracy .
- These electrostatic charges are negligible as long as the float rotates freely .
- Moisture or antistatic spray applied to the outside of the tube will successfully remove charges .

Hidden Floats

- The float may adhere to the stop at the top of the tube even if no gas is flowing .

  The float may disappear from view if there is no stop present e.g. broken float stop (Morgan & Mikhail, 2013).

***2-Vaporizers*:-**

- A vaporizer- is an instrument designed to change a liquid anesthetic agent into its vapor and add a controlled amount of this vapor to the fresh gas flow.
- Vaporizer - device for adding clinically useful concentrations of anesthetic vapor to a stream of carrier gas .

Vapor - gas phase of an agent that is normally liquid at room temperature and atmospheric pressure (Moyle et al., 2000).

Figure 22: External Form Vaporizer

(Mitchel & Sasis, 1997)

Vaporizers function :- (Morgan & Mikhail, 2013)

1. Vaporizers facilitate the change of a liquid anesthetic into its vapor phase .
2. Carrier vaporize of volatile anesthetic in to the final gas mixture .

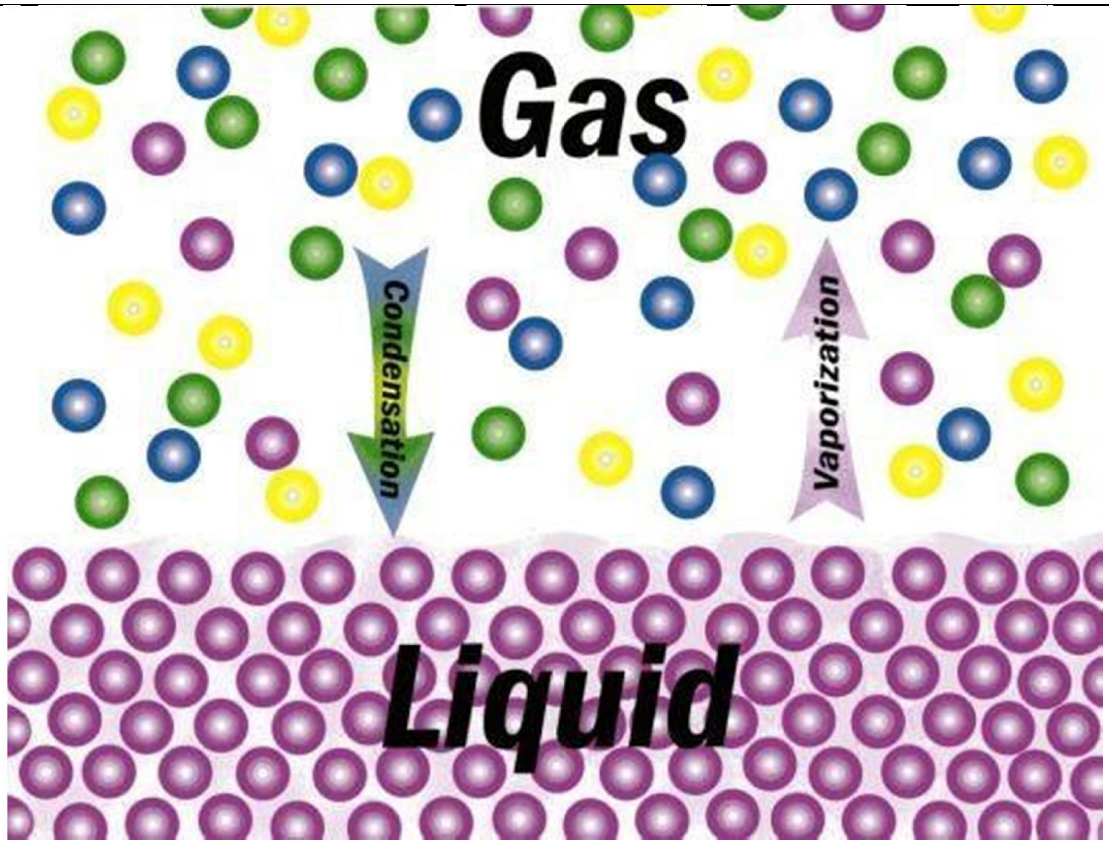


Figure (23): Illustration Vaporization With Condensation Vaporizer Function

(Morgan & Mikhail, 2013)

This illustration appear when a volatile liquid is in a closed container, some molecules escape from the surface of the liquid to enter the space above as vapor until the number of molecules in the vapor phase is constant.

These molecules bombard the walls of the container and create a pressure known as the saturated vapor pressure (SVP).

Under steady conditions of temperature, an equilibrium is established between the molecules in the vapor phase and those in the liquid phase .

If the temperature is increased, more molecules enter the vapor phase (evaporate), resulting in an increase in vapor pressure .

When the gas phase above the liquid contains all the vapor it can hold at that temperature, it is said to be saturated .

Vapor pressure is independent of atmospheric pressure but only on temperature and physical characteristics of the liquid .

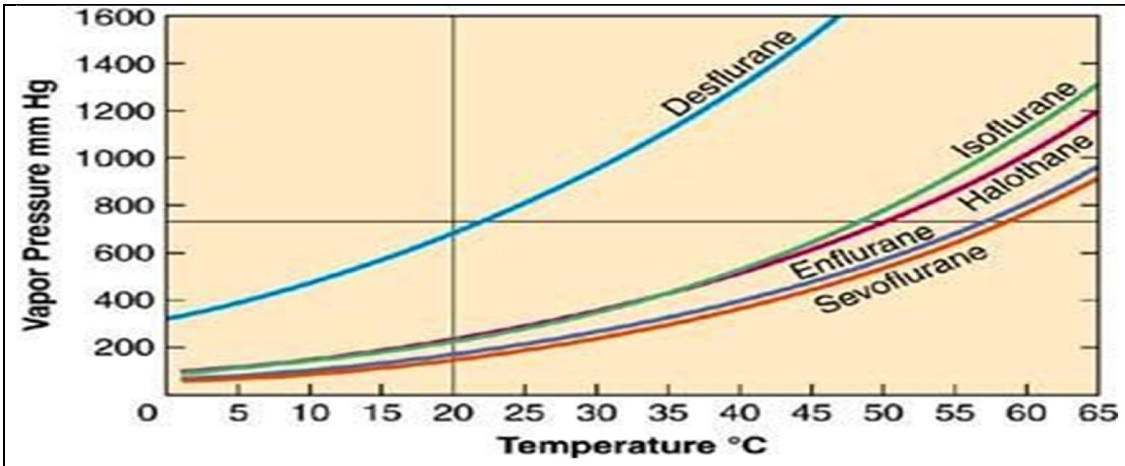


Figure (24): illustrates vapor pressure curves for the various volatile anesthetic agents at temperature

(Morgan et al., 2006)

This illustrates vapor pressure curves for the various volatile anesthetic agents.

Types of vaporizers:-

A. *Physics of Vaporization*
B. *Copper Kettle*

   The copper kettle vaporizer is no longer used in clinical anesthesia;

C. *Modern Conventional Vaporizers:* (Davis et al., 2000)

   All modern vaporizers are agent specific and temperature corrected, capable of delivering a constant concentration of agent regardless of temperature changes or flow through the vaporizer.

D. Electronic Vaporizers

Recent vaporizer

Datex-Ohmeda Aladin Cassette Vaporizer Figures -25-

- Used in some newer Ohmeda machines .
- Electronically controlled vaporizer designed to deliver the 5 different commonly used inhaled anesthetics (halothane, isoflurane, enflurane, sevoflurane, desflurane) .
- Consists of a permanent internal control unit housed within the machine and an interchangeable Aladin agent cassette which contains anesthetic liquid .
- Aladin agent cassettes are color coded for each agent .
- Also magnetically coded so that the machine can identify which anesthetic cassette has been inserted .

Cassettes are filled using agent specific fillers

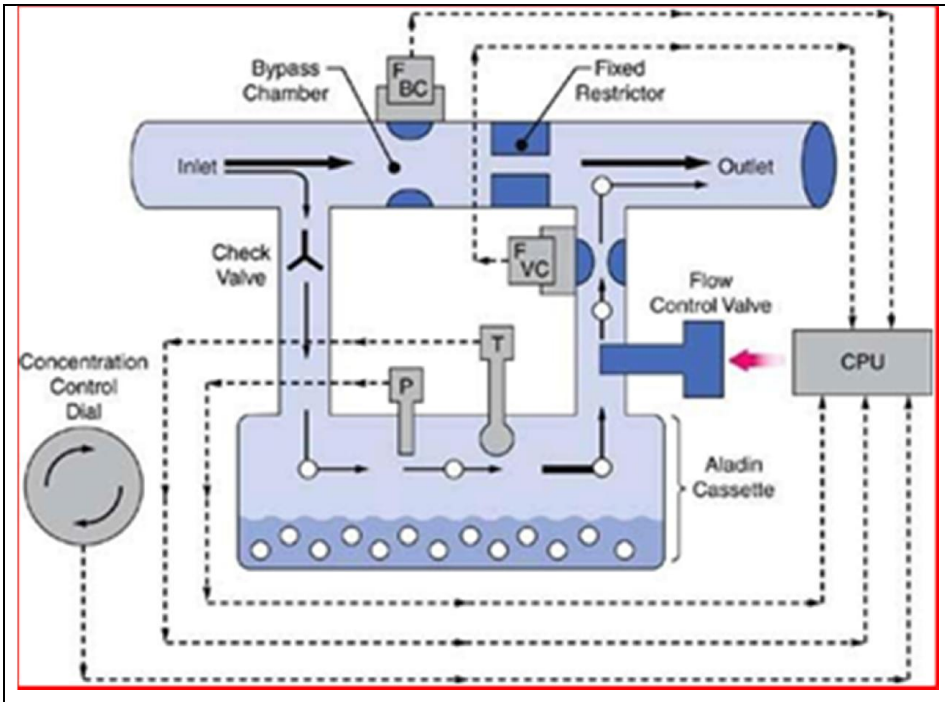


Figure (25): Datex-Ohmeda Aladin Cassette Vaporizer

- A fixed restrictor is located in the bypass chamber .
- Flow measurement units are located in the bypass chamber (F_{BC}) and in the outlet of the vaporizing chamber (F_{VC}) .

The heart of the vaporizer is the electronically flow control valve located in the vaporizing chamber's outlet. This valve is controlled by a central processing unit (CPU)

1. PCU receives input from;
    - Concentration Control Dial .
    - Pressure sensor (P) located inside the vaporizing chamber .
    - Temperature sensor (T) also located inside the vaporizing chamber
    - A flow measurement unit (F_{BC}) located in the bypass chamber .
    - A flow measurement unit (F_{VC}) located in the vaporizing chamber outlet .
    - Flow meters – regarding composition of the carrier gas .

2. Using data from these multiple sources, the CPU is able to precisely regulate the flow control valve to attain the desired vapor concentration.
3. A fixed restrictor located in the bypass chamber splits the vaporizer inlet flow into bypass chamber gas and vaporizing chamber gas .
4. A one-way check valve located at the inlet to the vaporizing chamber protects against back flow of agent into the bypass chamber .
5. Desflurane with a boiling point of 22.8 C will cause increase in sump pressure at higher temperatures .
6. When sump pressure exceeds the bypass chamber pressure, the one way check valve in the vaporizing chamber inlet closes shut preventing

carrier gas from entering the vaporizing chamber – the carrier gas then passes directly through the bypass chamber, and the electronically controlled flow control valve meters the appropriate flow of pure desflurane vapor .

7. When large quantities of anesthetic liquid are vaporized during high fresh gas flow rates, the vaporizer cools because of the latent heat of vaporization. To offset this cooling effect, the anesthetic machine is equipped with a fan which warms the vaporizer back up toward room temperature (Morgan & Mikhail, 2013).

*This is a boiling point for some types of the volatile anesthetics.

Table 2: Boiling Point for Some Types of the Volatile Anesthetics

Agent	Boiling Point (C^0, 760 mmHg)	Vapor Pressure (mmHg 20 C^0)	MAC in O_2 (%)
Halothane	50.2	243	0.75
Enflurane	56.5	175	1.68
Isoflurane	48.5	238	1.15
Desflurane	22.8	669	6.4
Sevoflurane	58.5	157	2.0

Classification of Vaporizers

Method of Regulating Output Concentration

- Concentration – Calibrated (variable bypass) Vaporizers
- Measured – Flow vaporizers

A. Method of Vaporization

- Flow-over
- Bubble through
- Injection

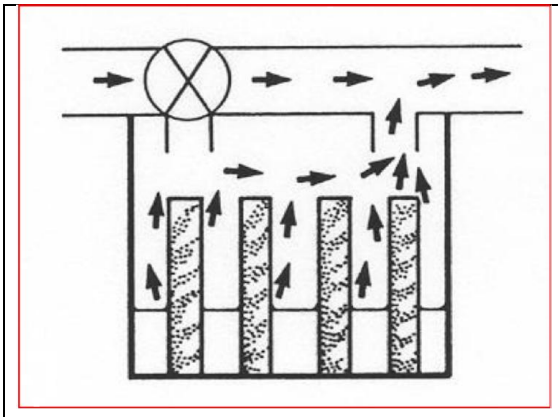
B. Temperature Compensation

- Thermo compensation
- Supplied heat

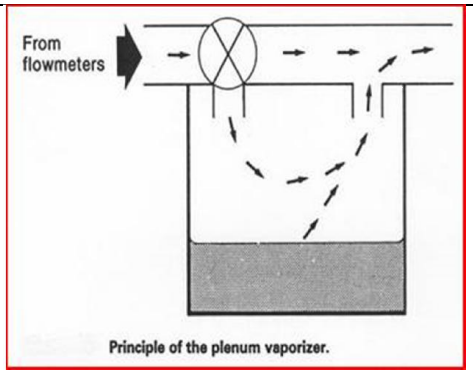
- No single method of classification is complete
- The above classification describes most of the important characteristics of different vaporizers
- Contemporary anesthesia vaporizers for halothane, isoflurane, enflurane and sevoflurane are classified as variable-bypass, flow-over, temperature-compensated, agent-specific, out-off circuit vaporizers (also called concentration calibrated, automatic plenum, dial-controlled)
- Desflurane vaporizer (Ohmeda Tec 6) is of different design)

A-Method of regulator output concentration :-

1-Variable bypass Figures -26-A&B



Figures -26-B: Variable bypass flowmetter positive pressure



Figures -26-A: Plenum Vaporizer Principle

- The total flow of gas arriving at the vaporizers from the machine flow meters is split into two streams
- One stream passes through the chamber containing the anesthetic agent (vaporizing chamber) and the other bypasses it
- These streams then reunite and pass to the patient

- Gas can be made to flow through a vaporizer in one of two ways 1-Positive pressure can be developed upstream of the vaporizer, e.g. by gas from the flowmeter, so that gas is pushed through. This is known as a **plenum** vaporizer

2-Negative pressure may be developed in the gas stream distal to the vaporizer, thus drawing gas through. This is known as a **draw-over** vaporizer (27)

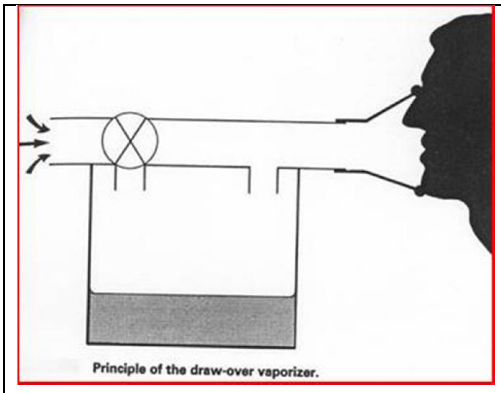


Figure 27: A Draw-Over Vaporizer Variable Bypass Negative Pressure

Negative pressure may be generated by either the patient's respiratory effort or by mechanical means.

NB* Draw-over vaporizers are very rarely used today

<u>2-Measured-Flow</u> – Figures -28-

- A measured-flow of anesthetic gas, usually oxygen, is used to pick up anesthetic vapor .
- The measured O_2 flow is set on a separate flow meter to pass to the vaporizer from which vapor at its SVP emerges.
- This is then diluted by an additional measured flow of gases from other (main) flow meters on the anesthesia machine No longer in use

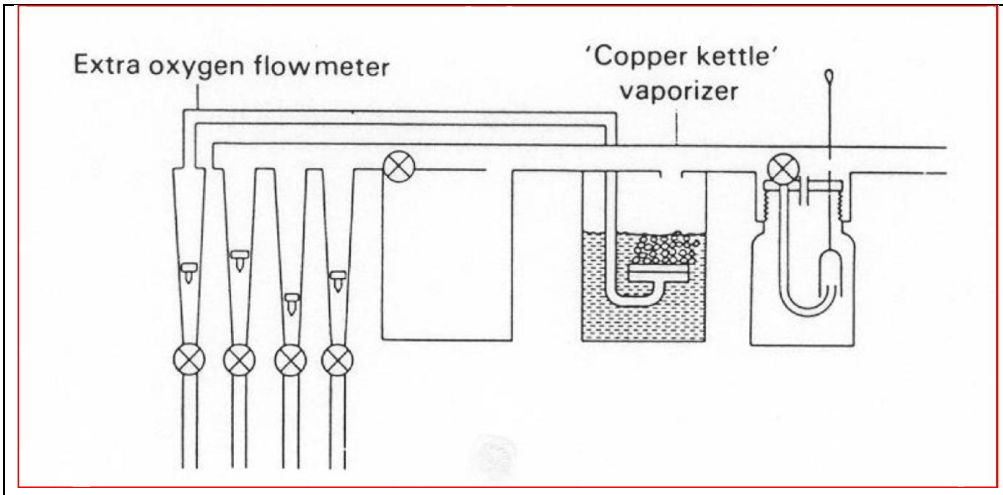


Figure 28: Measured-Flow Vaporizer (Copper Kettle Vaporizer)

Note Measured flow more at copper kettle which is not long uses

B-Method of vaporization :-

1-Flow over- **Figures -29-**

- The gas channeled to the vaporizing chamber flows over the liquid anesthetic multiple times to become saturated with vapor .
- A series of baffles repeatedly redirect the mixed gas flow onto the surface of the liquid anesthetic agent to achieve full saturation .

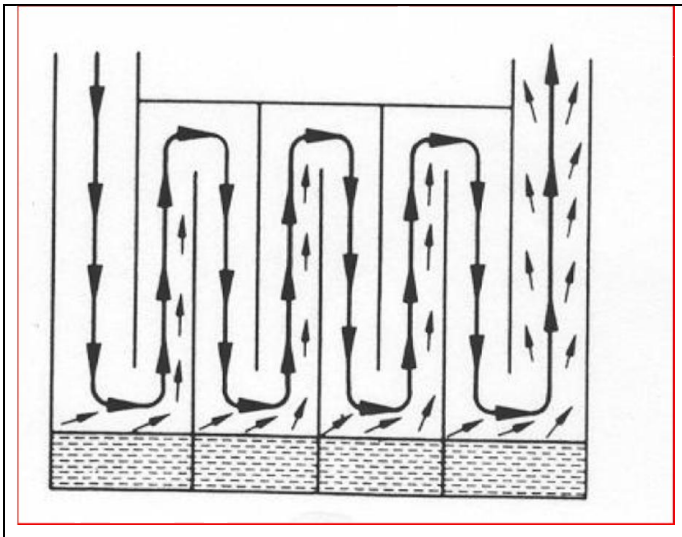
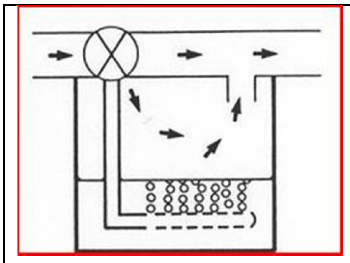


Figure 29: Flow Over Principle

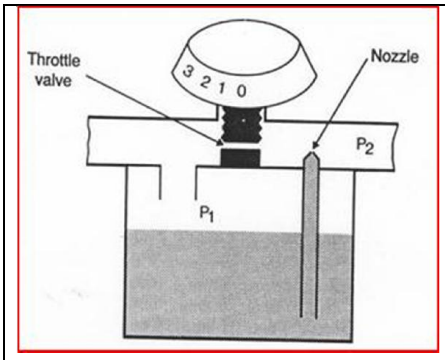
2-Bubble-through – Figures -30-

- Carrier gas is bubbled through the volatile liquid usually by means of a sintered disc of glass or metal to further increase the gas-liquid interface .

	**Figures (30): Bubble-through principle**

3-Injection Figures -31-

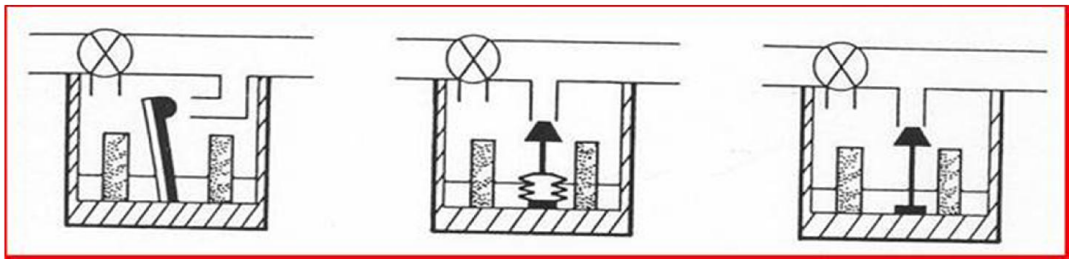
- Vapor concentration is controlled by injecting a known amount of liquid anesthetic (from a reservoir in the vaporizer or from the bottle of agent) into a known volume of gas

	**Figures -31): Injection principle**

- The anesthetic agent is delivered into the gas stream through a fine nozzle. The rate of delivery depends on the pressure difference P1 to P2 across the nozzle (see figure), and this is adjusted by the throttle valve .
- If flow through the vaporizer is increased, the pressure across the valve is increased and so more anesthetic is delivered to maintain the same concentration .
- Therefore, the vaporizer remains accurate despite changes in flow .

C-**Method of temp &compensation:-**

1-Thermo compensation – Figures -32- A,B&C



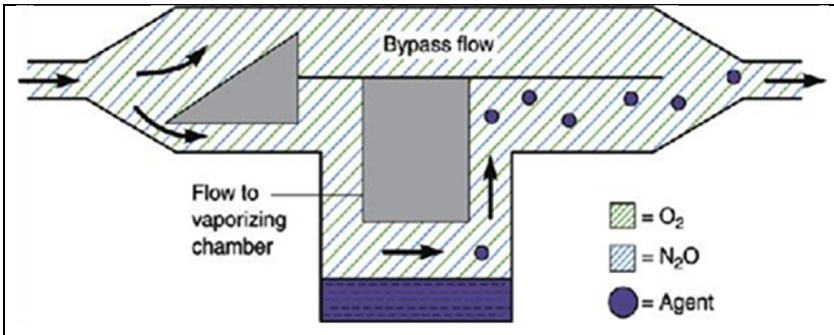
Figures -32-A,B&C: **Thermo compensation differential method**

An automatic temperature – compensating device helps maintain a constant vaporizer output over a wide range of temperatures .

2-Supplied heat

- An electric heater can also be used to supply heat to a vaporizer to maintain it at a constant temperature .

Operating Principle; fig 33



Figures (33): Operating Principle of Variable Bypass Vaporizers

- In a variable bypass vaporizer, the total fresh gas flow from the anesthesia machine flow meters passes to the vaporizer.
- The vaporizer splits the incoming gas flow into both a smaller flow (about 20%), which enters the vaporizing chamber to emerge with the agent at its saturated vapor concentration, and a larger bypass (about

80%), which when mixed with the vaporizing chamber output, results in the desired or “dialed-in concentration .

- An efficient system must exist to create a saturated vapor concentration in the vaporizing chamber .

To achieve full saturation, a large surface area must be available vaporization within the vaporizing chamber

- One method of achieving this is to place metal or fabric wicks in the vaporizing chamber, one end of which dips into the anesthetic liquid while the other end projects up into the chamber (fig 26-B-).
- Surface tension between the liquid anesthetic and the capillary channels in the wicks draws up the anesthetic and provides a large surface area of anesthetic which assists efficient vaporizer which have a large surface area anesthetic agent (fig 29).

- An alternative method is to bubble the gas through the liquid anesthetic by means of a sintered disc of glass or metal (fig 30).
- This produces large numbers of minute bubbles Also, a series of baffle can be used to redirect gas flow onto the surface of the liquid.

Characteristics of an ideal vaporizer

1. Its performance is not affected by changes in fresh gas flow, volume of the liquid agent, ambient temperature and pressure, decrease in temperature due to vaporization and pressure fluctuation due to the mode of respiration.
2. Low resistance to flow .
3. Light weight with small liquid requirement.
4. Economy and safety in use with minimal servicing requirements.
5. Corrosion and solvent-resistant construction .

Summary :-

Flow from the flow meters enters the inlet of the vaporizer

- The function of the concentration control valve is to regulate the amount of flow through the bypass and vaporizing chambers ***Splitting Ratio = flow though vaporizing chamber/flow through bypass chamber***

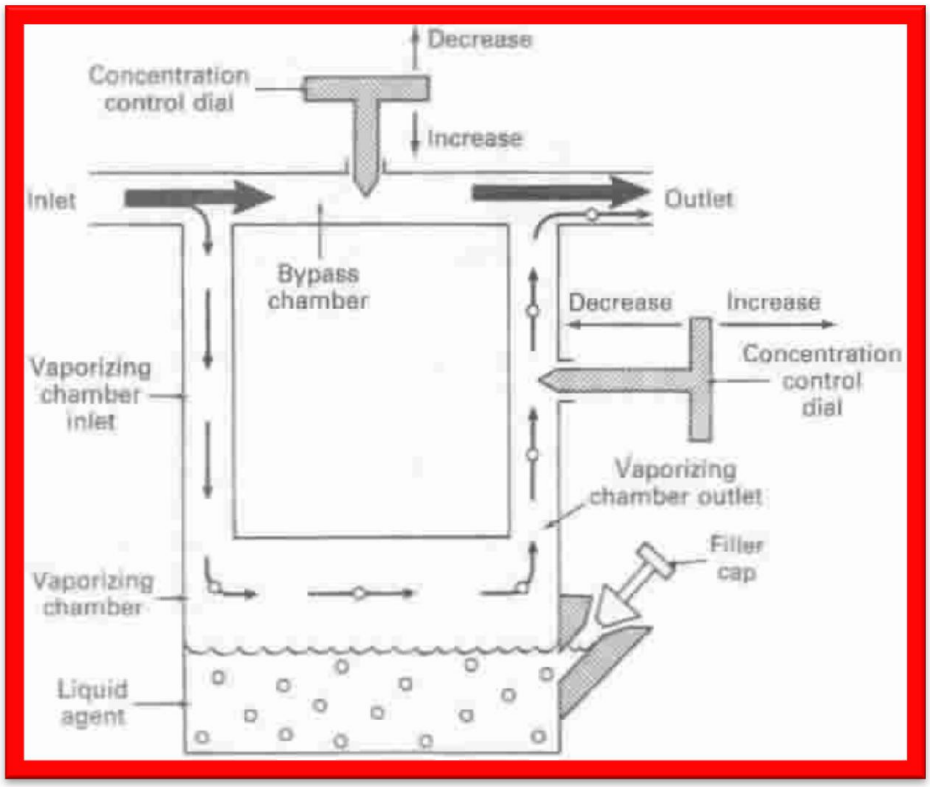


Figure (34): Vaporizer Structure of Aladine Cassette

Factors That Influence Vaporizer Output

- **Flow Rate**:

- Vaporizer output varies with the rate of gas flowing through the vaporizer and is most notable at extremes of flow rates .
- At low flow rates (<250 ml/min), the output of variable-bypass vaporizers is less than the dial setting .
- Volatile agents have high density and turbulence generated by low flow rates is insufficient to upwardly advance the molecules of vapor.

- At very high flow rates (e.g. 15 L/min), the output of most variable-bypass vaporizers is also less than the dial setting .
- This is because of incomplete mixing and saturation in the vaporizing chamber.

■ **Temperature**:

- At lower temperatures, the SVP of volatile agents falls unless the splitting ratio of the gas is altered so that more gas flows through the vaporizing chamber.
- Modern vaporizers contain a temperature controlled valve which adjusts the splitting ratio (fig 32) .
- One temperature control valve incorporates a bimetallic strip which consists of two metals which have different coefficients of thermal expansion and which are joined together (fig 32-A) .
- As the temperature changes, the shape of the strip alters so that it bends or straightens, the property of which is used to operate a valve (e.g. Ohmeda Tec Vaporizers.
- Another method is to use **small flexible bellows containing some fluid (liquid or gas)** that has a high coefficient of expansion (fig 32-B).
- As the temperature changes, the bellows expand or contract and thus open or close a valve.
- An **expansion element (metal rod)** may also be used (e.g. Dräger vaporizers) – (fig 32-C).
- It acts like the bellows to adjust the orifice to modify flow in the vaporizing chamber according to the temperature.

❖ **These compensatory devices allow more flow into the vaporizing chamber as the temperature decreases and vice-versa**.

■ **Back Pressure**: **If the volume of the vaporizing chamber in the vaporizer is larger than the bypass channel, gas may expand out of the inlet and outlet of the vaporizing chambers when the**

back pressure from the ventilator falls (i.e. from high pressure area to low pressure area) .

- Intermittent back pressure (e.g. positive pressure ventilation causes a higher vaporizer output than the dial setting.
- Thus gas containing anesthetic agent will flow into the bypass channel and increase the output concentration of the vaporizer .
- Gas molecules are compressed in both the bypass and vaporizing chambers during the inspiratory phase of positive-pressure ventilation .
- When the backpressure is suddenly released during the expiratory phase of positive pressure ventilation, vapor exits the vaporizing chamber via the vaporizing chamber outlet and retrograde through the vaporizing chamber inlet. The bypass however, has less resistance than the vaporizing chamber outlet therefore, the pressure in the bypass falls more quickly than that in the vaporizing chamber and gas containing vapor flow from the vaporizing chamber into the bypass.
- The concentration in the vaporizer output is increased because the gas in the bypass (which dilutes the gas from the vaporizing chamber) now carries vapor and the gas flowing from the vaporizing chamber is still saturated.

Greatest increase in pumping effect occurs at;-

- Low fresh gas flow rates .
- Low concentration dial settings .
- Small amount of liquid agent in vaporizer sump .
- Large and rapid changes in pressure.
  - **Atmospheric Pressure**: Changes in atmospheric pressure affect variable bypass vaporizer output as measured by volume % concentration, but not (or very little) as measured by partial pressure (lowering atmospheric pressure increases volume % concentration and vice versa)

Altered Barometric Pressure

Low Atmospheric Pressure – High Altitude

- Decreased barometric pressure will affect a concentration calibrated vaporizer by altering the splitting ratio.
- The high-resistance pathway through the vaporizing chamber offers less resistance under hypobaric conditions, increasing vaporizer output.

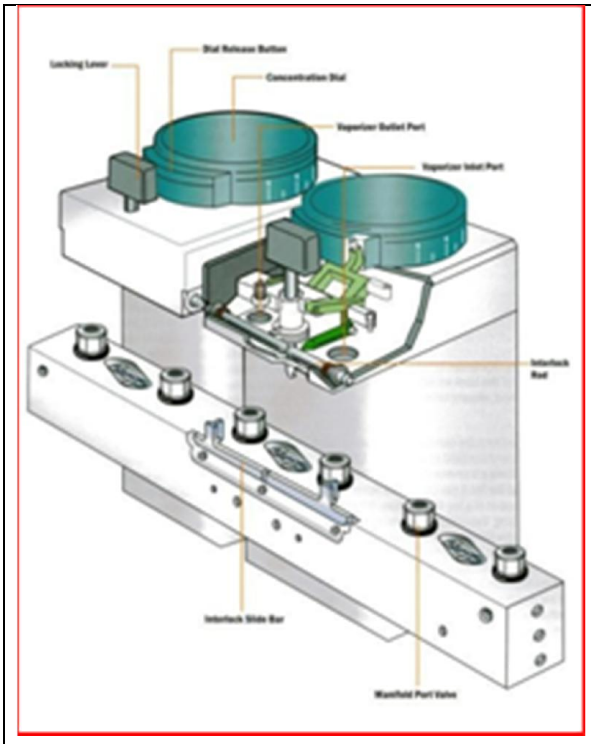
High Atmospheric Pressures – Hyperbaric Chamber

- When atmospheric pressure is increased, changes in the density of gases cause more resistance to flow through the vaporizing chamber and a decrease in vaporizer output.
  - **Carrier Gas**: Vaporizers are calibrated for 100% oxygen. Carrier gases other than this result in decreased vaporizer output decrease in output is due to N_2O being more soluble than O_2 in halogenated liquid.

Safety Features

1. Agent specific keyed filling devices - prevents filling with wrong agent
2. Overfilling is minimized because filler port is located at the maximum safe liquid level.

3. **Interlock system (Figures -35-)** – prevents simultaneous use of two vaporizers thereby preventing administration of more than one inhaled agent at the same time .

	**Figures (35): Safety Features Interlock system**

Hazards Associated with Filling

Overfilling and tilting (tipping) – may result in liquid agent entering the vaporizer bypass flow giving rise to lethal concentrations of the agent

- If this occurs, the vaporizer should be purged with a high flow rate of oxygen (10 L/min) from the machine flow meter and with the vaporizer concentration dial set to the maximum concentration setting .

> **Do not use O_2 flush valve for this purpose as it bypasses the vaporizer**

Vaporization of Mixed Anesthetic Liquids- Misfiling

- Vaporizer topped-off with incorrect agent .
- Vaporizer output is less easily predicted, and large errors in vapor administration can occur .
- More likely with vaporizers not equipped with keyed fillers.

Simultaneous Use of Two Different Vaporizers

- Could happen with older style vaporizer manifold that holds three vaporizers .
- If the center vaporizer is removed, the interlock system becomes disabled.

Leaks

- A loose filler cap is the most common source of leaks.
- Leaks can also occur at the O-ring junction between the vaporizer and its manifold .
- Leaks can cause awareness .
- Vaporizer must be in the "on" position to detect a leak .
- Positive and negative pressure leak tests can be used to detect vaporizer leaks.

Liquid Agent in Patient Breathing Circuit

Liquid agent may enter the breathing circuit intentionally or unintentionally.

May produce vapor concentrations that greatly exceed safe levels .

1 ml of liquid agent produces approximately 200 ml of vapor at 20 C^0

Approximate Volume of Anesthetic Vapor per ml of Liquid at 20 C^0

Table 3: Approximate Volume of Anesthetic Vapor per ml of Liquid at 20 C^0	
Desflurane	182
Enflurane	195
Halothane	226
Isoflurane	196
Sevoflurane	182

Because a typical adult circle breathing circuit (with 5-feet long inspiratory and expiratory limbs) has a volume of approximately 7 liters, 1 ml of volatile anesthetic liquid in such a circuit will produce a concentration of nearly 3%(approx. 200 ml/7000 ml x 100%) on complete mixing, and much greater concentrations with incomplete mixing .

2.5. VENTILATOR:-

Ventilators are used extensively in the operating room (OR) and the intensive care unit (ICU). All modern anesthesia machines are equipped with a ventilator. Historically OR ventilators were simpler and more compact than their ICU. The ventilators on some modern machines are just as sophisticated as those in the ICU and almost the same capabilities. Ventilators generate gas flow by creating a pressure gradient between the proximal airway and the alveoli. positive pressure. Anesthesia ventilators are mostly examples of bag-in-bottle (bellows-in-box) ventilators Basic principle, the reservoir bag of an anesthesia breathing system is replaced by bellows in a bellows housing and the APL (pop-off) valve is replaced by a ventilator pressure relief valve (PRV) . Inspiration occurs when compressed gas enters the bellows housing. The bellows is compressed and the PRV is held closed. Gas contained within the bellows, as well as fresh gas entering the patient circuit from the anesthesia machine are forced into the patient's lungs. At end inspiration, the bellows housing is no longer pressurized, the bellows refills and the PRV is able to open, venting excess patient circuit gas to the waste gas scavenging system.

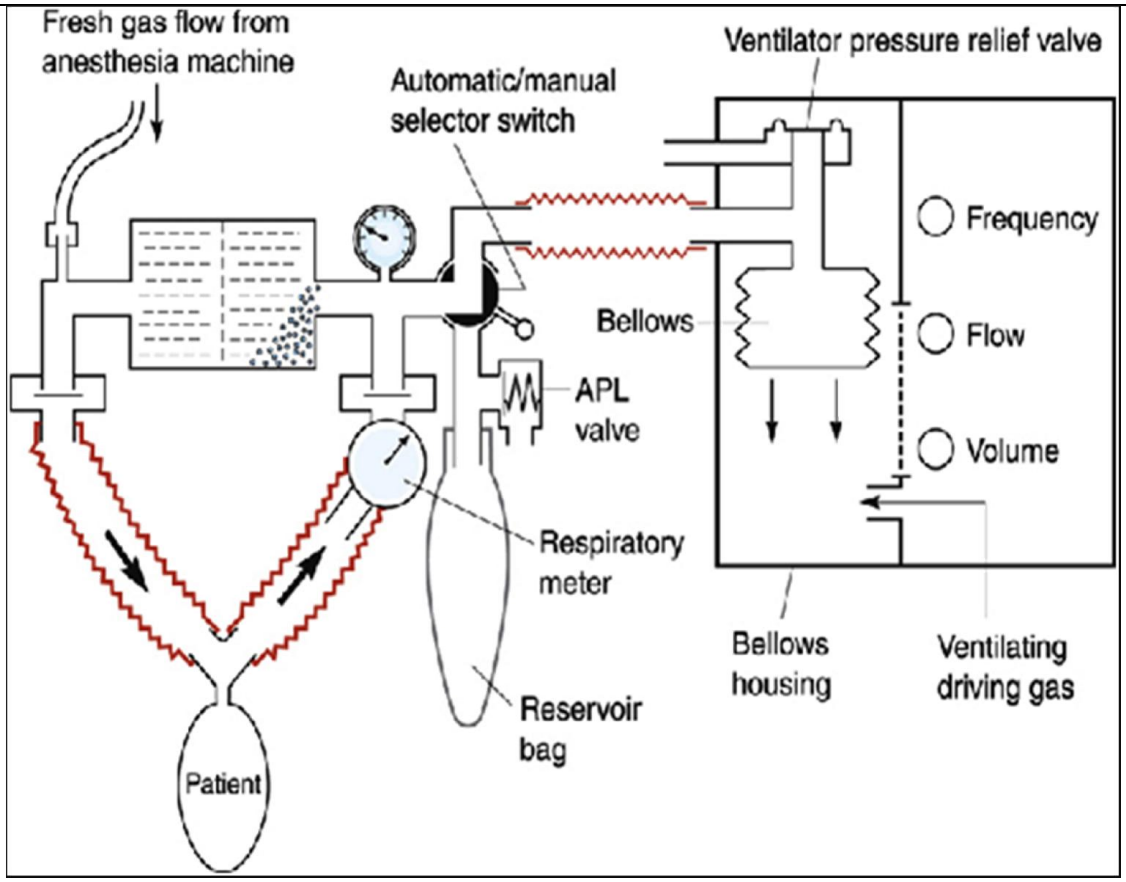


Figure (36): Schematic Ventilator with Circuit

Classification

1. **Power source**
2. **Drive mechanism**
3. **Cycling mechanism**
4. **Bellows type**

Power Source

- Compressed gas – Pneumatic
- Electricity – Electronic
- Both – Found in most modern ventilators

Drive Mechanism

- Double circuit, pneumatically driven (most anesthesia machine ventilators) ;
  - one circuit being the driving gas circuit and the other the patient circuit .
  - the interface between these two circuits is the ventilator bellows .
- The driving gas may be 100% oxygen or a mixture of oxygen and air .
- Ohmeda machines are driven by 100% oxygen .

Cycling Mechanism

- Time cycled
- Volume cycled
- Pressure cycled

- Most anesthesia machine ventilators are time cycled
- Use of a solid state timing device makes them time cycled and electronically controlled .
- Time cycled ventilators allow tidal volume and peak inspiratory pressure to vary depending on lung compliance.
- Tidal volume is adjusted by setting inspiratory duration and inspiratory flow rate .
- Volume cycled ventilators vary inspiratory duration and pressure in order to deliver a preset volume (there is usually a safety pressure limit)
- Many anesthesia ventilators are volume or pressure limited but time cycled .
- Pressure cycled ventilators will not cycle from the inspiratory phase to the expiratory phase until a preset pressure is reached.
- If a large circuit leak decreases peak pressures significantly, a pressure cycled ventilator may remain in the inspiratory phase indefinitely.

- A small leak, however may not markedly decrease tidal volume because cycling will be delayed until the pressure limit is met.

Bellows Classification

Determined by direction of bellows movement during the expiratory phase

- **Ascending (standing) bellows** – ascend during expiratory phase (fig37-A)
- **Descending(hanging) bellows**–descend during expiratory phase (fig37-B)
  - Ascending bellows is safer because it does not refill if a total disconnection occurs.
  - Descending bellows continues its upward and downward movement during a disconnection because room air is entrained by gravity into the breathing system at site of disconnection.

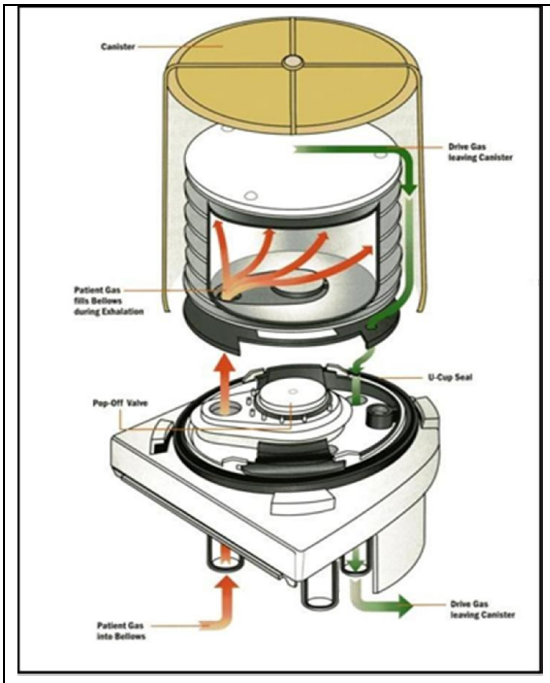


Fig. (37–A): Ascending (standing) bellows

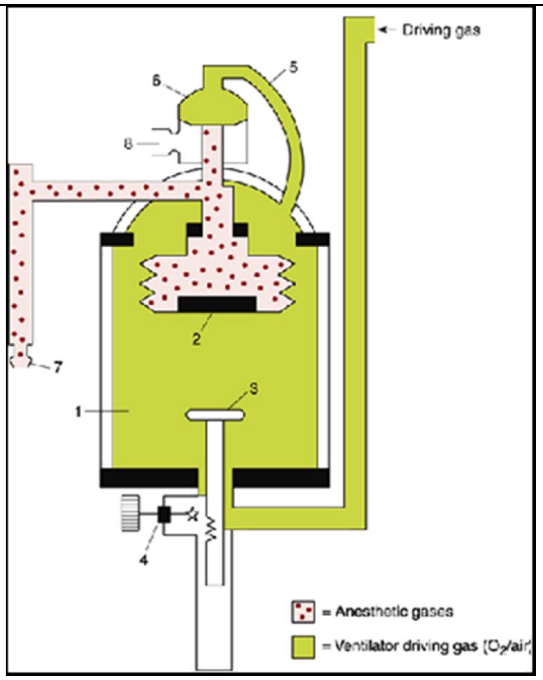


Fig (37–B): Descending (hanging) bellows

<u>Ascending Bellows Ventilator</u> – Operating Principles (Fig 38 A&B)

Inspiration	Expiration

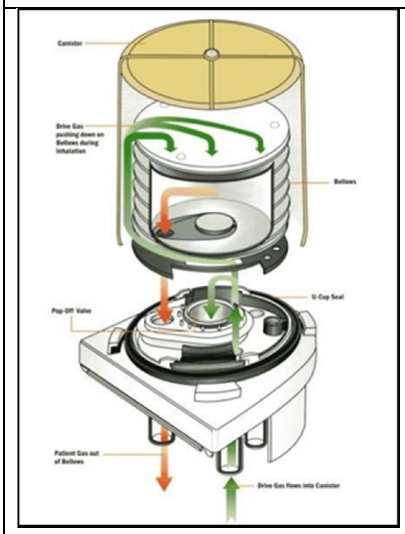
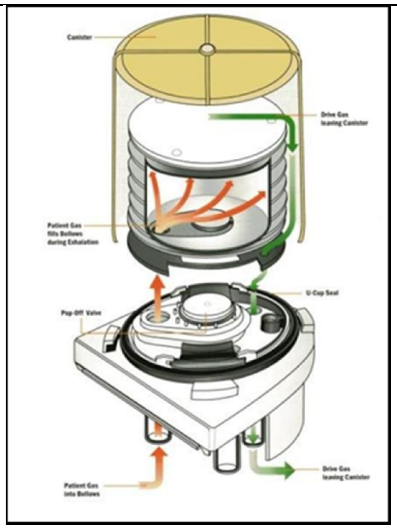

	

Fig 38 (A): Ascending Inspiration	**Fig 38 (B): Ascending Expiration**

- Breathing bag located within a clear plastic box.
- The bellows physically separates the driving gas (located outside the bellows) circuit from the patient gas circuit (located inside the bellows).

<u>The ventilatory cycle of the Ventilator 4 phases ;</u>

<u>A- Inspiratory phase;</u>

During inspiration, ventilators generate tidal volumes by producing gas flow along a pressure gradient.

1- The machine generates either a constant pressure (constant pressure generators) or

2- constant gas flow rate (constant-flow generators) during inspiration, regardless of changes in lung mechanics.

3- Non constant generators produce pressures or gas flow rates that vary during the cycle but remain consistent from breath to breath so a ventilator that generates a flow pattern resembling a half cycle of a sine wave (e.g., rotary piston ventilator) would be classified as a non constant-flow generator.

An increase in airway resistance or a decrease in lung compliance would increase peak inspiratory pressure but would not alter the flow rate generated by this type of ventilator.

B- Transition phase from inspiration to expiration ; .

Termination of the inspiratory phase can be triggered by a preset limit of time (fixed duration), a set inspiratory pressure that must be reached, or a predetermined tidal volume that must be delivered.

1-Time-cycled ventilators allow tidal volume and peak inspiratory pressure to vary depending on lung compliance.

2- Pressure-cycled ventilators will not cycle from the inspiratory phase to the expiratory phase until a preset pressure is reached. If a large circuit leak decreases peak pressures significantly, a pressure-cycled ventilator may remain in the inspiratory phase indefinitely.

3- Volume-cycled ventilators vary inspiratory duration and pressure to deliver a preset volume.

- modern ventilators overcome the many shortcomings of classic ventilator by incorporating secondary cycling parameters or other limiting mechanisms.

For example, time-cycled and volume-cycled usually incorporate a pressure-limiting feature that terminates inspiration when a preset, adjustable safety pressure limit is reached.

C- Expiratory phase;

- The expiratory phase of ventilators normally reduces airway pressure to atmospheric levels or some preset value of positive end-expiratory pressure (PEEP). Exhalation is therefore passive. Flow out of the lungs is determined primarily by airway resistance and lung compliance. PEEP is usually created with an adjustable spring valve mechanism or pneumatic pressurization of the exhalation (spill) valve.

D-Transition from expiration to inspiration;

This may be based on a preset time interval or a change in pressure. The behavior of the ventilator during this phase together with the type of cycling from inspiration to expiration determines ventilator mode.

- During controlled ventilation, the most basic mode of all ventilators, the next breath always occurs after a preset interval. Thus tidal volume and rate are fixed in volume-controlled ventilation, whereas peak inspiratory pressure is fixed in pressure-controlled ventilation.

- In the volume-control mode, the ventilator adjusts gas flow rate and inspiratory time based on the set ventilator rate and I:E ratio In contrast, intermittent mandatory ventilation (IMV) allows patients to breathe spontaneously between controlled breaths. Synchronized intermittent mandatory ventilation (SIMV) which prevent "fighting the ventilator" and "breath stacking"; whenever possible, the ventilator tries to time the mandatory mechanical breaths with the drops in airway pressure that occur as the patient initiates a spontaneous breath.

Problems

- Breathing circuit problems
- Bellows assembly problems
- Control assembly problems

Breathing Circuit Problems

- Disconnection – leading cause of critical incidents .
- Most common disconnection site is the Y-piece.
- Preexisting undetected leaks in compressed, corrugated disposable anesthetic circuit.
- Disconnection and leaks manifest more readily with ascending bellows.
- Most important disconnection monitor is a vigilant anesthesia care provider.
- Occlusion (obstruction) of breathing circuit may also occur; -high-pressure alarm may alert the anesthesiologist to this problem.

2.6. Other disconnection monitors

(a) Respiratory volume monitors

(b) Carbon dioxide

Bellows Assembly Problems

Leaks in bellows assembly from:

(a) Improper seating of the plastic bellows housing

(b) **Hole in the bellows**

- Hole in the bellows can cause alveolar hyperinflation and possibly barotrauma from high pressure driving gas entering the patient circuit.
- Value on oxygen analyzer increases if driving gas is 100% O_2 or decreases if driving gas is air/oxygen mixture.
- Ventilator relief valve incompetence – can cause hypoventilation because anesthetic gas is delivered to the scavenging system during the inspiratory phase instead of to the patient.
- Ventilator relief valve stuck in the closed position can produce barotrauma.
- Excessive suction from the scavenging system can draw the ventilator relief valve to its seat and close the valve during both the inspiratory and expiratory phases.

Control Assembly Problems

- Electrical or Mechanical problems
- Electrical failure can be total or partial
- Total failure is more obvious

Mechanical problems include:

(a) Leaks within the system

(b) Faulty regulators

(c) Faulty valves

Differences Among Ventilator Designs

Standing versus Hanging Bellows

- Modern anesthesia ventilators are of the standing (ascending) bellows design.
- With a disconnection, in which circuit pressure becomes equal to atmospheric pressure, the bellows cannot refill during exhalation.

Hanging (descending) bellows fills by gravity during exhalation so that the ventilator pressure relief valve does not require a PEEP design. With a disconnection, room air is entrained into the patient circuit via the leak and the bellows refills, emptying through the leak on the next inspiration.

North American Dräger versus Ohmeda

- Gas entering the bellows housing in an Ohmeda ventilator is **100% O_2** whereas in the Dräger AV-E the gas is an air/oxygen mixture .
- With a hole in the bellows, driving gas enters the patient circuit and dilutes the gases there causing O_2 enrichment with Ohmeda ventilator but decrease FiO_2 with Dräger ventilator.
- Dräger ventilator, tidal volume is determined by setting the expansion limit of the bellows during expiration, because the bellows is emptied during inspiration.
- The bellows is graduated from 0 ml to 2000 ml at the top of the housing.
- In the Ohmeda design, the bellows is graduated from 0 ml at the top to 1600 ml at the bottom of the bellows housing since tidal volume is displaced from the bellows by a metered volume of compressed O_2 during inspiration

- Dräger ventilator uses a Venturi and an air/O_2 mixture to compress the bellows which economizes the use of compressed O_2.
- Ohmeda ventilators incorporate a pressure relief valve (PRV) in the driving gas circuit which may be preset to 65 cm H_2O or may be adjustable (Inspiratory Pressure Limit). Such a valve (North America Dräger Pressure Limit Control), with variable relief pressure settings, is now available and may be retrofitted on standing bellows versions of these ventilators, thereby providing a pressure limit.

2.7. Venturi Principle

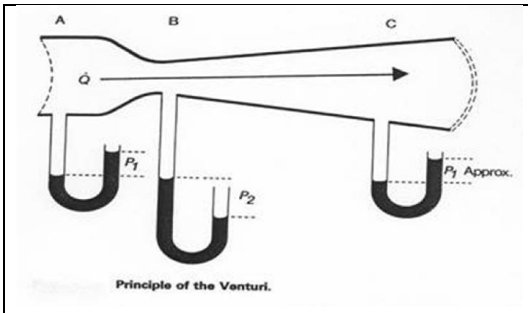


Fig 39 (A): Venturi Principle at atmospheric pressure

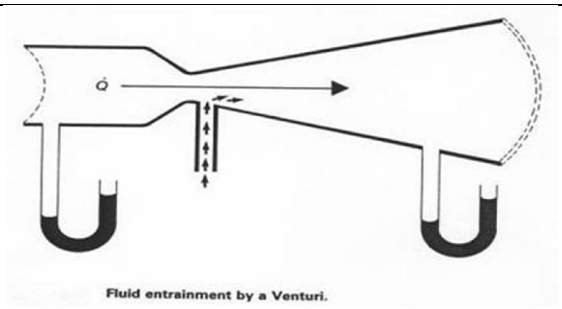


Fig 39 (B): Venturi Principle as fluid entrainment

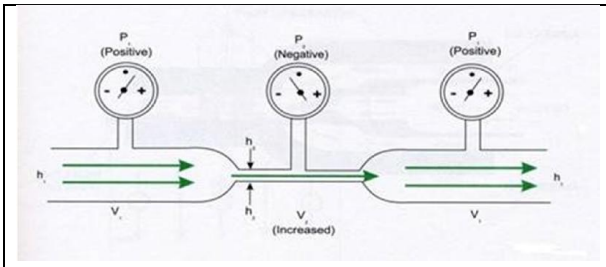


Fig 39 (C): Venturi Principle pressure indicator

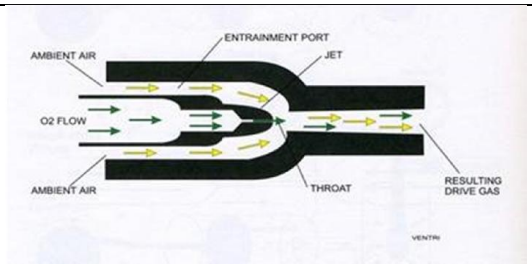


Fig 39 (D): Venturi Principle at atmospheric pressure

- Consider a tube with a constriction in which the cross section gradually decreases and then increases .
- If the pressure along the tube is measured, it is found that the pressure at the narrowest point is lower than elsewhere and is often below atmospheric pressure (figs 39A and 39C).
- Flowing fluid contains energy in two forms, **potential energy** associated with its pressure and **kinetic energy** associated with its flow.
- At constriction B, there is considerable increase in fluid velocity and a great gain of kinetic energy. Such an increase of kinetic energy can only occur if there is a fall in potential energy, because the total energy present must remain constant .

- A marked fall in pressure therefore occurs at this point to pressures below those at A and C If the pressure gauge at position P_2 is removed, leaving the side tube open and if pressure at this point is below atmospheric pressure, air or another fluid can be entrained through the side tube (figs 39B and 39D) .
- The driving fluid entrains fluid through a side tube because of the low pressure at the point where the fluid velocity is greatest (i.e. at the constriction) .
- Injectors working on this principle may be used to provide suction, either water or gas being used as the driving fluid .
- Other examples include **nebulizers** and **ventimasks**.
- In nebulizers, gas as the driving fluid enters by the center tube, entrains fluid from a side tube and breaks it up into droplets suitable for inhalation (fig 40A).
- In Ventimasks, oxygen moving at high speed entrains air into the oxygen flow (fig 40B).

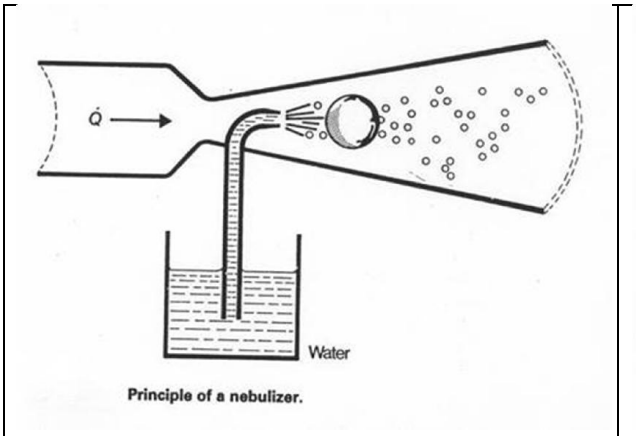


Fig 40 (A): Nebulizer Principle

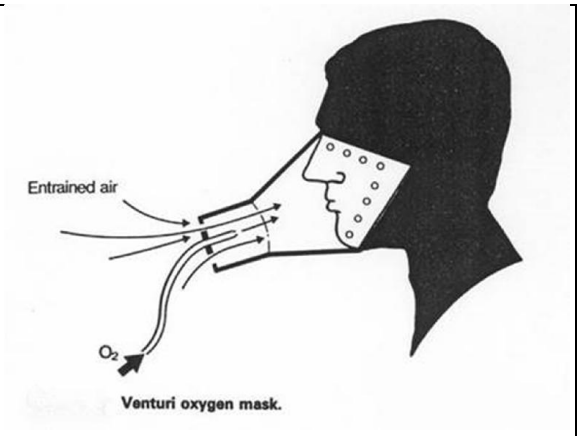


Fig 40 (B): Venture Oxygen Mask

Ventilator Circuit Design;

-Traditionally ventilators on anesthesia machines have a double-circuit system design and are pneumatically and electronically controlled**.**

-Newer machines also incorporate microprocessor control that relies on sophisticated pressure and flow sensors. This feature allows multiple ventilator modes, electronic PEEP, tidal volume modulation, and enhanced safety features. Some anesthesia machines have ventilators that use a single-circuit piston design .

A-*double circuit system ventilation ;*

- Tidal volume is delivered from a bellows in a clear rigid plastic enclosure. Pressurization of the plastic enclosure compresses the pleated bellows inside, forcing the gas inside into the breathing circuit**.** A ventilator flow control valve regulates drive gas flow into the pressurizing chamber**.**
- Newer machines may offer the option of using compressed air for pneumatic power. also incorporate a free breathing valve that allows outside air to enter the rigid drive chamber and the bellows to collapse if the patient generates negative pressure by taking spontaneous breaths during mechanical ventilation .

B- One Piston drive;

The ventilator substitutes an electrically driven piston for the bellows the ventilator requires either minimal or no pneumatic (oxygen) power. The major advantage of a piston ventilator is its ability to deliver accurate tidal volumes to patients with very poor lung compliance and to very small patients. During volume-controlled ventilation the piston moves at a constant velocity whereas during pressure controlled ventilation the piston moves with decreasing velocity.

c-spill valve;

Whenever a ventilator is used on an anesthesia machine, the circle system's APL valve must be functionally removed or isolated from the circuit. A bag/ventilator switch typically accomplishes this. When the switch is turned to "bag" the ventilator is excluded and spontaneous/ manual (bag) ventilation is possible. When it is turned to "ventilator," the breathing bag and the APL valve is excluded from the breathing circuit. The APL valve may be automatically excluded in newer anesthesia machines when the ventilator is turned on. The ventilator contains its own pressure-relief (pop-off) valve, called the spill valve, which is pneumatically closed during inspiration so that positive pressure can be generated. During exhalation, the pressurizing gas is vented out and the spill valve is no longer closed. Sticking of this valve can result in abnormally elevated airway pressure during exhalation.

2.8. BREATHING CIRCUITS And VALVES

Breathing Circuits, Valves

1. Anesthesia Breathing Circuits

A circuit is a gas pathway in direct connection with the patient through which gas flow occur at respiratory pressures, and into which a gas mixture of controlled composition may be dispensed .

Regarded as extending from the point of fresh gas inlet to the point at which gas escapes to the atmosphere or a scavenging system ..

Purpose;

- To deliver gas mixture from machine to patient
- To remove carbon dioxide
- To exclude air
- To condition temperature and humidity

Other Function ;

1-Converts continuous flow from anesthesia machine to intermittent flow

Facilitates controlled or assisted respiration .

2- Provides for gas sampling, airway pressure, flow and volume measurements.

Components of basic Anesthesia Circuits

1- 22 mm diameter corrugated tubing

2- Reservoir bag

3- Connecting piece or elbow to the patient's airway

4- ± Valve(s)

2. Classification Of Breathing Systems

The International Standards Organization classifies breathing systems as non rebreathing, partial rebreathing, and complete rebreathing.

Functional Classification

Rebreathing (partial or complete) – Have CO_2 absorption system

Non rebreathing –No CO_2 absorber system

Note: Rebreathing refers to CO_2 and not other gases

Structural

- Open system
- Semi-open system
- Semi-closed system
- Closed system

Table 4: Breathing Circuit Structure

Mode	Reservoir (Breathing Bag)	Rebreathing	Example
Open	No	No	Open drop
Semi-open	Yes	No	Non-rebreathing circuit or Circle system at high FGF
Semi-closed	Yes	Yes, partial	Circle system at low FGF
Closed	Yes	Yes, complete	Circle system, with APL (pop-off) valve closed

A. ***Open Circuit:***

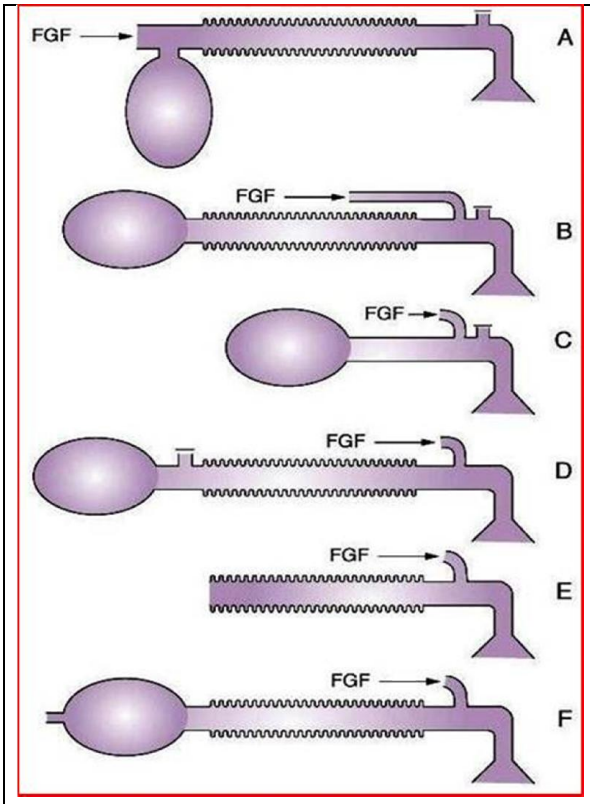
Patient's airway remains open to room air and no tubing, valves or reservoir bag are used

Types ;

1- Insufflation

2- Open drop

B. ***Semi Open Systems: Mapleson A***



Figures (41): ***Mapleson of A***-F

- A, B and C: The APL (pop-off) valve is located close to the patient .
- D, E and F: These are T-piece arrangements with gas leaving the circuit at a distance from the patient .

Extent of rebreathing depends on:

1. Patient's minute ventilation .
2. Pattern of ventilation .
3. Fresh gas flow rate.
4. Whether ventilation is spontaneous or controlled .

<u>Mapleson A</u> Figures -42 –A&B

During spontaneous ventilation, a fresh gas flow (FGF) rate equivalent to alveolar ventilation, (i.e. about 70% of minute ventilation will prevent rebreathing). A flow of about 5 L/min is required (in young healthy patients) to flush CO_2 from the system. Very inefficient in terms of fresh gas requirements during controlled ventilation. FGF rates of 3X the estimated minute ventilation is recommended during controlled ventilation .

Waste gas scavenging is difficult because the APL (pop-off) valve is close to the patient. Lack Breathing System (coaxial Mapleson A) addresses this problem

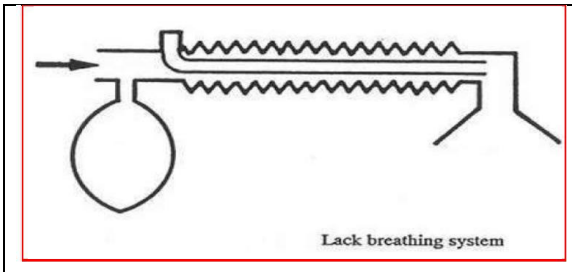
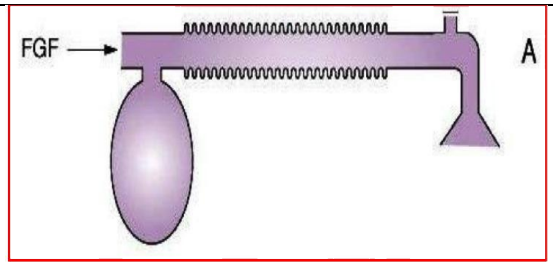


Figure 42(A): Coaxial Mapleson A



Figurs 42(B): Mapleson A

<u>Lack Breathing System</u>

- Patient breathes through concentric tubes .
- Outer tuber is inspiratory .
- Inner tube is expiratory .

- Does not readily permit the use of mechanical ventilators .
- Can be adapted for use with scavenging systems .

Mapleson B

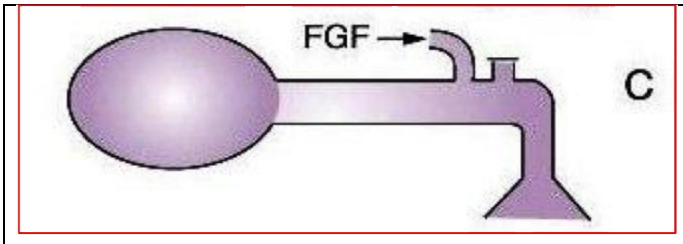
Functions similarly during both spontaneous and controlled ventilation

Rebreathing prevented with FGF's of at least 2X minute ventilation.

Mapleson C Figures -43

Also called Waters to-and-fro system. Component arrangement similar to Mapleson B but large bore tubing shorter (no corrugated tubing). **CO_2 absorber can be incorporated** . This change reduces the reservoir volume and allows good mixing of fresh and exhaled gases. FGF of at least 2X MV prevents rebreathing. CO_2 will build up at a slower rate than with Mapleson B

Used frequently for patient transport and resuscitation. Sometimes combined with Mapleson F for this purpose

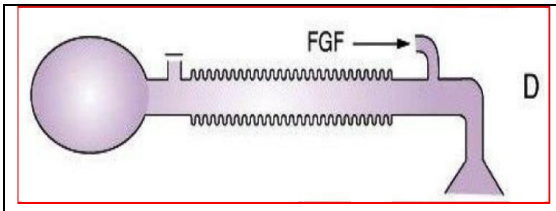
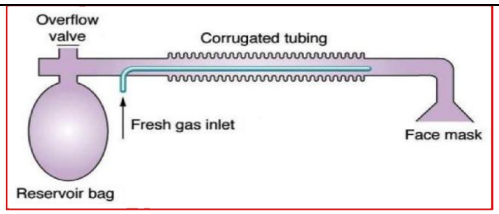


Figures -43): **Mapleson C**

Mapleson D and Bain Circuit Figures -44-A&B

Basically a T-piece with a long expiratory limb with reservoir bag and pop-off valve at the end. FGF of at least 2X MV required to prevent rebreathing during spontaneous ventilation and 2-3X MV during controlled ventilation

Bain circuit is coaxial Mapleson D

	
Figures -44-A): Mapleson D	**Figures -44-B): Bain circuit is coaxial Mapleson D**

Fresh gas enters the inner (small-bore) tubing and is delivered to the patient end. Exhaled gas is carried via the outer tubing to the reservoir bag and pop-off valve. Outer tubing made from transparent material allows inspection of inner tubing for kinking and disconnection. **Spontaneous ventilation:** - FGF 2.5-3X minute ventilation prevents rebreathing (200-300 ml/kg). **Controlled ventilation:** - FGF of 70 ml/kg/min results in normocapnia provided minute ventilation is adequate (120 ml/kg/min) in patients >40 kg

Bain Circuit: pre – use check

Pre – use check A

- Occlude the patient end.
- Close pop-off valve.
- Fill system with O2 until reservoir bag is distended.
- Then open patient end and flush O2 into circuit via inner tube.
- High O2 flow produces a Venturi effect at the patient end.
- Low pressure created at outer tubing end causes drawing of O2 along outer tubing to deflate reservoir bag.
- A disconnection or leak in inner tubing allows the high pressure to be transmitted from inner to outer tubing and reservoir bag remains inflated or distend further.

Pre – use check B

- Set one flow meter on 50 ml/min.
- Then occlude the patient end of inner tube using a small syringe.
- If inner tube is intact, this should cause the gas flow to cease and the flow meter bobbin to fall.

Test B is better because, if the inner tube is completely omitted, test A may give no indication that anything is wrong.

Advantages of Bain Circuit

- Light weight and convenient.
- Easily sterilized and reusable.
- Scavenging of gases from expiratory valve is facilitated because valve is located away from patient.
- Exhaled gases in outer reservoir tubing add warmth to inspired fresh gases

Hazards

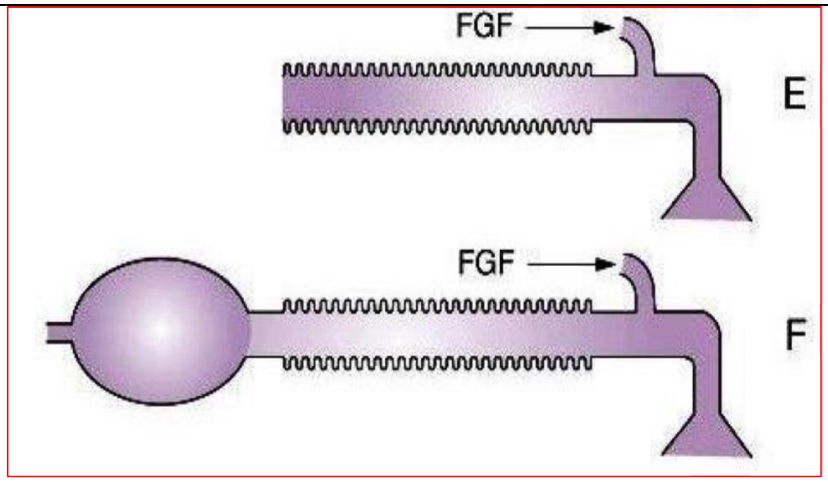
- Unrecognized disconnection of inner fresh gas hose leading to hypercabina
- Kinking of fresh gas hose leading to increased respiratory resistance .

Mapleson E **Figures -45-E&F**

Valve less T-piece arrangement

Modification of Ayre's original T-piece with addition of corrugated tubing to the expiratory limb, which becomes a reservoir for fresh gas during inspiration. Controlled ventilation is achieved with a "mechanical thumb" ventilator (intermittent occlusion of the expiratory limb).

Approximately 3X MV is required to prevent rebreathing



Figures -45): Mapleson E Ayre's original T-piece

Mapleson F: Jackson-Ree's modification of Ayre's T-piece Mapleson E

Mapleson F

- Jackson-Ree's modification of Ayre's T-piece (Mapleson E).
- Reservoir bag and a means of venting waste gases added to the end of the expiratory limb .
- Venting piece is usually a valve with an adjustable orifice that is connected to a waste gas .scavenging system.
- Used for controlled ventilation during an anesthetic procedure and for transportation of intubated patients.

Advantage;

- Popular for pediatric anesthesia because it is simple to assemble, inexpensive,

lightweight, easily positioned, and valve less (offering low resistance to breathing)

- 2-3 X MV prevents rebreathing.

Disadvantage – Lack of humidification

Summary

Relative efficiency of Mapleson's systems (With respect to prevention of rebreathing)

During spontaneous ventilation: A>D (FE)>C>B

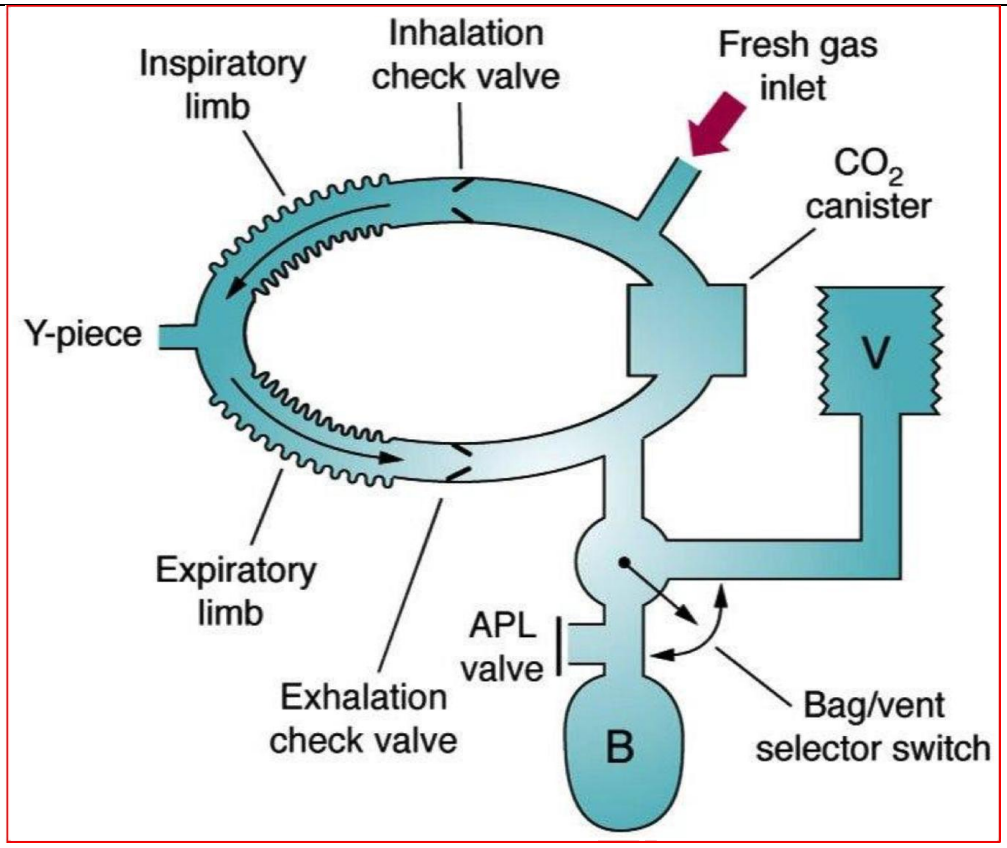
During controlled ventilation: D (FE)>B>C>A

***A D C B* = *All D*ogs *C*an *B*ite (Spontaneous) – this happens spontaneously**

***D B C A* = *D*og *B*ites *C*an *A*che (Controlled) – after the situation is controlled**

CIRCUITE SYSTEM **Figures -46-**

- Founded on the principle if sufficient oxygen is added to supply the body's basal needs and CO2 is absorbed, the same mixture of gases can be rebreathed repeatedly.
- Adult basal oxygen consumption varies between 200 and 400 ml/min.
- The system may be completely closed, or it may have a leak when used with slightly larger flows. Arrangement is variable , but to prevent re breathing of CO2.



Figures (46): Circuit System

<u>Components of the circle system</u> (Moyle et al., 2000)

1. Fresh gas inflow source.
2. Inspiratory and expiratory unidirectional valves.
3. Inspiratory and expiratory corrugated tubes.
4. Y-piece connector.
5. Overflow or pop-off valve [aka adjustable pressure limiting (APL) valve].
6. Reservoir (breathing) bag.
7. Canister containing a CO2 absorbent.

<u>NOTE;-</u>

At higher flows (> 6 L/min), the system becomes semi-closed and soda-lime becomes unnecessary, With basal flows (0.3-0.5L/min), rebreathing is total and expired CO2 is removed by soda lime – (closed system) (Al-Sheikh & Stacey, 2000).

C- Semi-closed

- Circle system at higher fresh gas flows.
- Associated with rebreathing of anesthetic gases.
- Most commonly used system in the US.
- The gas reservoir bag maintains an available reserve volume of gases to satisfy inspiratory flow rates of the patient (up to 6 L/min), which greatly exceeds conventional fresh gas flows (commonly 3-6 L/min).
- At higher gas flows (>6 L/min), carbon dioxide absorption usually becomes unnecessary (Morgan & Mikhail, 2013).

D-Closed system

- System may be "to-and-fro" or "circle".
- Fresh gas inflow (FGI) exactly matches that being taken up or consumed, by the patient.
- There is complete rebreathing of exhaled gases after absorption of CO2
- Fresh gas inflow into the circuit of a circle system permits the closure of the overflow(pop-off) valve.
- All exhaled CO2 is neutralized.
- Fresh gas inflow (150-500 ml/min) satisfies body's metabolic oxygen requirements and replaces anesthetic gases taken up by the body.
- Gases must be completely confined (venting is excluded).
- The nitrogen (N2) released by the patient may decrease the inspired O2 and N2O concentrations necessitating monitoring of these gases.

Advantages of circuit system;

- Relative stability of inspired concentration.
- Conservation of respiratory moisture and heat.
- Reduce of operating room pollution.
- PaCO2 depends only on ventilation, not fresh gas flow.

- Low fresh gas flows can be used so it is economically.
- The lengths of the tubing can be varied so that the machine can be placed away from the patient (e.g. MRI, head and neck surgery) .

Disadvantages of circuit system;

- Complex design = potential for malfunction.
- High resistance (multiple one-way valves) = higher work of breathing*;*
  - Soda-lime reaction with volatile agents may produce toxic compounds.
  - Rebreathing can occur if the unidirectional valves stick in the open position or cause total occlusion of the circuit if they stick in closed position.
  - Alkaline dust may pass to the patient .

The following rules must be followed;

- Unidirectional valves between the patient and the reservoir bag.
- Fresh-gas-flow cannot enter the circuit between the expiratory valve and the patient.
- Adjustable pressure –limiting valve;
  (APL cannot be located between the patient and the inspiratory valve).

Breathing Circuit Problems; (Dorsch & Dorsch, 1999)

- Disconnection – leading cause of critical incidents..
- Most common disconnection site is the Y-piece.
- Preexisting undetected leaks in compressed, corrugated disposable anesthetic circuit .
- Disconnection and leaks manifest more readily with ascending bellows.
- Most important disconnection monitor is a vigilant anesthesia care provider. Occlusion (obstruction) of breathing circuit may also occur; - high-pressure alarm may alert the anesthesiologist to this problem.

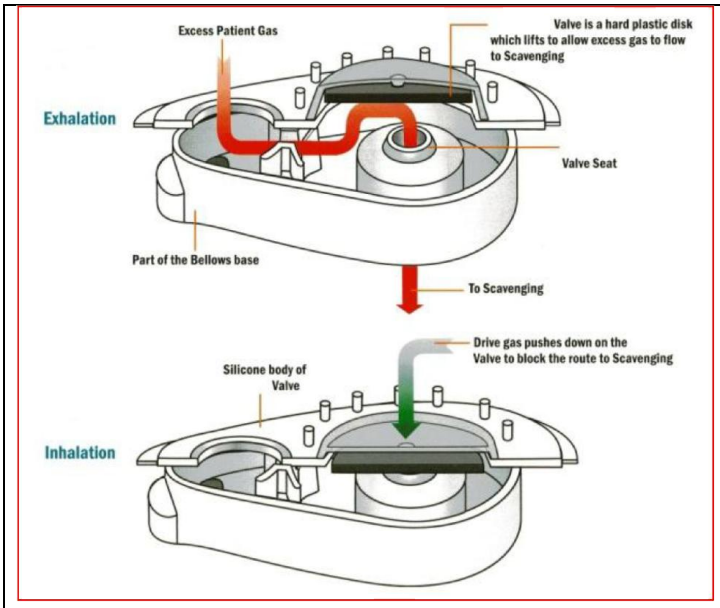
2.9. VALVES IN THE CIRCLE SYSTEM

A. Unidirectional Valves

B. Adjustable Pressure Limiting (APL) or "pop-off" valve

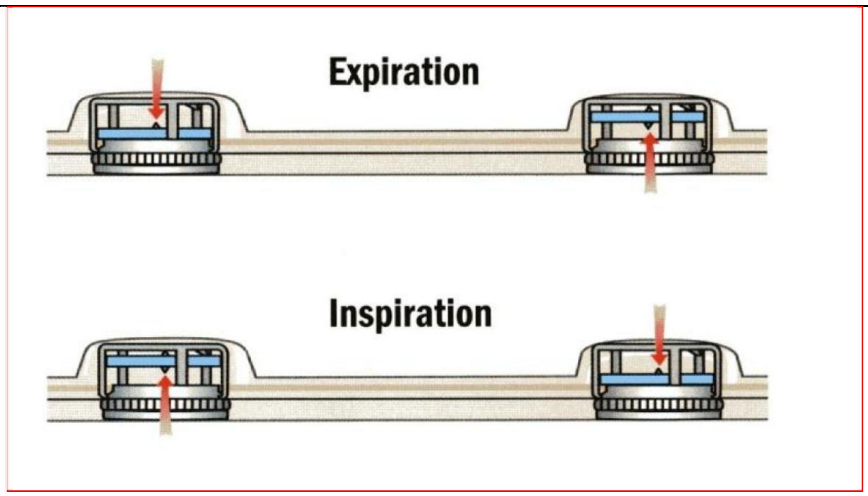
A-Unidirectional Figures -47-A&B

Two valves present in the circle system to ensure that gases flow toward the patient in one breathing tube and away in the other.



Figures (47(A): Unidirectional valve

(Al-Sheikh & Stacey, 2000)



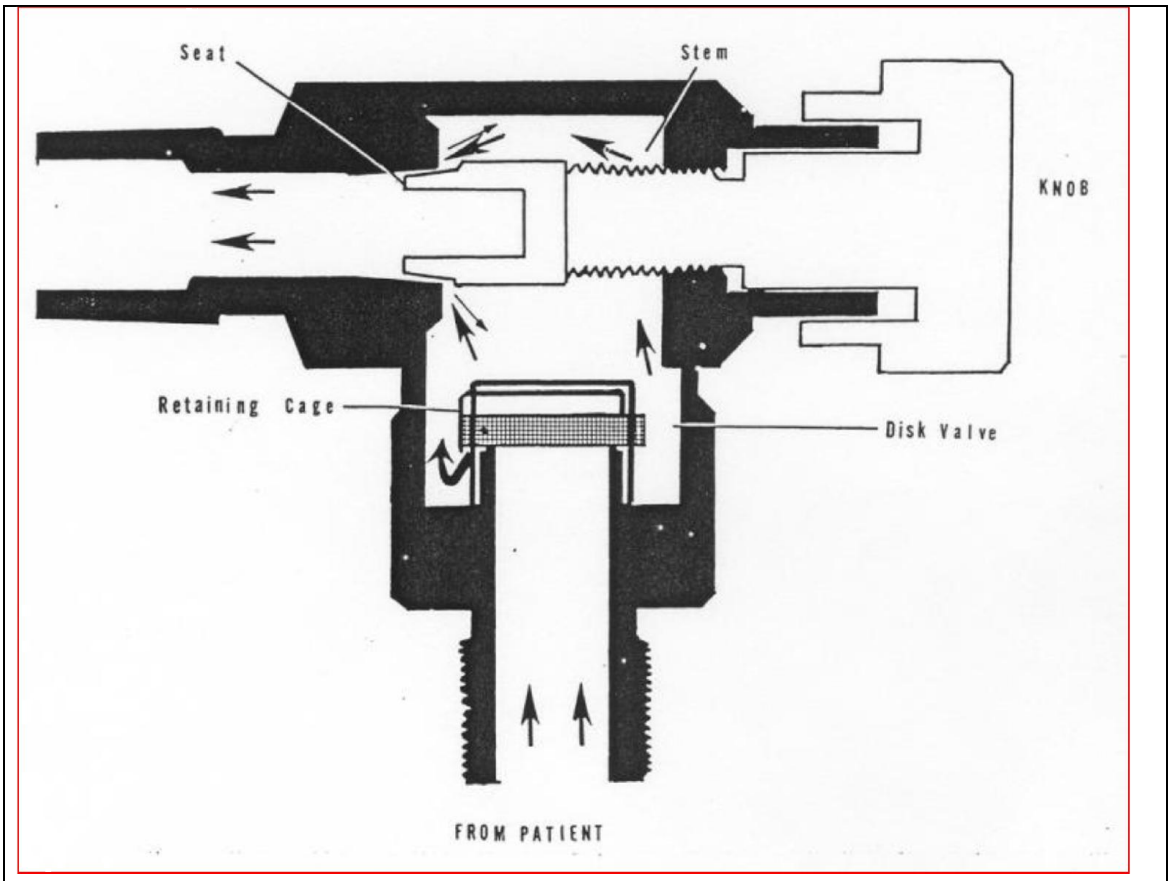
Figures 47 (B): Unidirectional valve

(Al-Sheikh & Stacey, 2000)

NOTE:-

Because of the unidirectional valves, apparatus dead space in the circle system is limited to the area distal to the point of inspiratory and expiratory gas mixing at the Y-piece; hence long tubing lengths can be used without significant CO2 rebreathing (Dorsch & Dorsch, 1999).

A. Adjustable Pressure Limiting (APL) or "Pop-off" valve **Figures -48-**



Figures (48): Adjustable Pressure Limiting (APL) or "Pop-off" valve

APL:-

- User adjustable valve that releases gases to atmosphere or a scavenging system.
- It is intended to provide control of pressure in the breathing system. The aim is to prevent damage to the patient's airways.
- They have a low opening pressure of about 28 mmHg (Moyle et al., 2000).

NOTE;

The 2 liter reservoir bag, when distended with pressure, seldom reaches pressure above 35 mmHg before it splits.

Unfortunately, a steady pressure of 28 mmHg at the alveoli will stop the pulmonary circulation (PA systolic pressure = 25 mmHg), so this hazard is not prevented by the APL valve (Dorsch & Dorsch, 1999).

Spontaneous Respiration

- APL valve remains closed during respiration.
- Opens during exhalation when its opening pressure is exceeded.
- Valve should be left fully open during spontaneous ventilation.
- Partial closure during spontaneous respiration will result in PEEP.

Manually Controlled or Assisted Ventilation

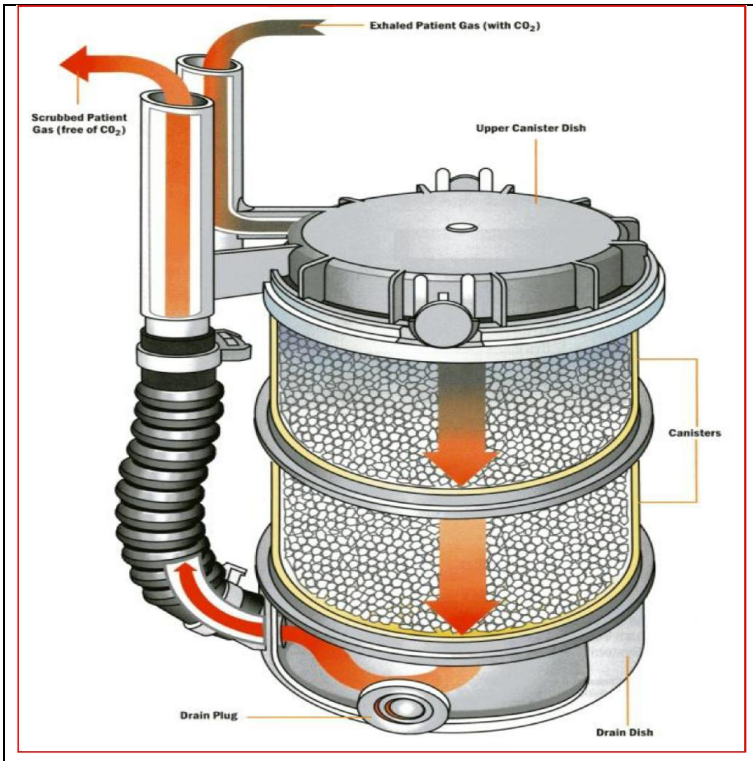
- Valve is usually left partially open.
- The bag is squeezed during inspiration and pressure increases until the relief pressure is reached. Before this, the patient receives all of the gas displaced from the bag.
- Frequent adjustment of the valve, made on the basis of chest movements and exhaled volume measurements may be necessary to achieve desired level of ventilation and maintain adequate filling of the bag.

Mechanical ventilation

- When a ventilator is used, gas will be vented from it during expiration
- The APL valve should be closed completely
- If left open, gas will be vented from the system during inspiration
- Selector valves that facilitate the change from manual to automatic ventilation are available.
- Most of these isolate the APL valve when the selector valve is turned to automatic (Morgan et al., 2006).

2.10. CARBON DIOXIDE ABSROBER

(Soda lime or Baralyme) Figures -49-



Figures (49): Canisters of Soda lime

- Central component in a circle system
- Canisters are large with minimal gas space equal to the largest expected patient tidal volume
- Design permits low gas flow rates, long dwell lines and thereby, more complete removal of CO2
- Canisters usually have 2 chambers so that one half of the absorbent (upstream chamber) can be completely exhausted before removal. The chambers are then reversed.

Baralyme (no longer commercially available) (A-

20% Ba (OH)2 (Barium hydroxide octahydrate) & (80% Ca (OH)2) (Mitchel & Sasis, 1997).

B- Soda lime;

Ca (OH2) + H20 94%

NaOH 5% KOH 1%

Silica or Kieselguhr (for hardening to reduce alkaline dust formation)

- The absorptive efficacy of soda lime is inversely related to its hardness; therefore little silica is used nowadays.
- Soda-lime granules are 3-6 mm (4-8 mesh) in size to minimize resistance to breathing and to allow plenty of surface for absorption.

Soda lime equation:

$CO2 + H2O \leftrightarrow H2CO3$

$H2CO3 + 2NaOH \leftrightarrow Na2CO3 + 2H2O + Heat$

$Na2CO3 + Ca(OH)2 \leftrightarrow CaCO3 + 2NaOH$

- Air space in the charged canister should equal the patients tidal volume
- Nearly half the volume in a properly packed canister consists of inter granular space
- Dura sorb is an improved soda-lime with a prolonged effective life which does not overheat
- Soda-lime must be fresh and tidal exchange must be adequate for efficient CO2 elimination
- Vertical position of the canister prevents “channeling” of gas flow down the edges, but even so, the center of the canister tend to be used preferentially, resulting in loss of efficiency which is not evident to the naked eye because the visible soda lime has not changed color.
- The 1 lb. Canister will last about 6 hour intermittently and 2 hours continuously

- Optimal and most frequently used granule size is 4-8 mesh size (¼ inch to 1/8 inch diameter or 3-6 mm)
- The maximal absorptive capacity is 26 L of CO2 per 100 gm of absorbent
- Channeling is the preferential passage of exhaled gases through the canister via the pathways of least resistance (Morgan & Mikhail, 2013).

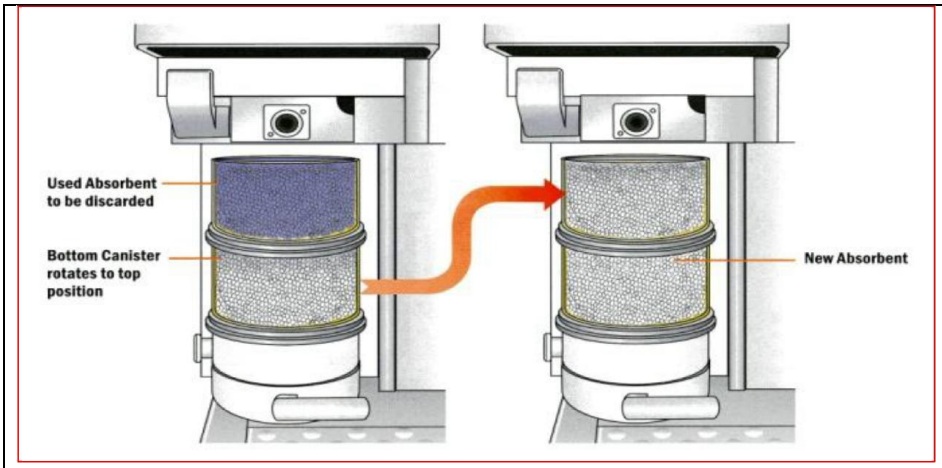
Indicator of Absorbent; table 5

pH sensitive and colorless when soda lime is fresh but become colored when pH decreases.

Table 5: Indicator of Absorbent (Davis et al., 2000)

Indicators for Absorbents

Indicator	Color When Fresh	Color When Exhausted
Phenolphthalein	white	pink
Ethyl violet	white	purple
Clayton yellow	red	yellow
Ethyl orange	orange	yellow
Mimosa Z	red	white



Figures (50): Color changed after uses (Indicator of Absorbent)

Not a metabolite of sevoflurane and is not formed in the body.

Compound A

- Compound A is nephrotoxic in rats – via proximal tubular necrosis leading to increase serum BUN, creatinine, protein, & glucose excretion
- Studies have not shown any evidence of compound A nephrotoxicity in humans even at high compound A exposures for as long as 17 hours (Anesth Analg 2001; 93: 1511-20), neither were any significant differences in renal function between low flow sevoflurane and low flow isoflurane in patients with preexisting renal disease exposed to compound A (Anesthesiology 2002; 97: 578-84)

Increased risk of Compound A production (Al-Sheikh & Stacey, 2000)

- Low inflow of fresh gas
- High concentrations of sevoflurane
- Higher absorbent temperatures
- Use of Baralyme

Carbon Monoxide (CO)

- CO formation occurs when volatile anesthetic agents pass through a CO2 absorbent that contains strong base and is dehydrated (majority of reported CO toxicity occurred after 2days of disuse of the absorbent particularly with continued airflow through the circle systemmaking the absorbent dry)
- Desflurane >> Enflurane >> Isoflurane – prolonged exposure to CO2 absorbents may result in anesthetic degradation leading to production of carbon monoxide (CO). Sevoflurane produces negligible amounts of CO

- A researcher at Duke University, NC found carboxyhemoglobin (COHb) concentrations as high as 29% in some patients on Monday mornings (Morgan & Mikhail, 2013).
- **CNS signs of CO toxicity include: headache, nausea, vomiting, dizziness, visual/motor disturbances, and diminished consciousness** (Ronald & Fanst, 2003).

Factors that increase CO production

- Use of dry absorbent
- Increased temperature
- Use of higher anesthetic concentrations
- Inhaled agent used: for a given MAC desflurane, enflurane >isoflurane >> halothane = sevoflurane
- Use of Baralyme in place of Soda lime (Ronald & Fanst, 2003)

Recommendations (Dorsch & Dorsch, 1999)

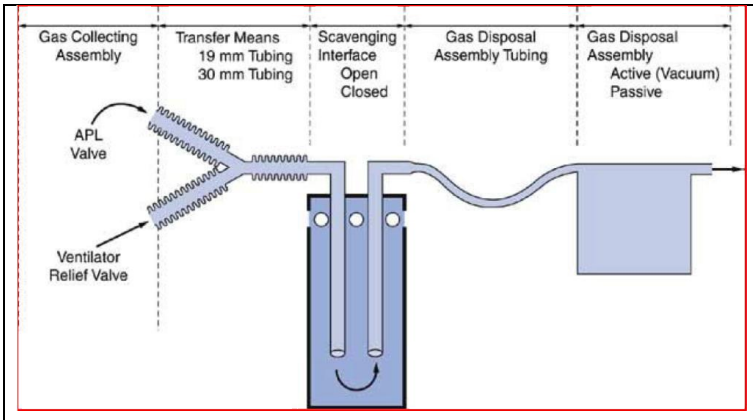
- Use fully hydrated absorbents
- Turn off your machine at the end of each day
- Replace absorbent if you think it is desiccated (dry) Consider changing the CO2 absorbent at regular intervals e.g. every Monday
- Choose an anesthetic agent that does not form CO e.g. sevoflurane
- Single best thing to do: use an absorbent that does not contain strong base.

2.11. SCAVENGING SYSTEMS

Scavenging is the collection and subsequent disposal of vented gases from the operating room.

Components of the scavenging system; Figures -51-

1. Gas collecting assembly
2. Transfer means
3. Scavenging interface (open or closed)
4. Gas disposal assembly tubing
5. Gas disposal assembly (active or passive)



Figures (51): Components of the scavenging system

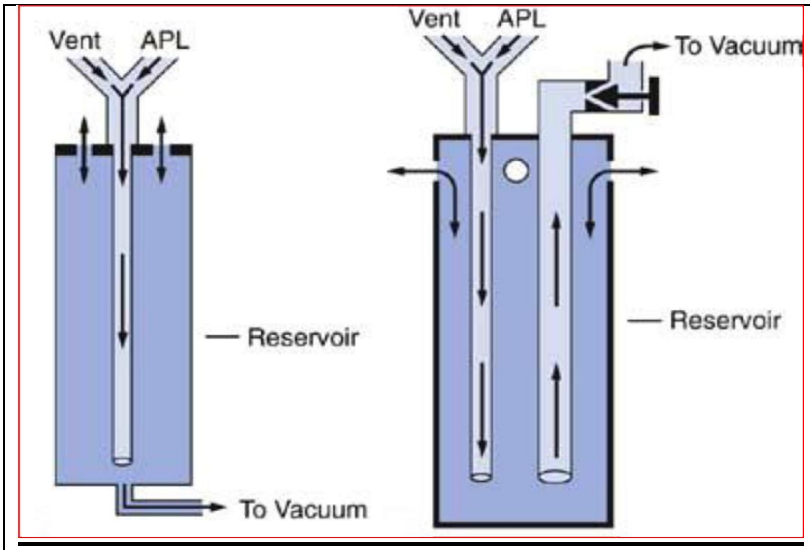
1+2 COMPONENT:-

- Waste gases leave the anesthesia circuit via the APL valve or via the ventilator pressure relief valve (PRV)
- These gases accumulate in the gas collecting assembly and is directed to the transfer tubing
- Transfer tubing carries excess gas from the gas collecting assembly to the scavenging interface
- The tubing must be either 19 mm or 30 mm in diameter
- Some manufacturers color code the transfer tubing with yellow bands to distinguish it from 22 mm breathing system tubing.

3-Scavenging interface:-

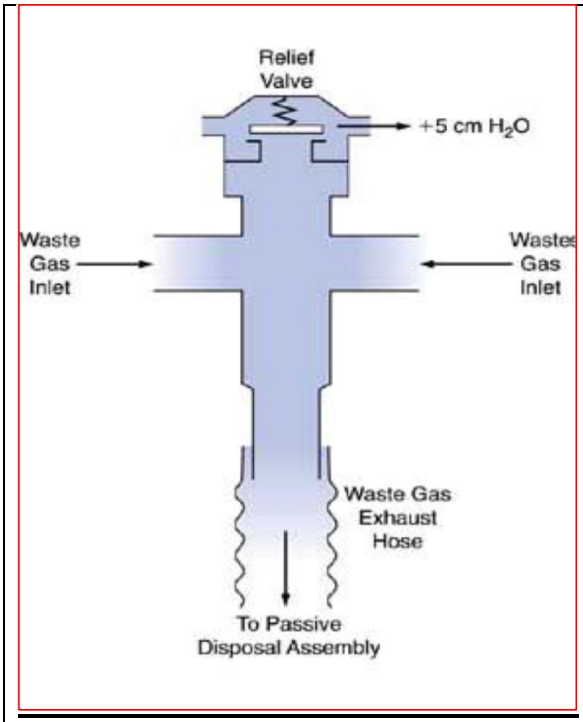
Protects the breathing circuit or ventilator from excessive positive or negative pressure. It should limit the pressures immediately downstream from the gas collecting assembly to between –0.5 and +10 cm H2O (Moyle et al., 2000).

Open Interface Figures -52-

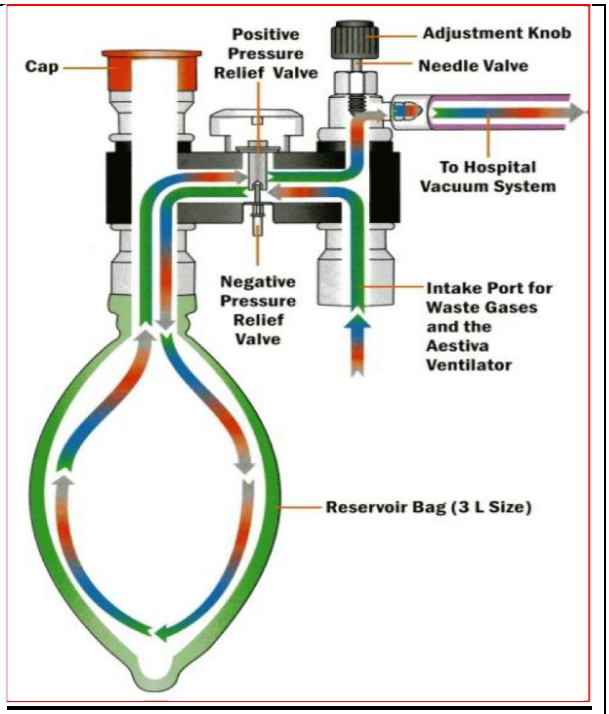


Figures (52): Open Interface Scavenging System

Closed Interface Figures -53-A&B



Figures (53-A): disposal assemply



Figures (53-B): closed interface

(Morgan et al., 2006)

Scavenging inter face:-

- Scavenging system (interface) is either open or closed
- Open interface relies on relief ports for +(ve) or –(ve) pressure relief
- Closed interface relies on relief valves
- Gas disposal can be active or passive
- Active disposal relies on suction
- Passive disposal relies on waste gas pressure (no suction) to push gas out

Positive-pressure relief valve is mandatory to vent excess gas in case of occlusion downstream from the interface, irrespective of the type of disposal system used.

Negative pressure relief is necessary to protect the breathing circuit or ventilator from excessive sub atmospheric pressure, if the disposal system is active (vacuum suction) (Dorsch & Dorsch, 1999).

Note;

- A reservoir is highly desirable with active systems because it stores excess waste gas until the evacuation system can eliminate it.
- Interfaces – can be open or closed, depending on the method used to provide positive pressure and negative pressure relief (Al-Sheikh & Stacey, 2002).

Open Interface; (Al-Sheikh & Stacey, 2000)

- Open reservoir scavenging interfaces are valve less
- Use continually open relief ports to provide pressure relief
- Relief ports are open to the atmosphere

- Allows both, positive-pressure and negative-pressure relief Waste gas from the circuit is directed to the bottom of the canister (all anesthetic gases are more dense than air)
- Hospital suction system aspirates gas from the bottom of the canister
- The reservoir canister contains the excess waste gas and thereby accommodates a range of waste gas flow rates from the patient circuit
- Because this type of interface depends on open relief ports for pressure relief, these ports must remain un occluded at all times
- ***Open interfaces should be used only with active disposal systems that utilize a central vacuum system***

Closed Interface;

- There are relief valves (not relief ports)
- Communicates with the atmosphere through valves
- **Two types** of closed interfaces are commercially available
  1. Positive-pressure relief only
  2. Both positive and negative-pressure relief.

Closed Interface;Positive-pressure only

- Single positive-pressure relief valve
- Used only with passive disposal systems
- Waste gas enters the interface at waste gas inlets
- Transfer of the waste gas from the interface to the disposal system relies on the pressure of the waste gas itself because a vacuum is not used
- The positive-pressure relief valve opens at a preset value of about +5 cm H2O if an obstruction between the interface and the disposal system occurs.

Closed Interface;negative&Positive-pressure

- If excessive suction is applied to the circuit, one or two negative pressure relief ("pop in") valves (-0.25 to –1.8 cm H2O) would open to preferentially draw in room air
- The reservoir stores transient excess gas until the vacuum system eliminates it
- Gas is vented to the atmosphere through the positive pressure relief valve if the system pressure exceeds +5 cm H2O
- Leakage of waste gases into the atmosphere occurs only if the reservoir bag becomes fully inflated and the pressure increases sufficiently to open the positive-pressure relief valve.

4-Gas Disposal Assembly Tubing;

- Conducts waste gas from the scavenging interface to the gas disposal assembly
- It should be collapse-proof

5-Gas Disposal Assembly;

- Ultimately eliminates excess waste gas
- **2 types – Active and Passive.**

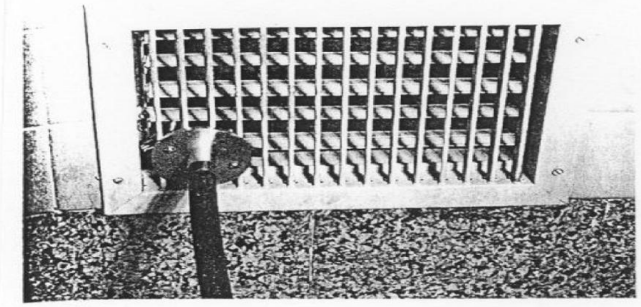
Active System;

- Most common
- Uses a central vacuum
- The vacuum is a mechanical flow-inducing device that removes the waste gases
- An interface with a negative-pressure relief valve is mandatory because the pressure within the system is negative
- A reservoir is desirable.

- The larger the reservoir, the lower the suction flow rate needed.

Passive System;

- Does not use a mechanical flow inducing device
- Pressure of the waste gas itself produces flow through the system
- Positive-pressure relief is mandatory
- Negative pressure and reservoir are unnecessary
- Excess waste gas is eliminated by venting through the wall, ceiling, floor or room exhaust grill of a non-recirculating air conditioning system.



A disposal line of waste anesthetic gases attached to the operating room air condition grill. (Reproduced by permission of Azar I: Anesthetic gas spillage and scavenging. *In* Cottrell J (ed): Occupational Hazards to Operating Room and Recovery Room Personnel. Boston, Little, Brown, 1981.)

Figure (53 C): Disposal Assemply Line of Waste Anesthesia Gases

(Al-Sheikh & Stacey, 2000)

Summary;

- Scavenging system (interface) is either open or closed
- Open interface relies on relief ports for +(ve) or – (ve) pressure relief
- Closed interface relies on relief valves
- Gas disposal can be active or passive
- Active disposal relies on suction
- Passive disposal relies on waste gas pressure (no suction) to push gas out

2.12. ANESTHESIA MACHINE CHECKOUT

- This should be done every day before administering anesthesia to the first patient and whenever any change has been made to the system, e.g. moving the machine even within the OR
- In addition a short checkout of the breathing system should precede each administration of an anesthetic

FDA Recommendations:

Step 1: Verify backup ventilation equipment is available and functioning

e. g. properly functioning manual resuscitator

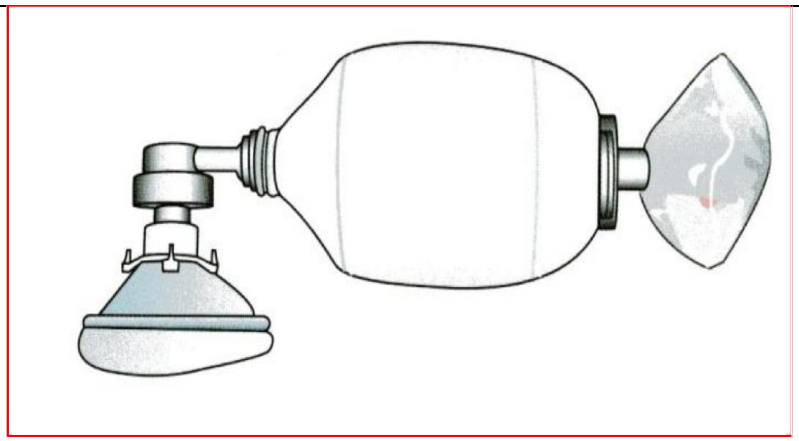
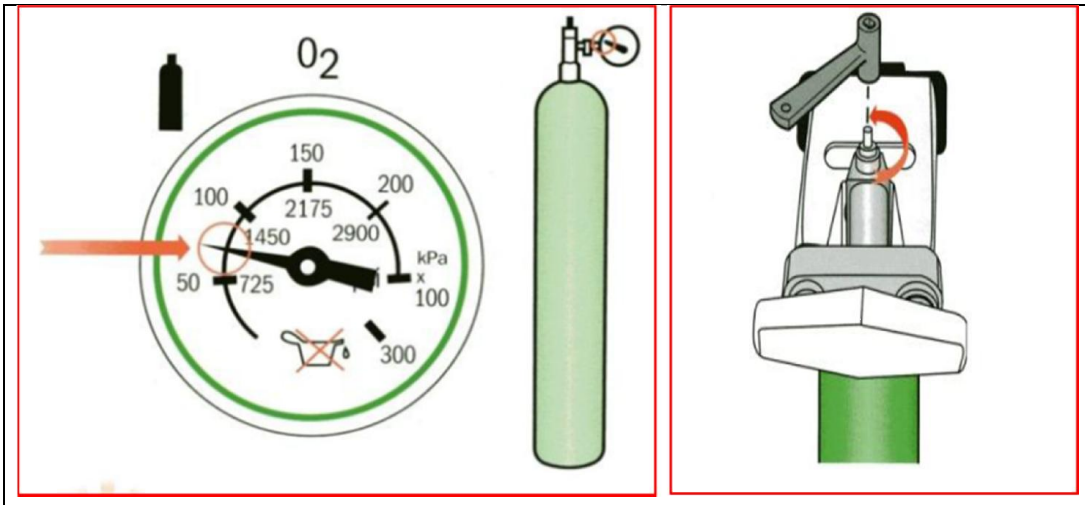


Figure (54): AMBU Bag

(Dorsch MP., 2014)

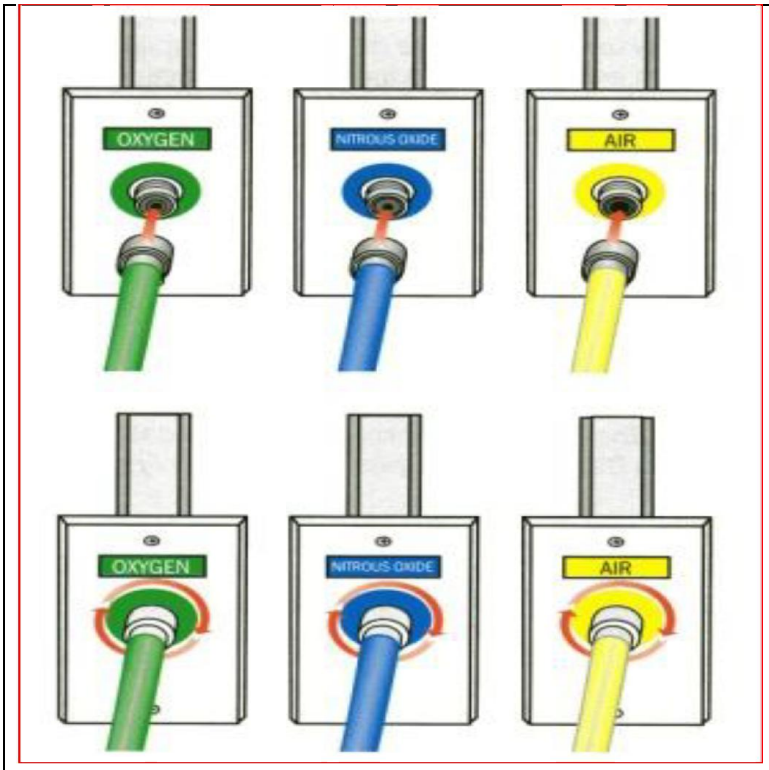
Step 2: check the oxygen cylinder supply; (Dorsch MP., 2014)



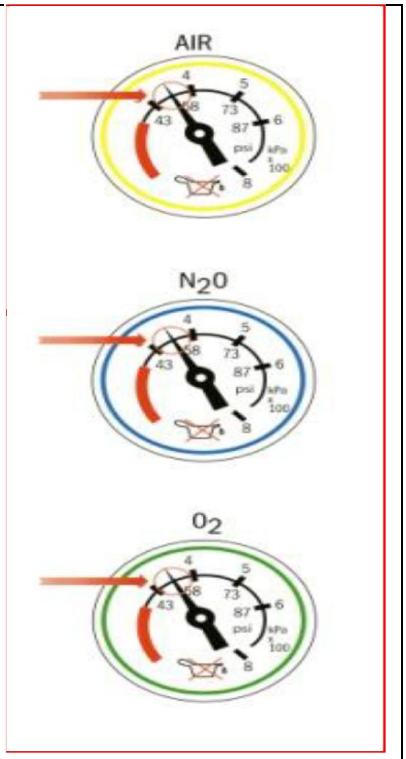
Figures (55-A): Cylinder Pressure Gauge (55-B): Hanger Yolk

a. Open oxygen cylinder and verify that it is at least half full (about 1000 psi)
b. Close cylinder – manufacturer recommends that cylinders remain closed so that they do not inadvertently get drained

<u>Step 3: Check central pipeline supplies</u>; (Dorsch & Thrap, 2012)



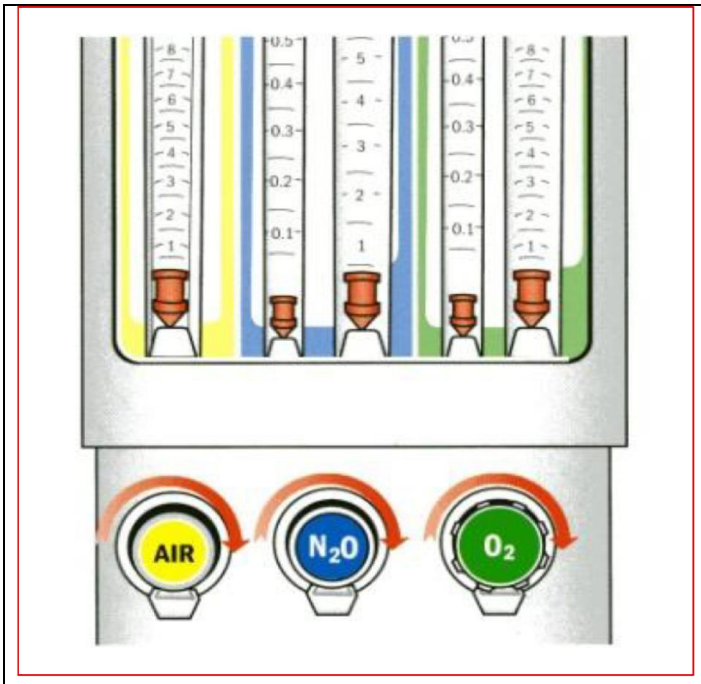
Figures (56-A): Pipeline Hoses Inlet Connection



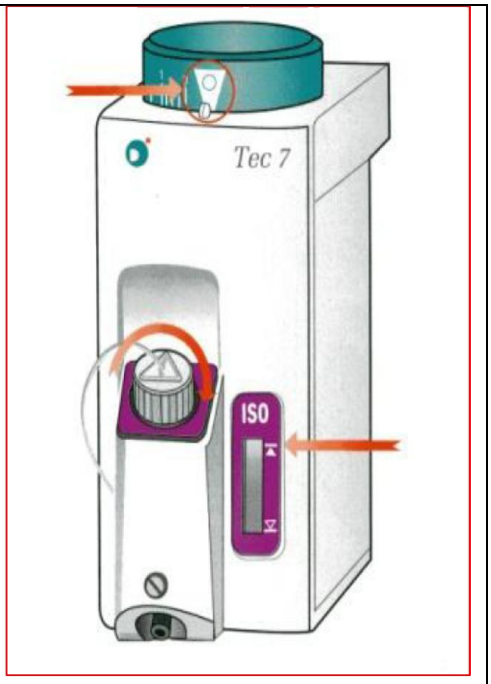
Figures (56-B): Pipeline Pressure Gauge

Check that pipeline hoses are connected and pipeline gauges read about 50 psi

Step 4: Check initial status of low pressure system; Figures -57-A&B (Dorsch & Thrap, 2012)



Figures (57-A): Flowmeter



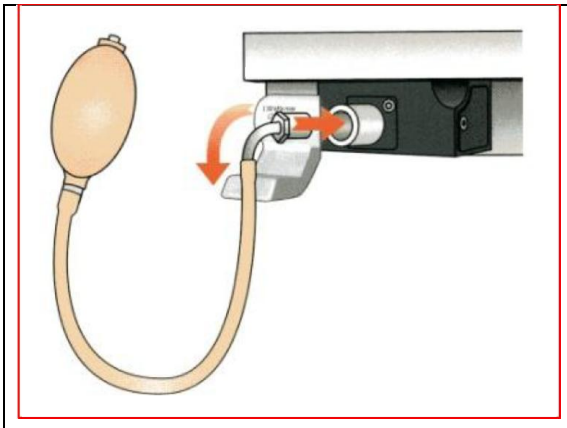
Figures (57-B): Vaporizer

a. **Close flow control valves and turn vaporizer off**

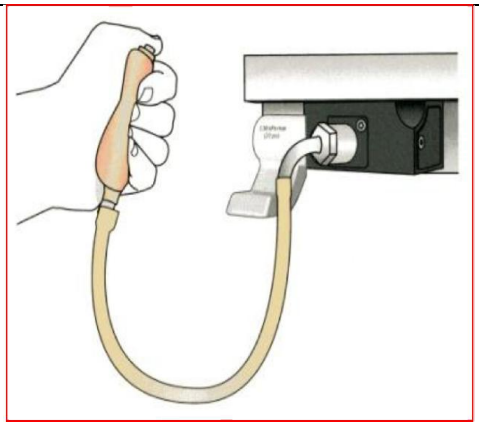
b. **Check fill level and tighten vaporizers' filler caps**

Step 5: Perform leak check of machine low pressure system;

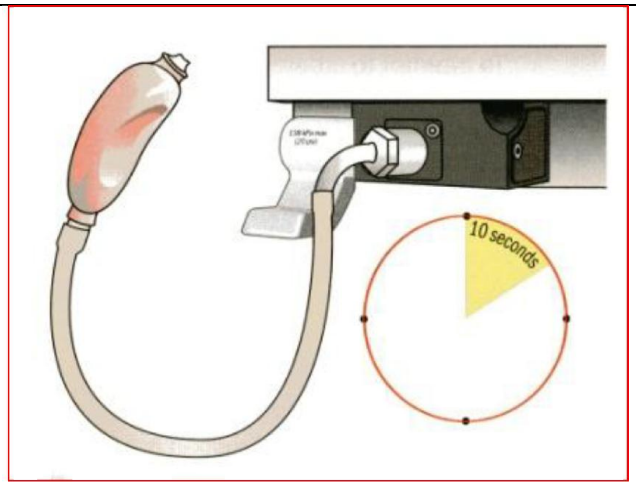
Figures -58-A,B&C (Moyle et al., 2000)



Figures (58-A): Suction Bulb



Figures (58-B): Bulb Squeeze



Figures (58-C): Bulb Collapsed 10 Seconds

a. Verify that the machine master switch and flow contr ol valves are OFF

b. Attach “suction bulb” to common (fresh gas) outlet

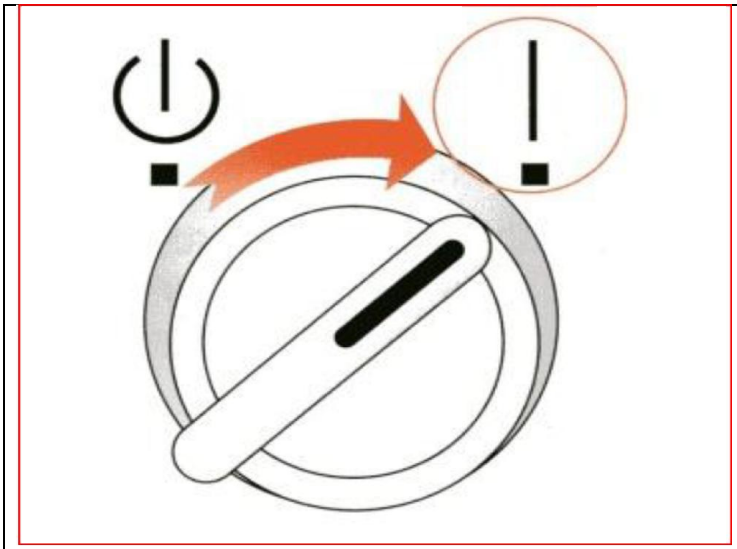
c. Squeeze bulb repeatedly until fully collapsed

d. Verify bulb stays fully collapsed for at least 10 seconds

e. Open one vaporizer at a time and repeat steps ***c*** and ***d*** above

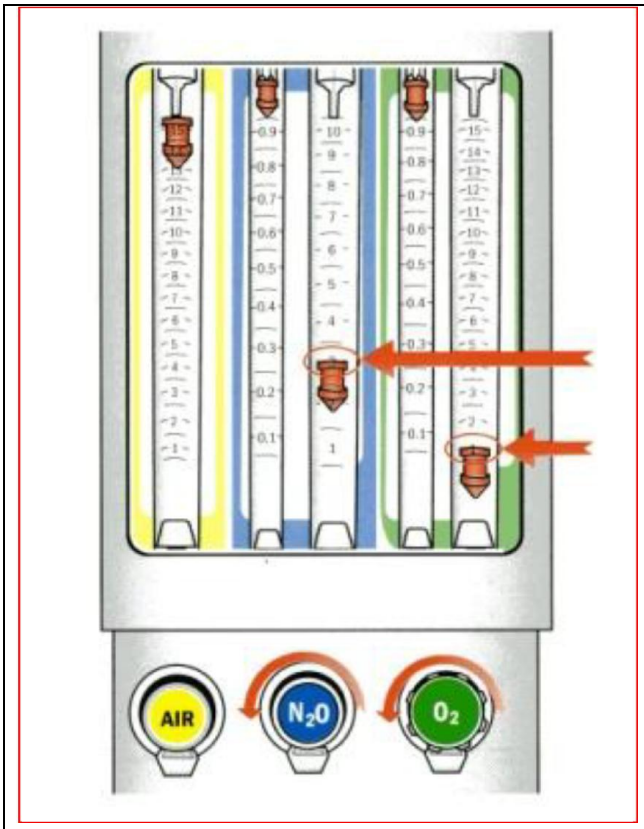
f. Remove suction bulb, and reconnect fresh gas hose

Step 6: Turn on machine master switch and all necessary electrical equipment; Figures -59- (Dorsch MP., 2014)



Figures (59): master switch

<u>Step 7: Test flow meters;</u> Figures -60- (Dorsch & Dorsch, 1999)



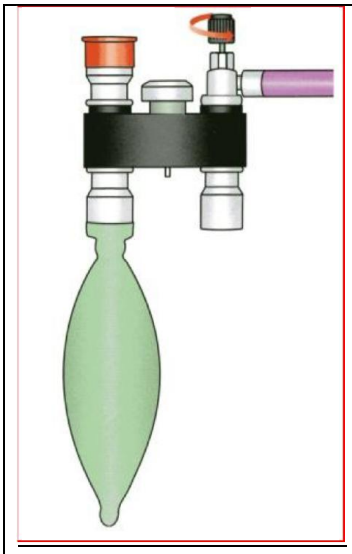
Figures -60): Flowmeter

a. Adjust flow of all gases through their full range, checking for smooth operation of floats and undamaged flowtubes

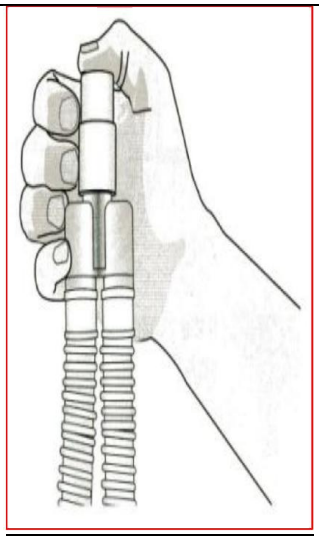
b. Attempt to create a hypoxic O2/N2O mixture and verify correct changes in flow and/or alarm .

Step 8: Adjust and check scavenging system;

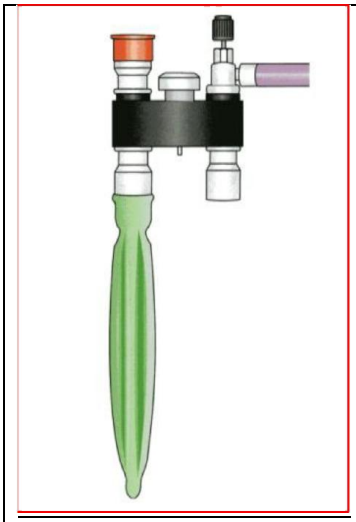
Figures -61-A,B,C&D (Al-Sheikh & Stacey, 2002)



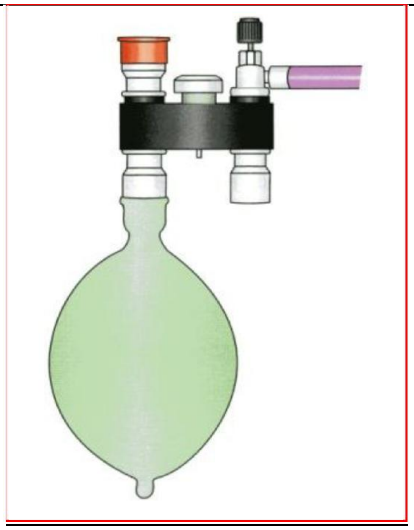
Figures (61-A): scavenging reservoir bag



Figures (61-B): Y Piece



Figures (61- C): Reservoir Bag Empty



Figures (61-D): Reservoir Bag Full Distended

a. Ensure proper connections between scavenging system and both APL (pop-off) valve and ventilator relief valve

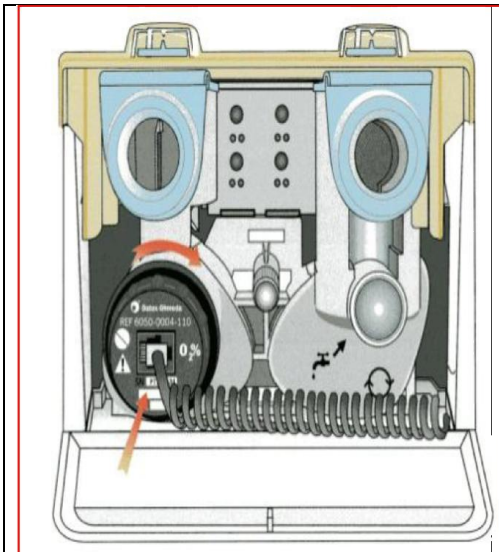
b. Adjust waste gas vacuum (if possible)

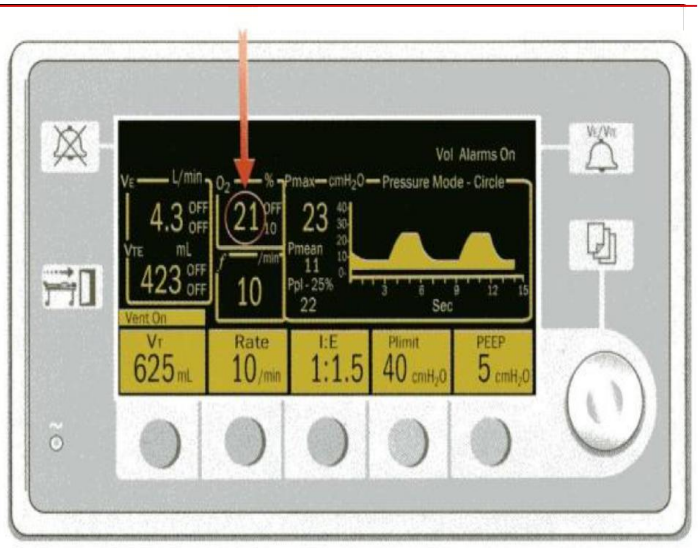
c. Fully open APL valve and occlude Y-piece

d. With minimum O2 flow, allow scavenger reservoir bag to collapse completely and verify that absorber pressure gauge reads about zero

e. With O2 flush activated, allow the scavenger reservoir bag to distend fully, then verify that absorber gauge reads < 10 cmH2O .

Step 9: Calibrate O2 Monitor; Figures -62-A&B





Figures (62-A): Oxygen monitor calibration	**Figures (62-B): Oxygen monitor main screen**
(Morgan & Mikhail, 2013)	

a. Ensure monitor reads 21% in room air (remove O2 cell and let it hang in room air to calibrate)

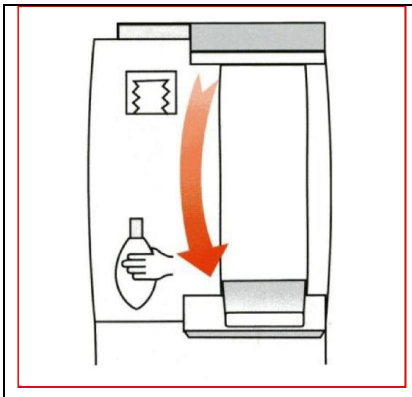
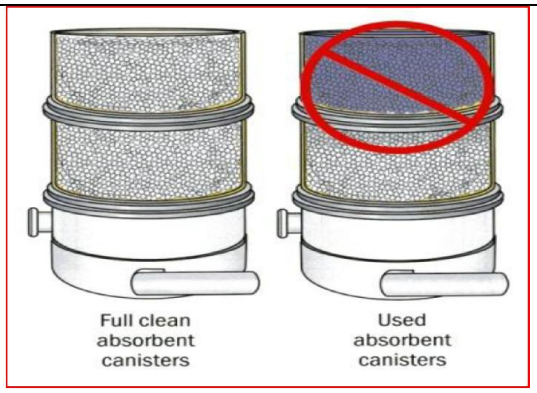
b. Verify low O2 alarm is enabled and functioning

c. Re-install sensor in circuit and flush breathing system with O2

d. Verify that monitor now reads greater than 90% **(Dorsch MP., 2014)**

Step 10: Check initial status of breathing system;

Figures -63-A&B (Moyle et al., 2000)

	
Figures (63-A): Pressurize Canster of Ventilator	**Figures (63-B): Canster of Soda Lime**

a. Set selector switch to “bag” mode

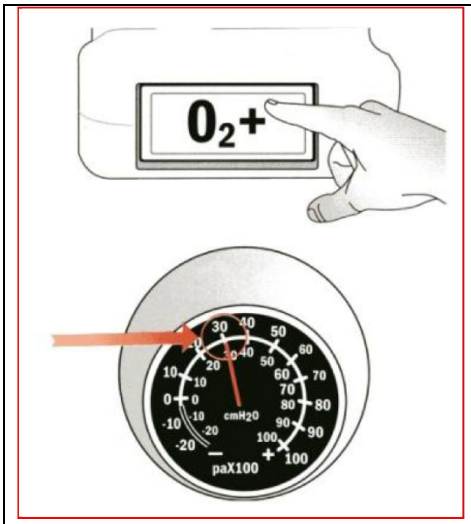
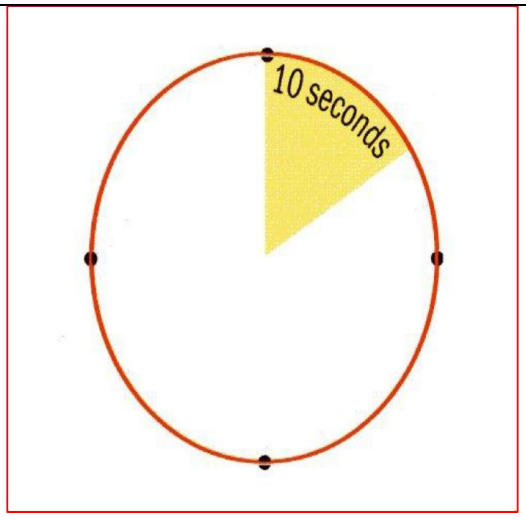
b. Check that breathing circuit is complete, undamaged and unobstructed

c. Verify that CO2 absorbent is adequate

d. Install breathing circuit accessory equipment (e.g. humidifier, PEEP valve) to be used during the case

Step 11: Perform leak check of the breathing system;

Figures -64-A&B (Dorsch & Dorsch, 2014)

	
Figures (64-A): Peak Pressure	**Figures (64-B): 10 second holding**

a. Set all gas flows to zero (or minimum)

b. Close APL (pop-off) valve and occlude Y-piece

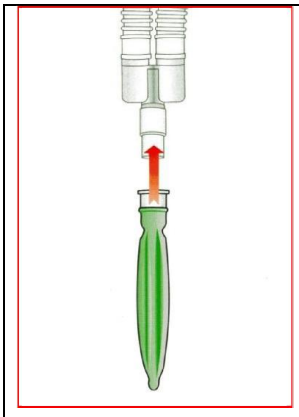
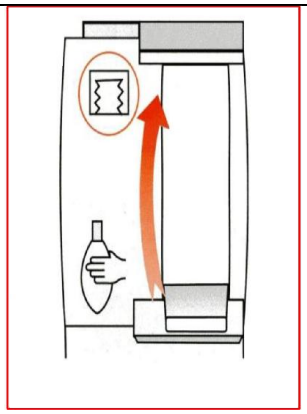
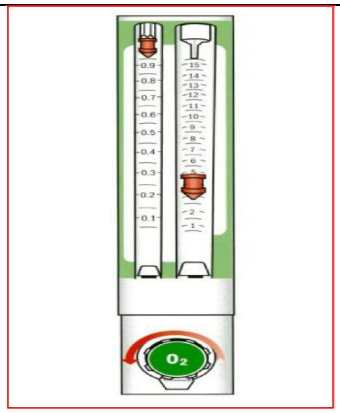
c. Pressurize breathing system to about 30 cmH2O with O2 flush

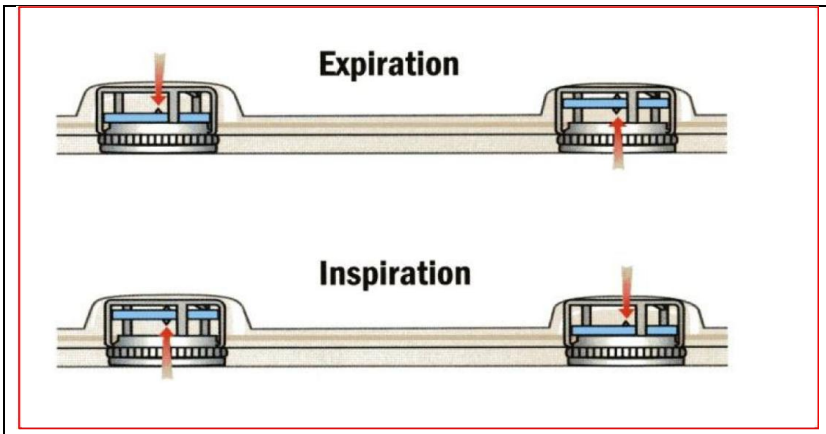
d. Ensure that pressure remains fixed for at least 10 seconds

e. Open APL (pop-off) valve and ensure that pressure decrease

Step 12: Test ventilation systems and unidirectional valves;

Figures -65-A,B,C&D (Dorsch MP., 2014)

		
Figures (65-A): reservoir bag connected to Y-Piece	**Figures (65-B): canster of ventilator**	**Figures (65-C): flowmeter setting 5L/ml**

	**Figures (65-D)**: Unidirectional Valve

a. Place a second breathing bag on Y-piece

b. Set appropriate ventilator parameters for next patient

c. Switch to automatic ventilation (ventilator) mode

d. Fill bellows and breathing bag with O2 flush and then turn ventilator ON

e. Set O2 flow to minimum, other gas flows to zero

f. Verify that during inspiration bellows delivers appropriate tidal volume and that during expiration bellows fill completely

g. Set fresh gas flow to about 5L/min

h. Verify that the ventilator bellows and simulated lungs fill **and empty** appropriately without sustained pressure at end expiration

i. Check for proper action of unidirectional valves

j. Exercise breathing circuit accessories to ensure proper function

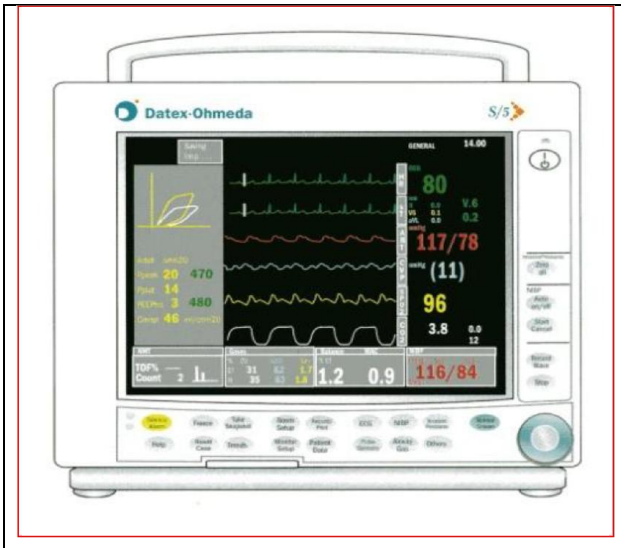
k. Turn ventilator OFF and switch to manual ventilation (Bag/APL) mode

l. Ventilate manually and assure inflation and deflation of artificial lungs and appropriate feel of system resistance and compliance

m. Remove second breathing bag from Y-piece .

Step 13: Check, calibrate and/or set alarm limits of all monitors;

(Morgan et al., 2006)



Figures (66): Monitor full parameter

- **Capnometer**
- Oxygen Analyzer
- Pressure Monitor with high and low airway alarms

- Pulse Oximeter
- Respiratory Volume Monitor (Spirometer)

Step 14: Check final status of machine; (Dorsch & Dorsch, 2014)

a. Vaporizers off

b. APL valve open

c. Selector switch to "bag"

d. All flow meters to zero

e. Patients suction level adequate

f. Breathing system ready to use

Note:

If an anesthesia provider uses the same machine in successive cases, steps 1-9 need not be repeated or may be abbreviated after an initial checkout (Moyle et al., 2000)**.**

Chapter three:

METHODOLOGY

Chapter 3: RESEARCH METHODOLOGY

3.1: Study area:

The current study was conducted at Sana'a city, Yemen.

3.2: Study design:

In the current study, a cross-sectional descriptive study was utilized. This design was concerned with description of a phenomenon of interest and focused on anesthesiologists' knowledge without trying to make interference.

3.3: Study population:

All anesthesiologists worked in the Hospitals affiliated to Sana'a city, Yemen, who voluntarily agree to participate in this study were included.

3.4: Sample size:

Due to the relatively small population of potential participants, and time restraint, (57 anesthesiologists) were invited to participate in this study.

3.5: Inclusion criteria:

All anesthesiologists working in Hospital, Sana'a city, Yemen regardless of their age, gender, and level of education, and who are professionally active for 1 year or more and gave informed consent to participate in the study will be included.

3.6: Exclusion criteria:

Newly appointed anesthesiologists (less than three months) during the time of study

3.7: Sampling method:

All the anesthesiologists from above mentioned setting who agree to participate in this study and fulfilled the inclusion criteria was introduced in the study. The total sample size was (57 anesthesiologists).

3.8: Study Tools:

Part I: Sociodemographic characteristics

This part was designed by the researcher to collect data about anesthesiologists' socio-demographic characteristics such as gender, age, qualification, experience, etc.

Part II: FDA Anesthesia Apparatus Checkout Recommendations

This part was adopted from FDA Recommendations (1993). It was designed to assess anesthesiologists' daily anesthesia machine checkout with a total of 58 items. The tool is a self-administered questionnaire designed in English language. The questionnaire was primarily designed to report the anesthesia machines checkout and how anesthesiologists deal with anesthesia machines. The questions in this survey consisted of a series of closed statements answered “Yes” or “No”.

Moreover, pilot study was implemented on 5 anesthesiologists to explore clarity and content validity of the tool.

Operational definition of variables (Dependent and independent variables):

Dependent variables:

Anesthesiologists' knowledge about anesthesia machines checkout (appendix Part II)

Independent variables:

Anesthesiologists' sociodemographic characteristics**;** (appendix Part I)

3.9: Data Analysis:

The collected data was coded then entered into an IBM compatible computer, using SPSS version 20 for windows. Quantitative variables were expressed as number and percentages while qualitative variables were expressed as mean (X) and standard deviation (SD). The arithmetic mean (X) was used as a measure of central tendency, while the standard deviation (SD) was used as a measure of dispersion.

3.10: Pilot study:

A pilot study was carried out on 5 anesthesiologists to test feasibility, objectivity, and applicability of the data collection tool. Based on results of the pilot study needed refinements and modifications were done.

3.11: Ethical consideration:

1. Verbal consents were obtained from anesthesiologists after explaining the purpose and nature of the study.
2. Each anesthesiologist was free to either participate or not in the current study and had the right to withdraw from the study at any time without any rational. Also, anesthesiologist will be informed that obtained data will be used only for research purpose and not for their evaluation.
3. Confidentiality and anonymity of each subject was assured through coding of all data.

Chapter four:

RESULTS

Chapter 4: RESULTS

Part one: Sociodemographic data

Table 4.1: Sociodemographic data of the anesthesiologists

	No	%
1) Hospital owner		
Teaching	19	33.3
Public	13	22.8
Private	9	15.8
General	9	15.8
Specialty	7	12.3
2) Age		
≤ 30	16	28.1
31–40	20	35.1
41–50	12	21.1
≥ 51	9	15.8
Mean & SD	37.33±9.76	
3) Gender		
Male	50	87.7
Female	7	12.3
4) Education level		
Consultant	13	22.8
Arabic Board	6	10.5
Technician	27	47.5
Operators	11	19.3
5) Years of experience		
≤ 5	22	38.6
6-10	14	24.6
11-15	8	14
≥ 16	13	22.8
Years of experience	9.63±8.05	
6) Duty		
Full time duty	49	86
Part time duty	8	14
7) TYPE OF ANESTHESIA MACHINE		
Ohmeda	49	86
Dragger mandary	8	14

Table 4.1 showed that one third (33.3%) of the hospitals in which study was implemented were teaching hospitals, and nearly one quarter of them (22.8%) were public hospital. High percentage (35.1%) of the participants their age range between 31-40 years, the mean age of the anesthesiologist's is 37.33±9.76 years, and the majority (87.7%) of them were males. Regarding educational level, nearly the half (47.5%) of the participated anesthesiologists were technician, and consultants comprised 22.8%, and the least percentage (10.5%) of them had Arabic Board. Regarding years of experience, the highest percentage (38.6%) of the participants, have been working in the field of anesthesia for ≤ 5 years, and nearly one quarter (24.6%) of them worked for a period ranged between 6-10 years, the mean years of experience was 9.63±8.05 years. The majority (86%) of the anesthesiologists were working full time duty, and also used **Ohmeda** anesthesia machine.

Part two: FDA Anesthesia Apparatus Checkout Recommendations

Table 4.2: Emergency Ventilation Equipment Checkout

	Yes	%	No	%
Verify Backup Ventilation Equipment				
a. Available	53	93	4	7
b. Functioning	48	84.2	9	15.8

Regarding emergency ventilation equipment checkout, the majority (93%) of the anesthesiologist reported that they verify the backup ventilation equipment for availability, while 84.2% of them correctly checked them for functioning.

Table 4.3: High-Pressure System Checkout

	Yes	%	No	%
1. Check Oxygen Cylinder Supply				
a. Open O_2 cylinder and verify at least half full (about 700 psi).	15	26.3	42	73.7
b. Open cylinder.	20	35.1	37	64.9
2. Check Central Pipeline Supplies				
a. Check that hoses are connected and pipeline gauges read about 28 psi.	22	38.6	35	61.4

Table 4.3 showed the high-pressure system checkout. The results showed that during checking oxygen cylinder supply, nearly three quarters (73.7%) of the anesthesiologists said they open O_2 cylinder and verify at least half full, and nearly two thirds (64.9%) of them closed the cylinder. Moreover, during checking central pipeline supplies, 38.6% of the participants mentioned they checked hoses are connected but they underestimated that pipeline gauges reading.

Table 4.4: Low-Pressure System Checkout

	Yes	%	No	%
1. Check Initial Status of Low-Pressure System				
a. Open flow control valves and turn vaporizers off.	23	40.4	34	59.6
b. Check fill level and tighten vaporizer's filler caps.	43	75.4	14	24.6
2. Perform Leak Check of Machine Low-Pressure System				
a. Verify that the machine master switch & flow control valves are ON	21	36.8	36	63.2
b. Attach "Suction Bulb" to common (fresh) gas inlet.	24	42.1	33	57.9
c. Squeeze bulb repeatedly until fully collapsed.	32	56.1	25	43.9
d. Verify bulb stays *fully* collapsed for at least 10 seconds.	34	59.6	23	40.4
e. Close one vaporizer at a time and repeat "c" and" as above.	27	47.4	30	52.6
f. Remove suction bulb, and reconnect fresh gas hose.	33	57.9	24	42.1

In initial status of low-pressure system checkout, about two fifths (40.4%) of the participants, incorrectly mentioned that they closed flow control valves and turn vaporizers off. On the other hand, more than three quarters (75.4%) of them correctly checked fill level and tighten vaporizer's filler caps. During performing leak check of machine low-pressure system, 63.2% of the participants correctly verify that the machine master switch & flow control valves are off, while 42.1% of them incorrectly mentioned that they attach "Suction Bulb" to common (fresh) gas inlet. Moreover, more than two fifths of the participants did not know that they should squeeze bulb repeatedly until fully collapsed, verify bulb stays *fully* collapsed for at least 10

seconds**,** and remove suction bulb, and reconnect fresh gas hose with (43.9%, 40.4 & 42.1 consecutively). Also, nearly the half (47.4%) of them incorrectly mentioned that they closed one vaporizer at a time and squeeze bulb repeatedly until fully collapsed, and they verify bulb stays *fully* collapsed for at least 10 seconds.

Table 4.5: Turn on Machine Master Switch Checkout

	Yes	%	No	%
Turn On Machine Master Switch only	22	38.6	35	61.4

In relation to turning on machine master switch checkout, nearly two thirds (61.4%) of the anesthesiologists correctly reported they turn on machine master switch and all other necessary equipment.

Table 4.6: Test Flow meters Checkout

	Yes	%	No	%
Test Flow meters				
a. Adjust flow of all gases through their full range, checking for smooth operation of floats and undamaged flow tubes.	43	75.4	14	24.6
b. Attempt to create a hypoxic O_2/NO_2 mixture and verify correct changes in flow and/or alarm.	18	31.6	39	68.4

More than three quarters (75.4%) of the respondents reported that they adjust flow of all gases through their full range, checking for smooth operation of floats and undamaged flow tubes. Nearly one third (31.6%) of them incorrectly detected the fault O_2/NO_2 mixture. They incorrectly

attempted to create a hypoxic O_2/NO_2 mixture and verify correct changes in flow and/or alarm.

Table 4.7: Scavenging System Checkout

Scavenging System	Yes	%	No	%
Adjust and Check Scavenging System				
a. Ensure proper connections between the scavenging system and both APL (pop-off) valve and ventilator relief valve.	39	68.4	18	31.6
b. Adjust waste gas vacuum (if possible).	41	71.9	16	28.1
c. Fully open APL valve and open Y-piece.	29	50.9	28	49.1
d. With minimum O_2 flow, allow scavenger reservoir bag to collapse completely and verify that absorber pressure gauge reads about zero.	41	71.9	16	28.1
e. With the O_2 flush activated, allow the scavenger reservoir bag to distend fully, and then verify that absorber pressure gauge reads <20 cm H_2O.	28	49.1	29	50.9

During the adjustment and checking scavenging system, more than two thirds (68.4%) of the participants correctly reported they ensure proper connections between the scavenging system and both APL (pop-off) valve and ventilator relief valve. Both adjustment of waste gas vacuum, and allowing scavenger reservoir bag to collapse completely with minimum O_2 flow, and verify that absorber pressure gauge reads about zero were correctly mentioned by 71.9% of the participants. Fully open APL valve and occlude Y-piece, and with the O_2 flush activated, allow the scavenger reservoir bag to distend fully, and then verify that absorber pressure gauge reads <10 cm H_2O, both were incorrectly mentioned by about the half of the respondents.

Table 4.8: Breathing System Checkout

Breathing System	Yes	%	No	%
1. Calibrate O_2 Monitor				
a. Ensure monitor reads 70% in room air.	9	15.8	48	84.2
b. Verify low O_2 alarm is enabled and functioning.	40	70.2	17	29.8
c. Reinstall sensor in circuit and flush breathing system with CO_2.	18	31.6	39	68.4
d. Verify that monitor now reads greater than 90%.	43	75.4	14	24.6
2. Check Initial Status of Breathing System				
a. Set selector switch to "vent" mode.	29	50.9	28	49.1
b. Check that breathing circuit is complete, undamaged and unobstructed.	30	52.6	27	47.7
c. Verify that CO_2 absorbent is adequate.	50	87.7	7	12.3
d. Install breathing circuit accessory equipment (e.g., humidifier, PEEP valve) to be used during the case.	29	50.9	28	49.1
3. Perform Leak Check of the Breathing System.				
a. Set all gas flows to 10L/min (or minimum).	28	49.1	29	50.9
b. Open APL (pop-off) valve and occlude Y-piece.	24	42.1	33	57.9
c. Pressurize breathing system to about 55 cm H_2O with O_2 flush.	35	61.4	22	38.6
d. Ensure that pressure remains fixed for at least 20 seconds.	21	36.8	36	63.2
e. Open APL (pop-off) valve and ensure that pressure decreases.	22	38.6	35	61.4

Regarding calibrate O_2 monitor checking breathing system, high percentage of respondent (75.4%, and 70.2% respectively) reported the verify that monitor now reads greater than 90%, and verify low O_2 alarm is enabled and functioning. In relation to Checking Initial Status of Breathing System, the majority (87.7%) of the respondents, reported that they verified that CO_2 absorbent is adequate. About the half (50.9%) of them both incorrectly

mentioned they set selector switch to "vent" mode, and installed breathing circuit accessory equipment (e.g., humidifier, PEEP valve) to be used during the case. In relation to Performing Leak Check of the Breathing System, nearly the half (49.1%) of them incorrectly reported that they set all gas flows to zero (or minimum). The results also showed that 61.4% of anesthesiologist agree with pressurizing breathing system to about 55 cm H_2O with O_2 flush. Also 61.4% reported incorrectly that they open APL (pop-off) valve and ensure that pressure decreases.

Table 4.9: Manual and Automatic Ventilation Systems Checkout

Manual and Automatic Ventilation Systems	Yes	%	No	%
Test Ventilation Systems and Unidirectional Valves				
a. Place a second breathing bag on expiratory - piece.	14	24.6	43	75.4
b. Set appropriate ventilator parameters for next patient.	41	71.9	16	28.1
c. Switch to automatic ventilation (BAG) mode.	21	36.8	36	63.2
d. Fill bellows & breathing bag with O_2 flush and then turn ventilator OFF.	37	64.9	20	35.1
e. Set O_2 flow to minimum, other gas flows to zero.	42	73.7	15	26.3
f. Verify that during inspiration bellows delivers appropriate tidal volume and that during expiration bellows fills completely.	42	73.7	15	26.3
g. Set fresh gas flow to about 10 L/min.	35	61.4	22	38.6
h. Verify that the ventilator bellows and simulated lungs fill and empty appropriately without sustained pressure at end expiration.	41	71.9	16	28.1
i. Check for proper action of unidirectional valves.	42	73.7	15	26.3
j. Exercise breathing circuit accessories to ensure proper function.	40	70.2	17	29.8
k. Turn ventilator ON and switch to manual ventilation (Bag/APL) mode.	31	54.4	26	45.6
l. Ventilate manually and assure inflation and deflation of artificial lungs and appropriate feel of system resistance and compliance.	40	70.2	17	29.8
m. Remove second breathing vent from Y-piece.	28	49.1	29	50.9

Test ventilation systems and unidirectional valves showed that more than three quarters (75.4%), agree to place a second breathing bag on inspiratory-piece, and 71.9 % correctly set appropriate ventilator parameters for next patient. Nearly two thirds (64.9%) of the anesthesiologists incorrectly mentioned that they fill bellows & breathing bag with O_2 flush and then turn

ventilator OFF. Also more than the half (54.4%) of them incorrectly mentioned that they turned ventilator ON and switch to manual ventilation (Bag/APL) mode. Three items had the same response with 73.7%, these were regarding setting O_2 flow to minimum, other gas flows to zero; checking for proper action of unidirectional valves; and verifying that during inspiration bellows delivers appropriate tidal volume and that during expiration bellows fills completely.

Table 4.10: Monitors Checkout

Monitors	Yes	%	No	%
Check, Calibrate and/or Set Alarm Limits of all Monitors				
○ Capnometer	50	87.7	7	12.3
○ Oxygen Analyzer necessary	41	71.9	6	28.1
○ Pressure Monitor with High and Low Airway Alarms	46	80.7	11	19.3
○ Pulse Oximeter	24	42.1	33	57.9
○ Respiratory Volume Monitor (Spirometer)	40	70.2	17	29.8

Table 4.10 discusses the check, calibrate and/or set alarm limits of all monitors. The result showed that the majority reported they check, calibrate and/or set alarm limits of capnometer, pressure monitor with high and low airway alarms and respiratory volume monitor (spirometer) with 87.7%, 80.7% & 70.2% consecutively. On the other hand, only 42.1% mentioned they check, calibrate and/or set alarm limits of pulse oximeter.

Table 4.11: Final Position Checkout

Final Position	Yes	%	Yes	%
Check Final Status of Machine				
a. Vaporizers off	19	33.3	38	66.7
b. APL valve open	32	56.1	25	43.9
c. Selector switch to "bag"	33	57.9	24	42.1
d. All flow meters to zero	37	64.9	20	35.1
e. Patient suction level adequate	46	80.7	46	80.7
f. Breathing system ready to use	47	82.5	10	17.5

In relation to checking final status of machine, the highest response (82.5%) was regarding checking of breathing system ready to use, followed by checking adequate patient suction level (80.7%). More than one third (35.1%) of them incorrectly reported checking all flow meters to zero. APL valve open was recognized by more than the half (56.1%) of the participants. Two thirds (66.7%) of the participants incorrectly reported to set vaporizers off.

Chapter five:
DISCUSSION

Chapter 5: Discussion

The results of the present study showed that the majority (87.7%) of the anesthesiologists were males, and high percentage (35.1%) of them their age range between 31-40 years, and nearly the half (47.5%) of them were technician, and consultants comprised 22.8%. Regarding years of experience, the highest percentage (38.6%) of the participants, have been working in the field of anesthesia for ≤ 5 years. The majority (86%) of the anesthesiologists were working full time duty, and also used Ohmeda anesthesia machine. Cooper et al. (1984) found that 70% of the critical incidents noted were attributed to human error. Olympio et al. (1996) hypothesized that the poor rate of fault detection was because of the lack of adequate training in checkout procedures. Despite extensive instruction, anesthesia residents, at best, could only perform 81% of a checkout procedure (Olympio, 2003).

The results showed that during checking oxygen cylinder supply, nearly three quarters (73.7%) of the anesthesiologists said they open O_2 cylinder and verify at least half full. In accordance with our result, (Larson et al., (2007), reported that 73.7% of the participants detected empty oxygen cylinder during checking of oxygen cylinder supply.

In the initial status of low-pressure system checkout, results of the present study showed that about three quarters (75.4%) of the anesthesiologists correctly checked fill level and tighten vaporizer's filler caps. Concern about environmental contamination and waste of expensive

volatile agents has created the desire for minimal (<0.5 lpm) or low flow (<1.0 lpm) anesthesia (Olympio, 2003, & Baum, 1996). A small volume of the breathing circuit would contribute to a faster change of inspired anesthetic concentrations (smaller time constant); conventional circuits are large (>6 l).

Verification that the machine master switch & flow control valves are closed was mentioned by about nearly two thirds (63.2%) of the participated anesthesiologists. This mean inadequate checkout and possibility of leak. A low-flow system should not have any leaks, which accumulate over multiple connections (Olympio, 2003). Variable bypass vaporizers are either fixed-mounted or removable. If tilted, liquid agent could enter the bypass chamber, vaporize, and then deliver an overdose of agent to the circuit. Inadequate volatile agent could be delivered if there is a leak around the mounting O-rings, which must be determined properly during pre-use checkout (Olympio, 2003 & Myers et al 1997). Changing and filling vaporisers during use. It may be necessary to change a vaporiser during use. Where possible, repeat the leak test; failure to do so is a common cause of critical incidents. Vaporisers must always be kept upright. Tilting a vaporiser can result in delivery of dangerously high concentrations of vapour (Hartle et al. 2012)

More than three quarters (75.4%) of the respondents reported that they adjust flow of all gases through their full range, checking for smooth operation of floats and undamaged flow tubes. Nearly one third (31.6%) of the anesthesiologists in this study incorrectly detected the fault O_2/NO_2

mixture. They incorrectly attempted to create a hypoxic O_2/NO_2 mixture and verify correct changes in flow and/or alarm. This result was lower than that reported by (Larson et al 2007), in which 50.6% of the participants found the oxygen/nitrous fail-safe linkage disconnect.

Flow meters should be well calibrated at low level and retain their O_2/N_2O proportionating capability. Increased humidity in low flow circuits might cause more condensation (Olympio, 2003). Misconnection of O_2 pipeline hose to N_2O cylinder in the manifold room by technical personnel has resulted in hypoxic gas delivery (Ishikawa et al., 2002 & Hay, 2000). Faulty interface between gear wheels of O_2 and N_2O flow meters in ageing machines contributed to failure of the flow proportionating devices while defective rubber seal of flow meter control tube was responsible for hypoxic gas delivery (Ishikawa et al., 2002 & Hay, 2000).

Development of a stricture in the O_2 central supply system outlet as a result of degradation of the O-ring and a structural defect in the pipeline delivery at the ceiling level of the operating room resulting in accidental switching off of the O_2 supply valve by the N_2O pipeline have contributed to delivery of hypoxic gas mixtures (Desaki, et al., 2011, Sugiuchi, et al., 2000).

During the adjustment and checking scavenging system, more than two thirds (68.4%) of the participants correctly reported they ensure proper connections between the scavenging system and both APL (pop-off) valve and ventilator relief valve are not necessary. This indicate a problems in the

scavenging system checkout. Kinking or disconnection of new APL and/or PEEP valve pilot lines may cause inappropriately high, or no pressure during controlled mechanical ventilation (CMV), depending on the timing of the event. A similar situation has occurred with a conventional machine (Olympio, 2003, and Eisenkraft, 1989). Long term exposure to trace anaesthetic gases released into the operating room during the conduct of general anaesthesia may be harmful to health-care personnel involved. Anaesthesiologists appear to have a predisposition to the development of various organ system disorders that may be attributable to long-term exposure to trace anaesthetic gases (Dorsch & Dorsch, 2007). Therefore, the need for scavenging cannot be overemphasised.

In the present study result showed that checking breathing circuit for completeness, undamaged and unobstructed was mentioned by about the half (52.6%) of the participants. Craig and Wilson (1981), found that human error was responsible for 65% of the incidents “with failure to perform a preanesthetic check, the most common associated factor.” Fasting and Gisvold (2002) noted that 31% of equipment problems involved the anesthesia machine and breathing circuit, with the main cause of human error being insufficient checking of the anesthesia machine before use, especially between cases. They stated, “In our study, human error was the main contributing factor in one-quarter of cases, and most of these involved the anesthesia machine.

Also more than the half (54.4%) of the anesthesiologists incorrectly mentioned that they turned ventilator (ON) and switch to manual ventilation (Bag/APL) mode. Failure to be able to ventilate is a major cause of morbidity and mortality related to anesthesia care. Because equipment failure with resulting inability to ventilate the patient can occur at any time, a self-inflating manual ventilation device (eg. AMBU bag) should be present at every anesthetizing location for every case and should be checked for proper function (Dosch, 2014).

As recently as Patient injuries from anesthesia gas delivery equipment: A closed claims update. It was reported that failure to check a disposable breathing circuit contributed to a patient fatality. The Closed Claims study of gas delivery equipment concluded that "The majority (85%) of claims involved provider error with (n = 7) or without (n = 27) equipment failure. Thirty-five percent of claims [and 75% of breathing circuit claims] were judged as preventable by preanesthesia machine check." (Dosch and Tharp, 2016). In relation to checking final status of machine, the highest response (82.5%) was regarding checking of breathing system ready to use, followed by checking adequate patient suction level (80.7%). Despite the advent of highly automated machines, manual checkout procedures remain crucial to minimizing undiagnosed failures (Eng & Durieux, 2012).

Chapter six:

CONCLUSION & RECOMMENDATIONS

Chapter 6: conclusion and recommendations

Conclusion

The participated anesthesiologists in this study indicated generally inadequate checkout of the anesthesia machines. The adjustment and checking of scavenging system, also indicated a problems in the scavenging system checkout. Verification that the machine master switch & flow control valves are closed was mentioned by nearly two thirds of the anesthesiologists. This mean inadequate checkout and possibility of leak. Long term exposure to trace anesthetic gases released into the operating room during the conduct of general anesthesia may be harmful to health-care personnel involved. Lack of compete checkout may put the patient at risk for intra-operative malfunctions as well increase operating room pollution and exposure of operating room personnel to anesthetic gases.

Recommendations

- ✯ Anesthesiologists should be put under an obligation to use the check sheet before anesthesia and file the sheet in the medical record.
- ✯ The use of routine checks and associated checklists is an important part of training in anesthesia, and is part of the competency based training.
- ✯ Checking each component of anesthesia machine for appropriate functioning prior to use is essential to ensure patient safety.
- ✯ Institute a program of routine inspection and regular maintenance of equipment in order to reduce anesthetic gas leaks and to have the best performance of scavenging equipment and room ventilation.
- ✯ Periodic monitoring (preferably at least semiannually) of waste gas concentrations is needed to ensure that the anesthesia delivery equipment and engineering/environmental controls work properly and that the maintenance program is effective.
- ✯ Ensure the proper use of personal protective equipment during clean-up and containment of major spills of liquid anesthetic agents.

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Annex

Annex

Knowledge of anesthesiologist about anesthesia work station checkout

A. Sociodemographic characteristics

1) Hospital name

1. Public ( )
2. Private ( )
3. General ( )
4. Specialty ( )
5. Teaching ( )

2) Age: …….

3) Gender:

1. Male ( )
2. Female ( )

4) Qualification

1. Consultant ( )
2. Arabic Board ( )
3. Technicians ( )
4. Operators ( )
5. Others specify ( )

5) Years of experience: …… years

6) Type of duty

6. Full time duty ( )
1. Part time duty ( )

7) Type of anesthesia machine: ……..

The FDA Anesthesia Apparatus Checkout Recommendations

1) Emergency Ventilation Equipment	Yes	No
2. Verify Backup Ventilation Equipment		
c. Available	( )	( )
d. Functioning	( )	( )
2) High-Pressure System		
3. Check Oxygen Cylinder Supply		
a. Open O_2 cylinder and verify at least half full (about 1000 psi).	( )	( )
b. Close cylinder.	( )	( )
4. Check Central Pipeline Supplies		
a. Check that hoses are connected and pipeline gauges read about 50 psi.	( )	( )

3) Low-Pressure System	( )	( )
5. Check Initial Status of Low-Pressure System		
a. Close flow control valves and turn vaporizers off.	( )	( )
b. Check fill level and tighten vaporizer's filler caps.	( )	( )
6. Perform Leak Check of Machine Low-Pressure System		
a. Verify that the machine master switch & flow control valves are OFF	( ) ( )	( ) ( )
b. Attach "Suction Bulb" to common (fresh) gas outlet.	( )	( )
c. Squeeze bulb repeatedly until fully collapsed.	( )	( )
d. Verify bulb stays *fully* collapsed for at least 10 seconds.	( )	( )
e. Open one vaporizer at a time and repeat "c" and" as above.	( )	( )
f. Remove suction bulb, and reconnect fresh gas hose.		
7. *Turn On Machine Master Switch and all other necessary equipment.	( )	( )
8. *Test Flow meters		
a. Adjust flow of all gases through their full range, checking for smooth operation of floats and undamaged flow tubes.	( )	( )
b. Attempt to create a hypoxic O_2/N_2O mixture and verify correct changes in flow and/or alarm.	( )	( )
4) Scavenging System	( )	( )
9. Adjust and Check Scavenging System		
a. Ensure proper connections between the scavenging system and both APL (pop-off) valve and ventilator relief valve.	( )	( )
b. Adjust waste gas vacuum (if possible).	( )	( )
c. Fully open APL valve and occlude Y-piece.	( )	( )
d. With minimum O_2 flow, allow scavenger reservoir bag to collapse completely and verify that absorber pressure gauge reads about zero.	( )	( )
e. With the O_2 flush activated, allow the scavenger reservoir bag to distend fully, and then verify that absorber pressure gauge reads <10 cm H_2O.	( )	( )
5) Breathing System	( )	( )
10. Calibrate O_2 Monitor		
e. Ensure monitor reads 21% in room air.	( )	( )
f. Verify low O_2 alarm is enabled and functioning.	( )	( )
g. Reinstall sensor in circuit and flush breathing system with O_2.	( )	( )
h. Verify that monitor now reads greater than 90%.	( )	( )
11. Check Initial Status of Breathing System		
a. Set selector switch to "Bag" mode.	( )	( )
b. Check that breathing circuit is complete, undamaged and unobstructed.	( )	( )
c. Verify that CO_2 absorbent is adequate.	( )	( )

d. Install breathing circuit accessory equipment (e.g., humidifier, PEEP valve) to be used during the case.	( )	( )
12. Perform Leak Check of the Breathing System.		
a. Set all gas flows to zero (or minimum).	( )	( )
b. Close APL (pop-off) valve and occlude Y-piece.	( )	( )
c. Pressurize breathing system to about 30 cm H_2O with O_2 flush.	( )	( )
d. Ensure that pressure remains fixed for at least 10 seconds.	( )	( )
e. Open APL (pop-off) valve and ensure that pressure decreases.	( )	( )
6) Manual and Automatic Ventilation Systems		
13. Test Ventilation Systems and Unidirectional Valves		
a. Place a second breathing bag on Y-piece.	( )	( )
b. Set appropriate ventilator parameters for next patient.	( )	( )
c. Switch to automatic ventilation (Ventilator) mode.	( )	( )
d. Fill bellows & breathing bag with O_2 flush and then turn ventilator ON.	( )	( )
e. Set O_2 flow to minimum, other gas flows to zero.	( )	( )
f. Verify that during inspiration bellows delivers appropriate tidal volume and that during expiration bellows fills completely.	( )	( )
g. Set fresh gas flow to about 5 L/min.	( )	( )
h. Verify that the ventilator bellows and simulated lungs fill *and empty* appropriately without sustained pressure at end expiration.	( )	( )
i. Check for proper action of unidirectional valves.	( )	( )
j. Exercise breathing circuit accessories to ensure proper function.	( )	( )
k. Turn ventilator OFF and switch to manual ventilation (Bag/APL) mode.	( )	( )
l. Ventilate manually and assure inflation and deflation of artificial lungs and appropriate feel of system resistance and compliance.	( )	( )
m. Remove second breathing bag from Y-piece.		
7) Monitors		
14. Check, Calibrate and/or Set Alarm Limits of all Monitors		
o Capnometer	( )	( )
o Oxygen Analyzer	( )	( )
o Pressure Monitor with High and Low Airway Alarms	( )	( )
o Pulse Oximeter	( )	( )
o Respiratory Volume Monitor (Spirometer)	( )	( )
8) Final Position		
15. Check Final Status of Machine		
a. Vaporizers off	( )	( )
b. APL valve open	( )	( )
c. Selector switch to "Bag"	( )	( )
d. All flowmeters to zero	( )	( )
e. Patient suction level adequate	( )	( )
f. Breathing system ready to use	( )	( )