The anesthesia machine

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PART-I

The anesthesia machine

- Receives medical gases(O_2 ,N_2O,Air) under pressure.
- Controls the flow of each gas separately.
- A desired gas mixture is created at a determined flow rate before inhalational vapor is added .
- Gas & vapor mixtures are delivered to common outlet (exit port).
- Reaches the patient through a breathing system(circuit).

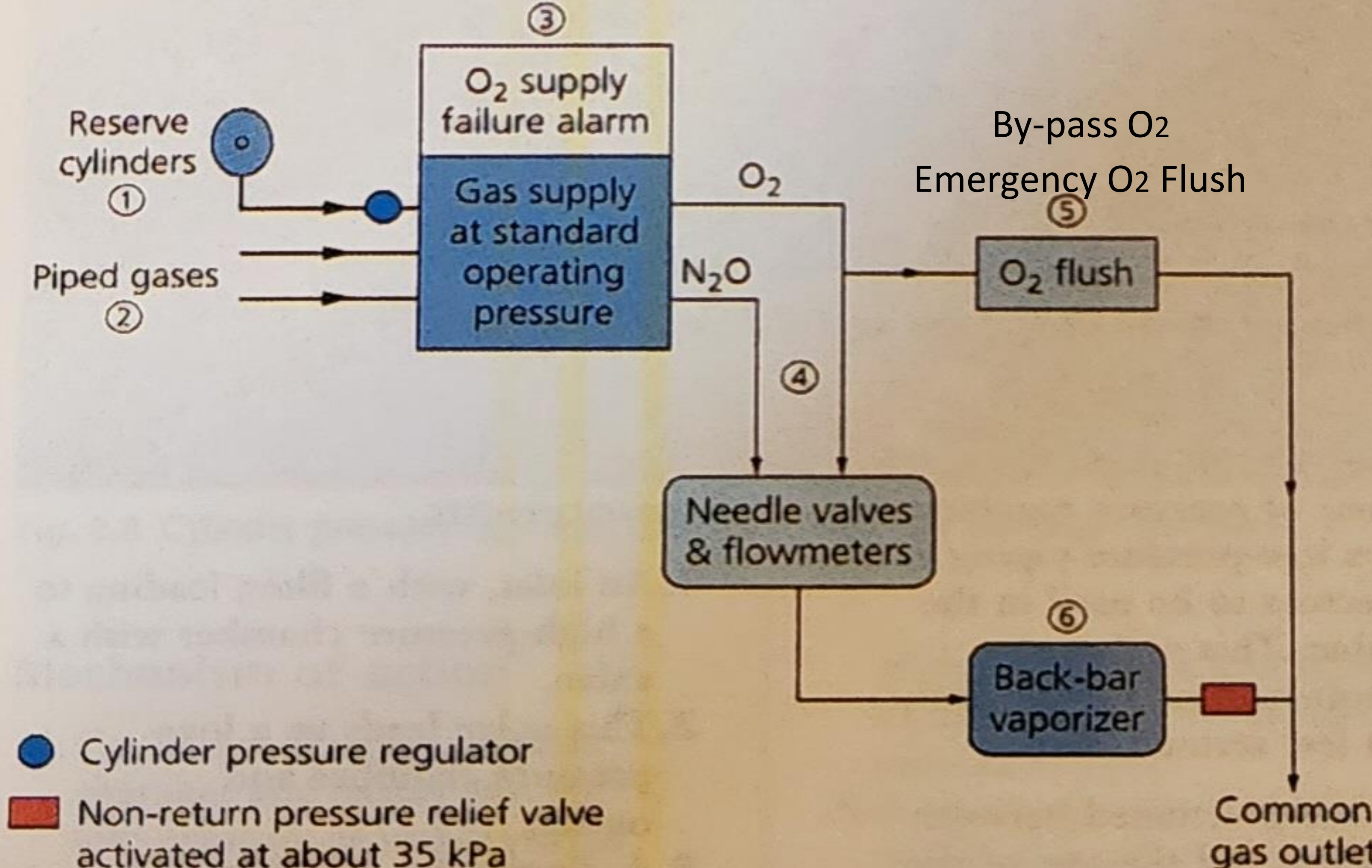
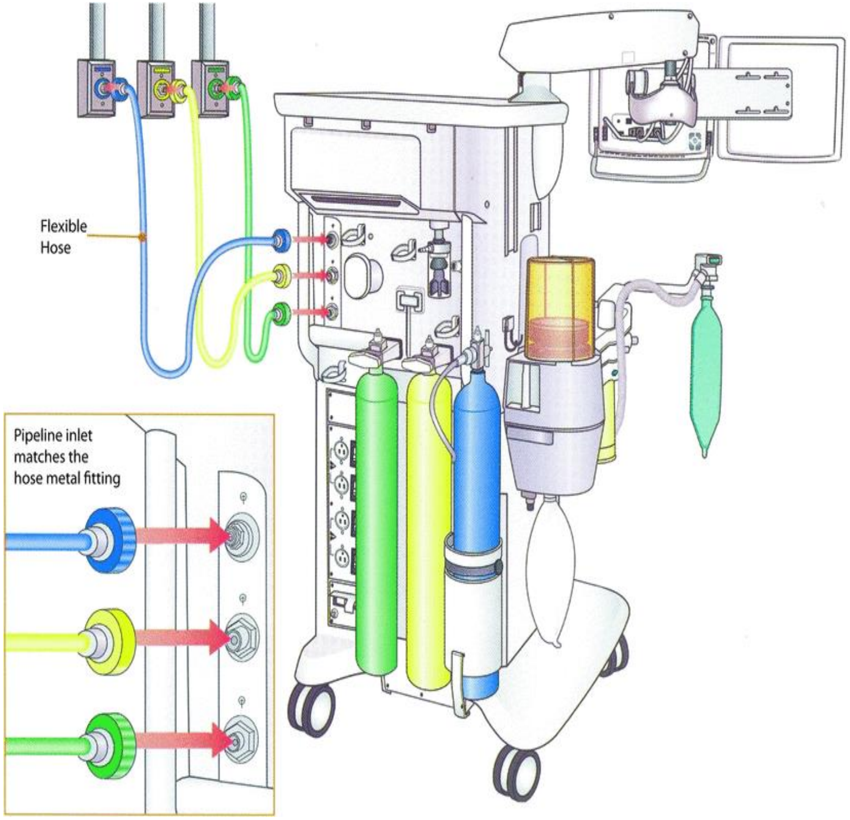


Fig. 2.2 Diagrammatic representation of a continuous flow anaesthetic machine. Pressures throughout the system: 1. O_2: 13 700 kPa, N_2O: 4400 kPa; 2. pipeline: about 400 kPa; 3. O_2 supply failure alarm activated at <250 kPa; 4. regulated gas supply at about 400 kPa; 5. O_2: flush 45 L/min at a pressure of about 400 kPa; 6. back-bar pressure 1–10 kPa (depending on flow rate and type of vaporizer).

Anesthetic machine

- ***Back***



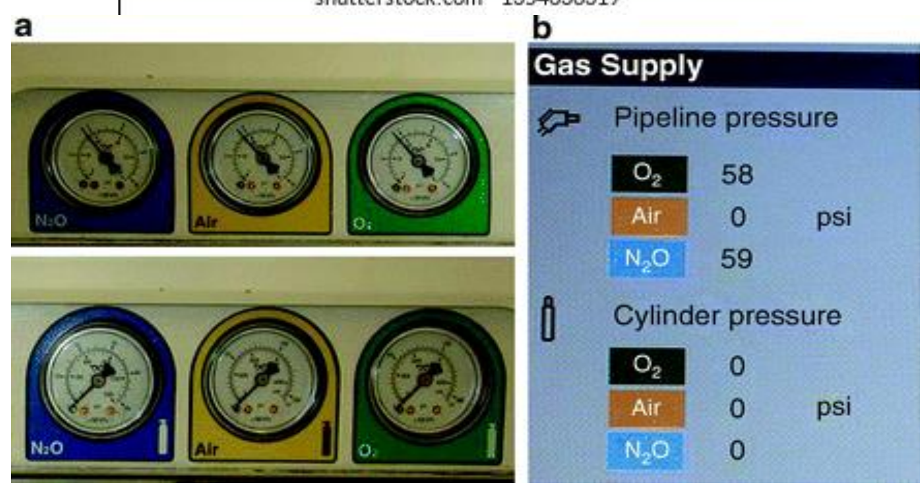
- ***front***

Components of anesthetic machine

1. *Gas supplies.*
2. *Pressure gauges.*
3. *Pressure regulators (pressure reducing valves)*
4. *Bank of flow-meters.*
5. *Vaporizers.*
6. *A common gas & vapor outlet.*
7. *A variety of other features (high-flow O_2 flush , pressure relief valves, O_2 supply failure alarm & suction apparatus.*
8. *Most modern anesthesia machines incorporate a circle breathing system & a bag in bottle type of ventilator .*

Pressure gauges (Bourdon)

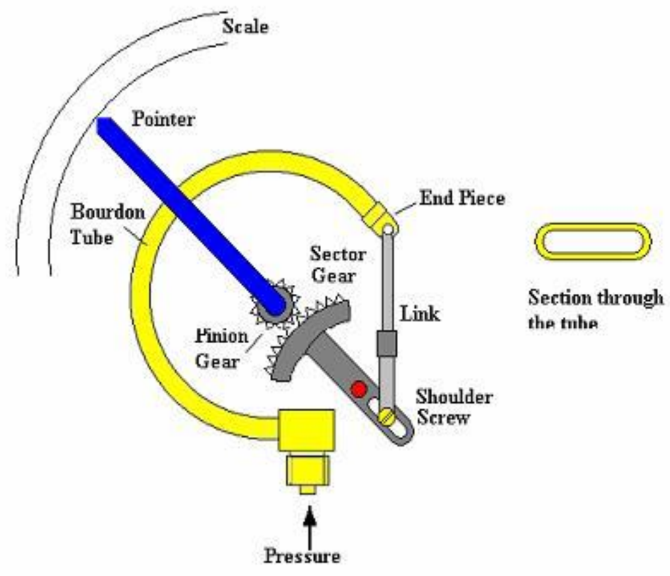
- ***They measure the pressure in the cylinders or pipelines.***
- ***O2, N2O & medical air pressure gauges are mounted in a front-facing panel on the anesthetic machine .***



- ***some modern gauges are digitally displayed.***

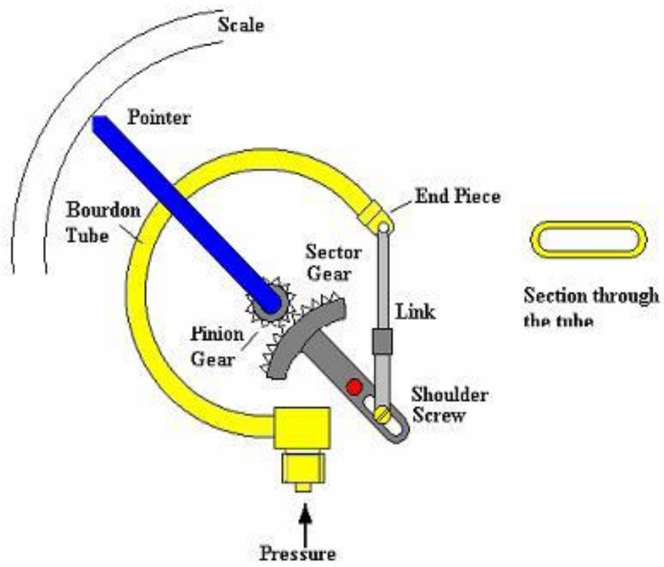
1. Pressure gauge components

1. ***A robust , flexible & coiled tube, oval in cross section that withstands high pressure when the cylinder is switched on .***
2. ***The tube is sealed in its inner end and connected to a needle pointer which moves over a dial.***
3. ***The outer end is exposed to gas supply.***



Mechanism of action of Pressure Bourdon gauge

1. ***The high-pressure gas uncoils the tube.***
2. ***Uncoiling causes movement of the needle pointer on a calibrated dial indicating the pressure***



Problems in practice and safety features

1. *Each pressure gauge is color-coded and calibrated for that particular gas.*
2. *Pipeline pressure gauges can not be used for cylinders and vice versa since this may cause inaccuracy and /or damage to the gauge.*
3. *The face of the gauge is made of heavy glass as a protection and if the coiled tube ruptures ,the gas vents from the back of the gauge.*

Pressure regulator(reducing valve)

Pressure regulators

Pressure regulators are devices that convert variable, high pressures to constant lower output pressures. They are usually positioned at the back of the anaesthetic machine or under its tray.

The reason why pressure regulators are used in anaesthetic practice are:

- Variable cylinder pressure
- Maintaining constant flow
- Pressure surging
- Gas leaks

Fig 1: Gas cylinders attached to pressure regulators at the back of the

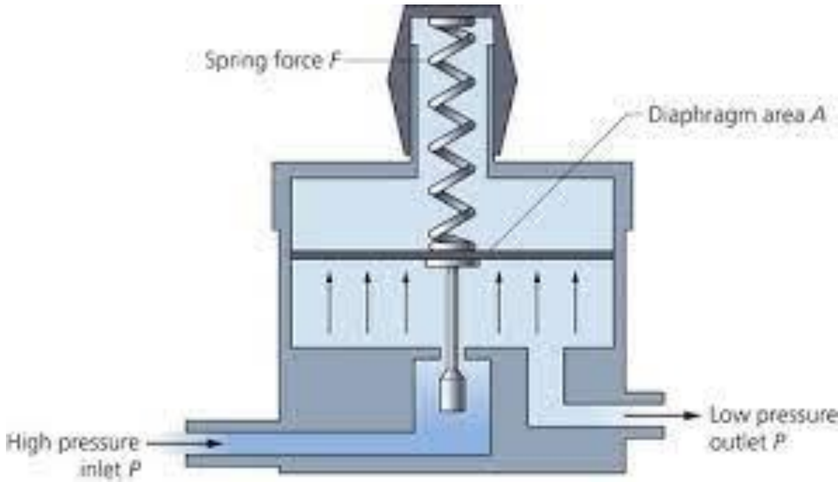
Fig 2: Pressure regulator positioned under the anaesthetic machine tray

Pressure regulator (reducing valve)

- *Gases & vapor are stored at high pressure in cylinders, a pressure regulator reduces the pressure to a constant safer operating pressure of about 400 kPa (just below the pipeline pressure) Temperature and pressure of the cylinder content decreases with use ,thus constant flow can not be maintained unless there is a pressure regulator and needs continuous readjustment.*
- *Pressure regulators protect the components of the anesthetic machine against pressure surges.*
- *The use of regulators allow low-pressure piping and connectors to be used in the machine, thus in case of gas leaks the consequences will be less serious.*
- *They are positioned between the cylinders and the rest of the machine*

Components of Pressure regulator(reducing valve)

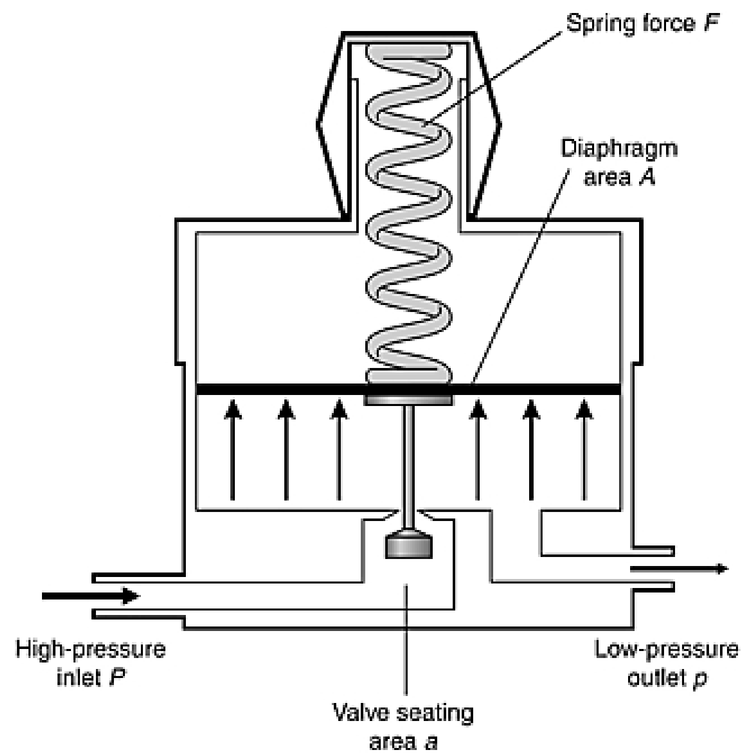
1. ***An inlet with a filter , leading to a high pressure chamber with a valve.***
2. ***This valve leads to a low-pressure chamber.***
3. ***A diaphragm attached to a spring inside the low pressure chamber.***



Mechanism of action of Pressure regulator(reducing valve)

1. ***Gas enters the high-pressure chamber then to the low-pressure chamber via the valve.***
2. ***The high pressure forces the valve to close . The opposing spring force ties to open the valve. The balance between these two forces maintain a constant flow at a pressure of about 400 kPa.***

Pressure regulating valve



Problems in practice and safety features

1. ***Ice formation inside the regulator , when the cylinder contains water vapor which may condense and freeze as a result of heat loss when the gas expands on entry to the low-pressure chamber.***
2. ***The diaphragm can rupture.***
3. ***Relief valve (usually set at 700 kPa) is positioned downstream the regulator allows gas escape when the regulator fails.***
4. ***A one-way valve is fitted at the cylinder supply line prevents back flow and loss of gas when the cylinder is not connected from the pipeline to the. Some times this one-way valve is incorporated into the regulator design.***

Second-stage regulators and flow restrictors

- *Used to control pipeline pressure surges in the form of a flow restrictors which is a constriction between the pipeline and the rest of the machine .*
- *A lower pressure (100-200 Kpa) is achieved.*
- *If there are only flow restrictors without regulators in the pipeline supply, adjustment of the flow-meter is usually necessary whenever the pipeline pressure changes.*
- *Flow restrictors may also be used down-stream of the vaporizers to prevent back pressure effect.*

Unidirectional or One-way valve or Back-flow check valve or Fail-safe valve

- *These are usually located next to the yoke inlet.*
- *Their function is to ;*

1. *prevent back-flow , loss and leakage of gas from an empty yoke.*
2. *Accidental trans-filling of paired cylinders.*

PART-II

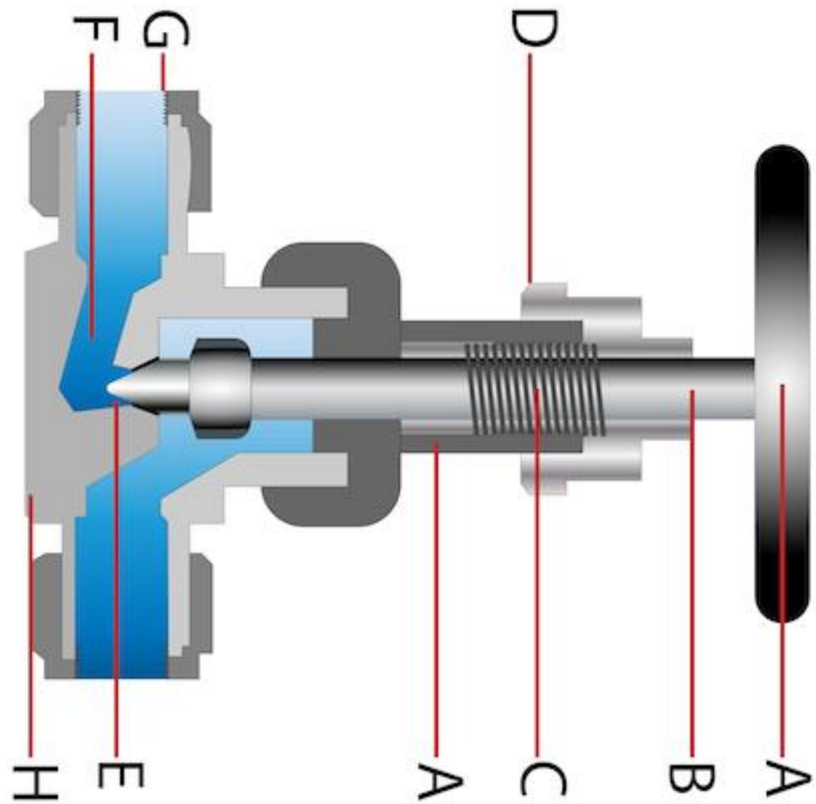
Flow control (needle) valves

- ***These valves control the flow through the flow-meters by manual adjustment, positioned at the base of each flow-meter tube.***
- ***Increasing the flow rate of a gas is achieved by turning the valve in an anti-clockwise direction.***

Components of flow control or needle valve

Components:

1. ***The body (G),made of brass , screws into the base of the flow-meter.***
2. ***The stem (B)screws into the body & ends in a needle(E). It has threads (C) allowing fine adjustment.***
3. ***The flow control knobs (A)are color-coded.***
4. ***A flow control guard in some designs ,to prevent accidental change in the flow-meters***

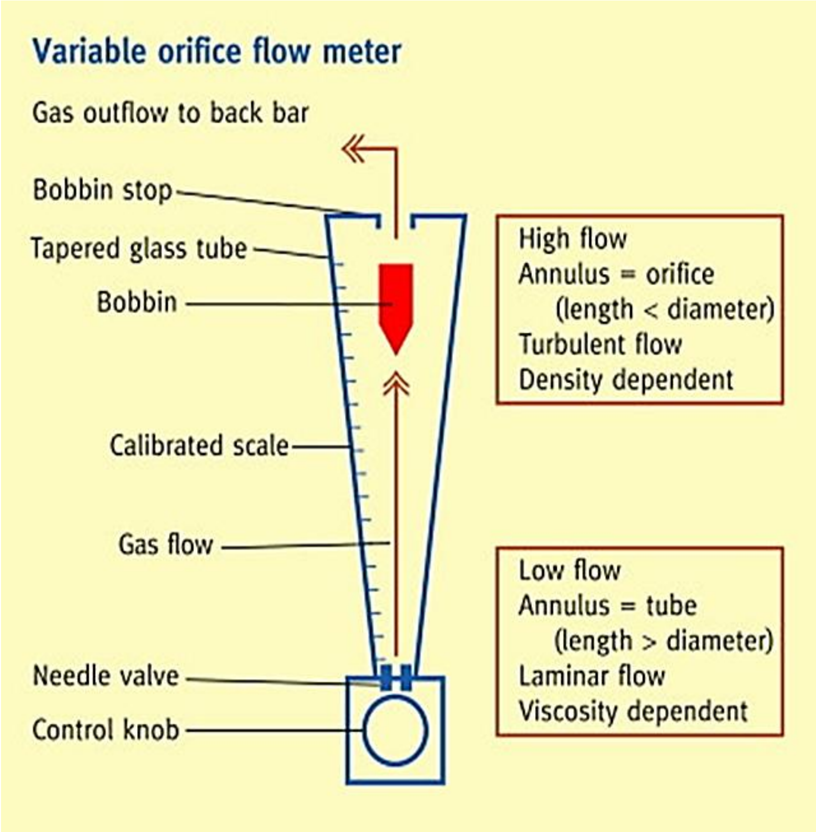


Flowmeters

- ***Measure the flow rate of the gas passing through them.***
- ***Individually calibrated for each gas.***
- ***Calibration occurs at room temperature & atmospheric pressure.***
- ***Their accuracy is about +/- 2.5%***
- ***The unit of flow is (L/min) above 1litre/min ,and***
- ***100 ml/min below that.***

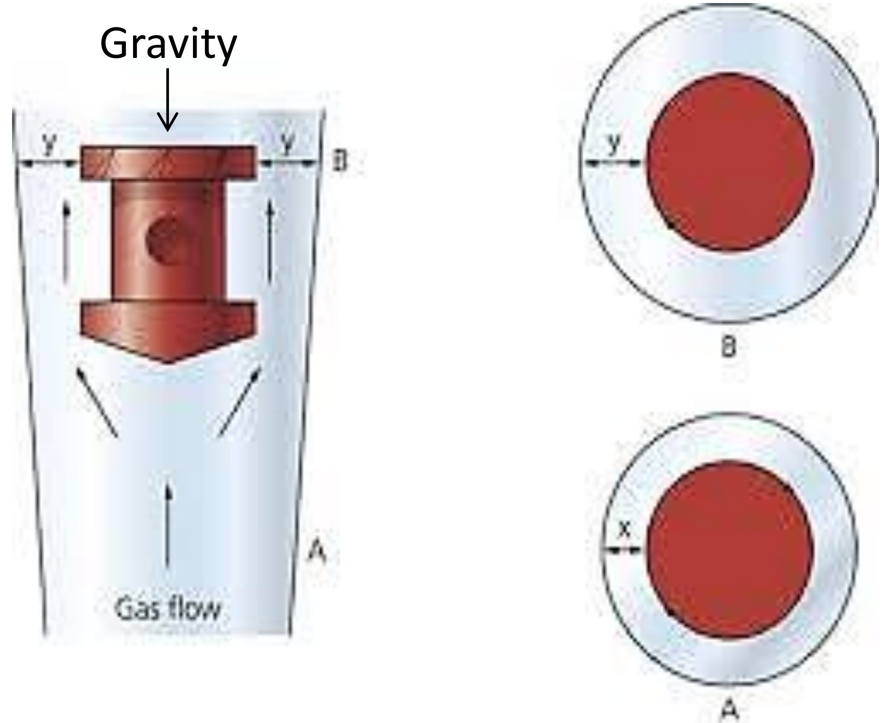
components

1. ***A flow control (needle) valve.***
2. ***A tapered transparent plastic or glass tube(wider at the top).***
3. ***Light weight rotating bobbin or ball .Bobbin stops at either ends of the tube to be visible to the operator at extremes of flow.***



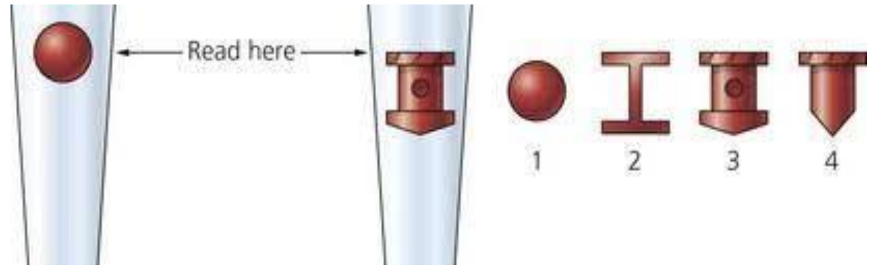
Mechanism of action

1. ***The needle valve is opened the gas is free to enter the tapered tube.***
2. ***The bobbin floats within the tube its position is controlled by two forces: the gravity and the gas flow . A constant pressure difference exists across the bobbin as it floats.***
3. ***The gas around the bobbin widens as the gas flow increases i.e. at low flow rates it’s narrower and longer (tubular) and flow around it is laminar; while at high flow rates its wider and shorter (ring-like) and the flow is turbulent.***



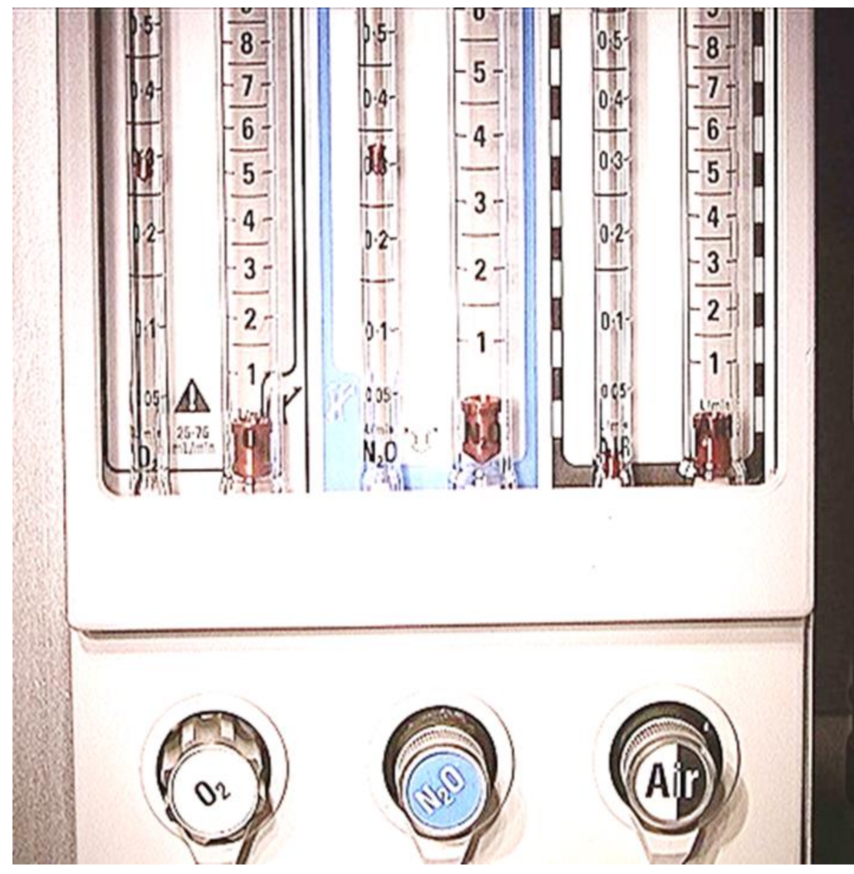
Mechanism of action

4- The top of the bobbin has slit (flutes) cut into its sides causing the bobbin to rotate as gas flows across it. A dot in its middle parts indicates that the bobbin rotates & not sticking.



5- The reading of the flowmeter is taken from the top of the bobbin or the mid-point of the ball.

6-When low flow rates (below 1L/min) is used ,an arrangement of two flow meters in series is used ,one of them reads up to 1L/min ,allowing fine adjustment and one flow control is used for both.



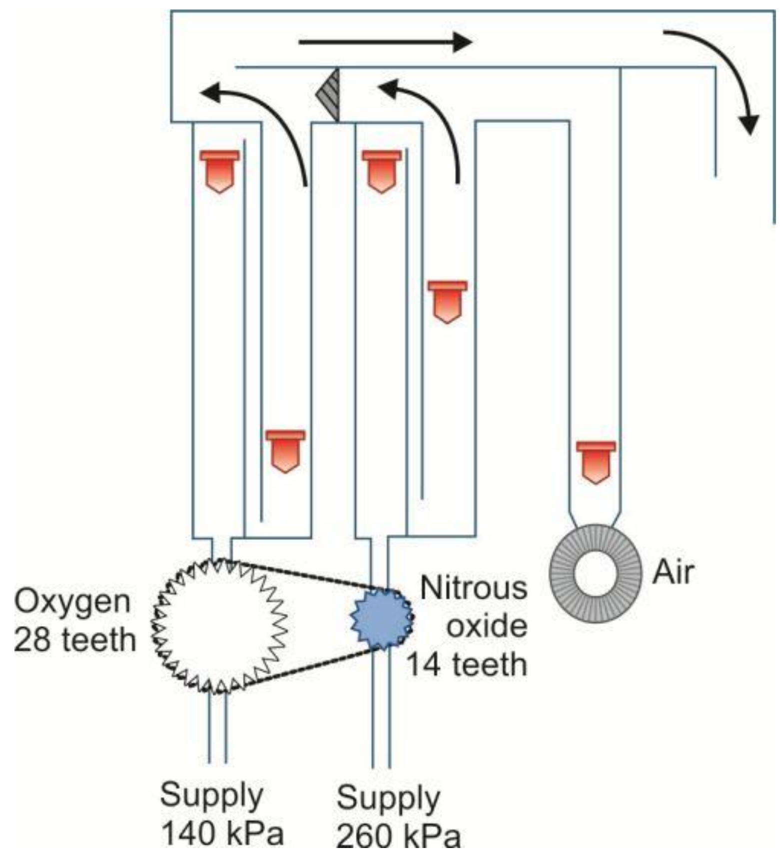
7-There is a stop on the O_2 flow control valve to ensure a minimum flow of 200-300 ml/min ,this ensures that O_2 can not be discontinued completely.

Problems in practice and safety features

1-The flow control knobs are color-coded for each gas. The oxygen control knob is situated to the left(in UK) & to the right in USA and Canada . In some designs it is larger with larger ridges and longer stem than other control knobs making it easily recognizable.

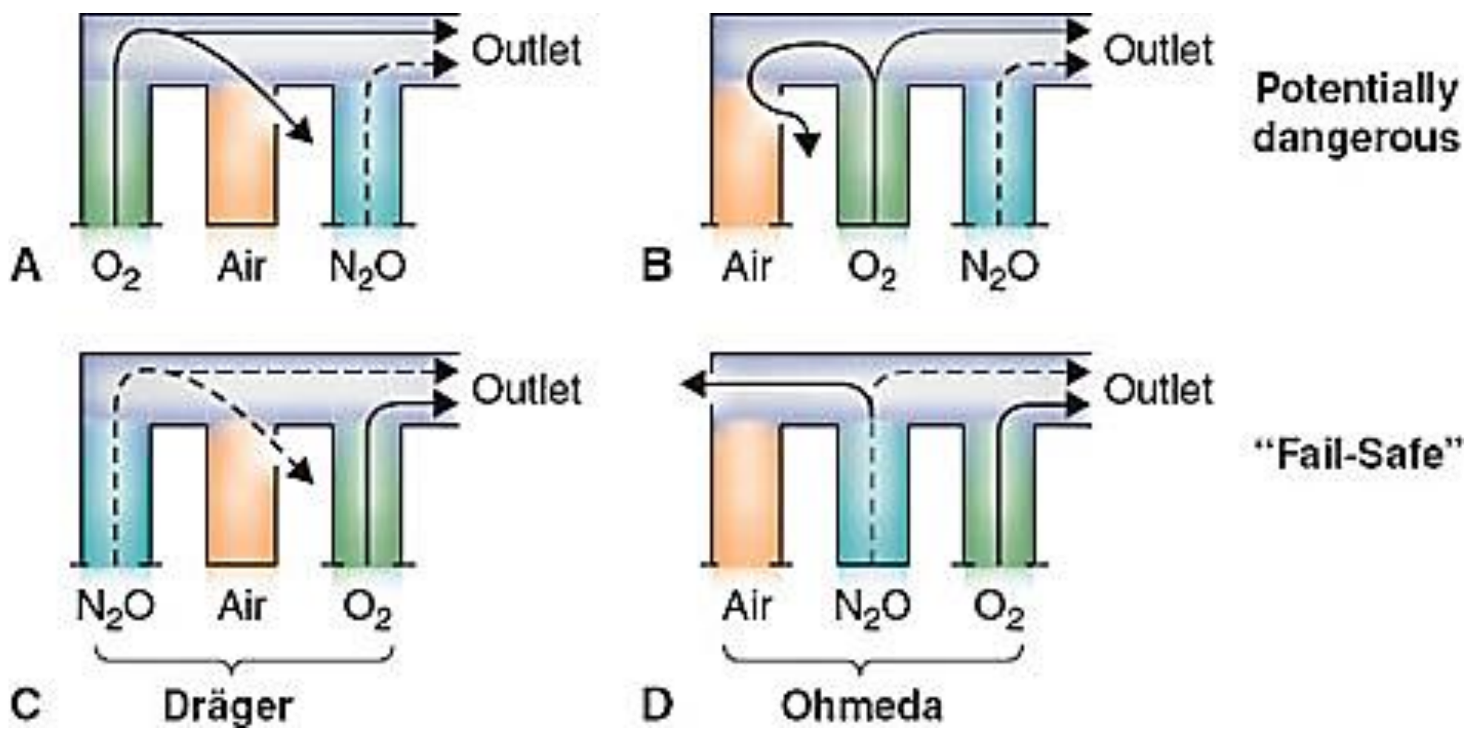
Problems in practice and safety features

2-Presence of interactive O_2 and N_2O controls makes it impossible to open control N_2O knob valve independently without O_2 delivery to the patient in case of O_2 failure , thus prevents delivery of gas mixture with O_2 below 25% or hypoxic mixture to the patient.



Problems in practice and safety features

3-Any crack or fracture in a flowmeter tube may result in the delivery of hypoxic mixture ;thus O_2 gas is the last to be added to the mixture delivered to the back bar.



Problems in practice and safety features

4- Inaccurate flow measurement can result from:

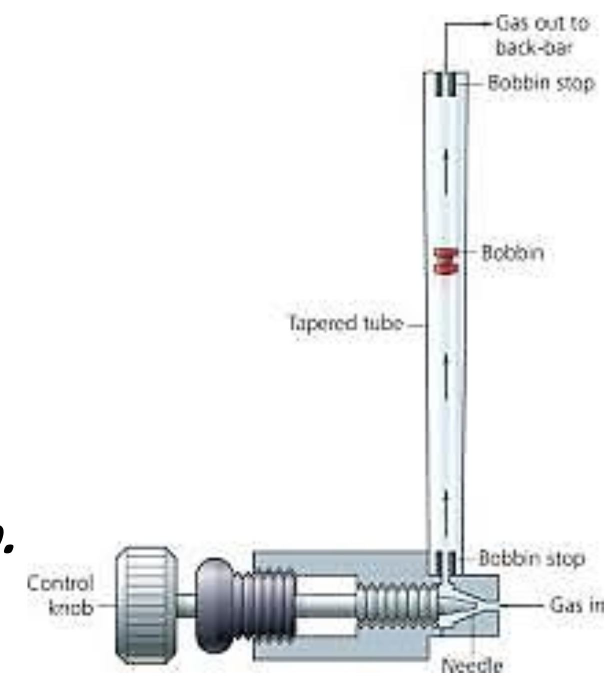
A: Sticking of the bobbin to the flowmeter tube wall because of:

1. ***Dirt from contaminated gas supply, this is prevented by positioning filters at the gas inlets to the anesthesia machine.***
2. ***Static electricity : the charge usually builds up over a period of time , leading to inaccuracies up to 35% , this is prevented by a covering the inner surface of the flowmeter tube by thin film of Tin-oxide or gold.***
3. ***Non-vertical flowmeter tubes, this is prevented via a bubble level on the anesthetic machine that makes the tubes vertical.***

Problems in practice and safety features

B- <u>**Back pressure:**</u> ***at the common gas outlet can result in a drop of the bobbin happens with minute volume divider ventilators that can lead to inaccuracies of about 10% , this is prevented by positioning flow restrictors down-stream of the flowmeters.***

5- Failure to see the bobbin at the extreme ends of the flowmeter can lead to accidents ,this is prevented illuminating the bank of flowmeters and installing a wire stop at the Bobbin top of the tube that prevents the bobbin to reach the top.



Problems in practice and safety features

6- If CO_2 is included in some designs , the flowmeter is designed not to allow more than 500ml /min to be added to the FGF to avoid dangerous levels of CO_2.

7- In modern designs highly accurate computers controlled gas mixers are available .They can detect wrong gas connection .

Digital flowmeters

Vaporizers

A vaporizer is designed to add a controlled amount (usually expressed in percentage of saturated vapor) of an inhalational agent after changing it from liquid to vapor to the FGF.

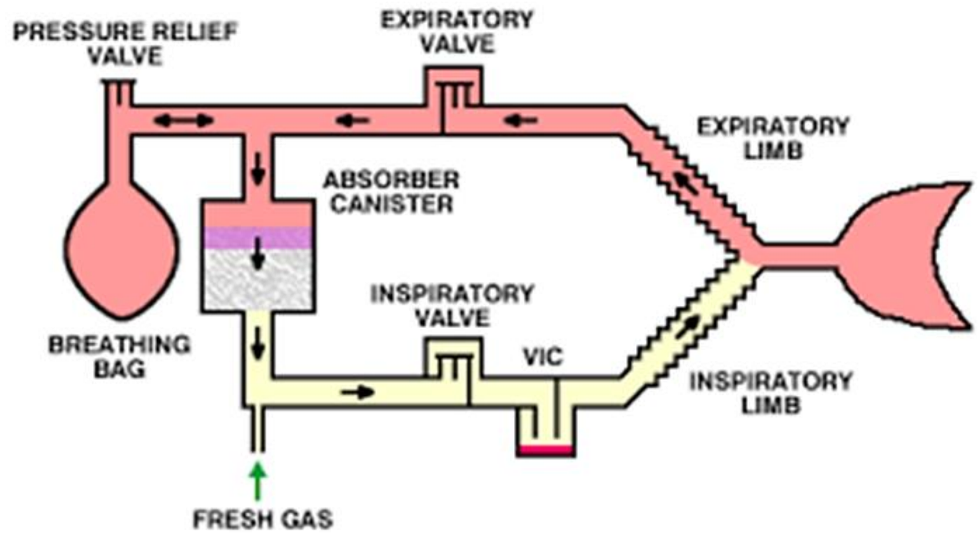
Classification:

They are classified according to location:

1- Vaporizers inside the breathing system.

2- Vaporizer outside the breathing system

Vaporizer Inside Circuit (VIC)



Vaporizer Outside Circuit (VOC)

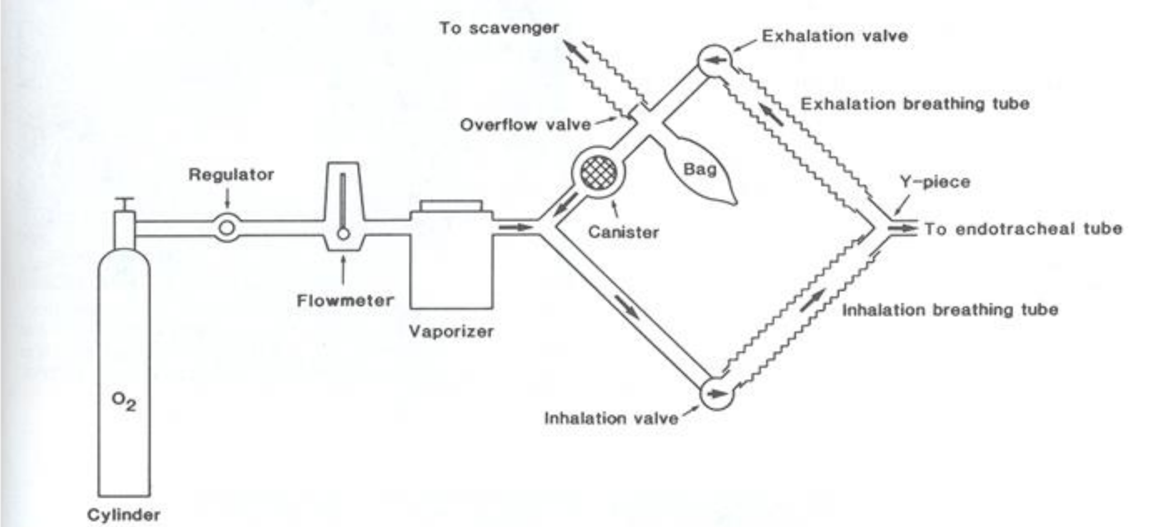
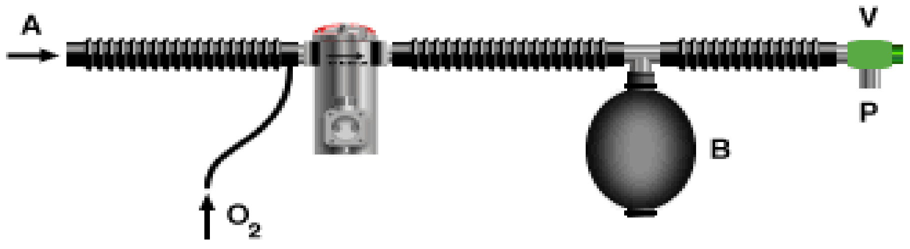


Figure 14.14. Diagram of the relationship of an out of the system precision vaporizer to the various components of an anesthetic machine and a circle breathing system (Biomedical Learning Resources Center).

Vaporizers Inside the breathing system or Circuit

Advantages:

1. ***Gases pass through a very low resistance, the patient uses his respiratory effort e.g. Goldman , Oxford Miniature Vaporizer ; OMV).***
2. ***Simple in design.***
3. ***Light in weight.***
4. ***Agent non-specific.***
5. ***Small.***
6. ***Inexpensive.***
7. ***For the above reasons ,can be used in the (field) or in otherwise difficult environments.***



Draw-over vaporizer

Disadvantages:

Inefficient as their performance is affected as the temperature of the anesthetic agent decreases due to loss of latent heat of vaporization.

Vaporizers Outside the breathing system

Gases are driven due to gas pressure through a plenum vaporizer which is:

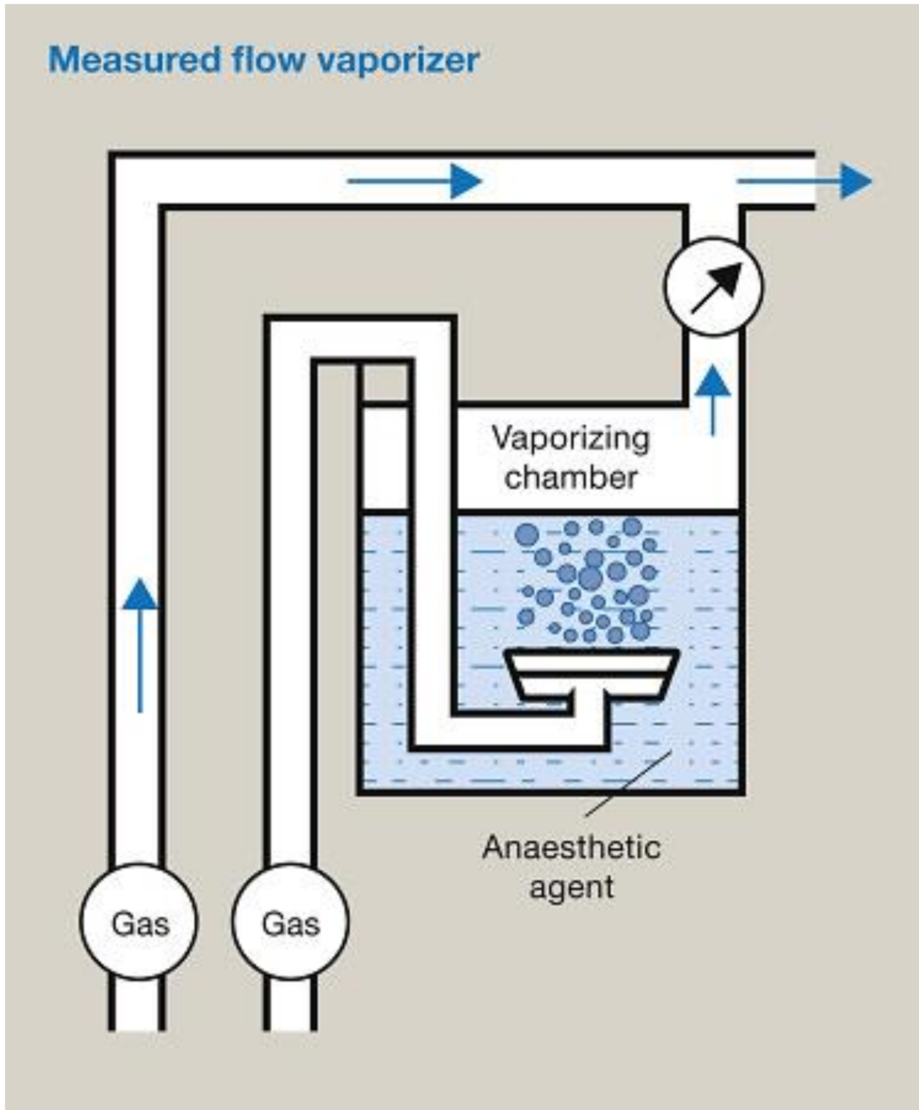
1. ***High resistance.***
2. ***Unidirectional.***
3. ***Agent specific.***

PART-III

Characteristics of the ideal vaporizer

1. *Its performance is not affected by changes in FGF , volume of liquid agent , ambient temperature and pressure , decrease in temperature due to vaporization and pressure fluctuation due to the mode of ventilation.*
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.*

The principle of simple anesthetic vaporizers

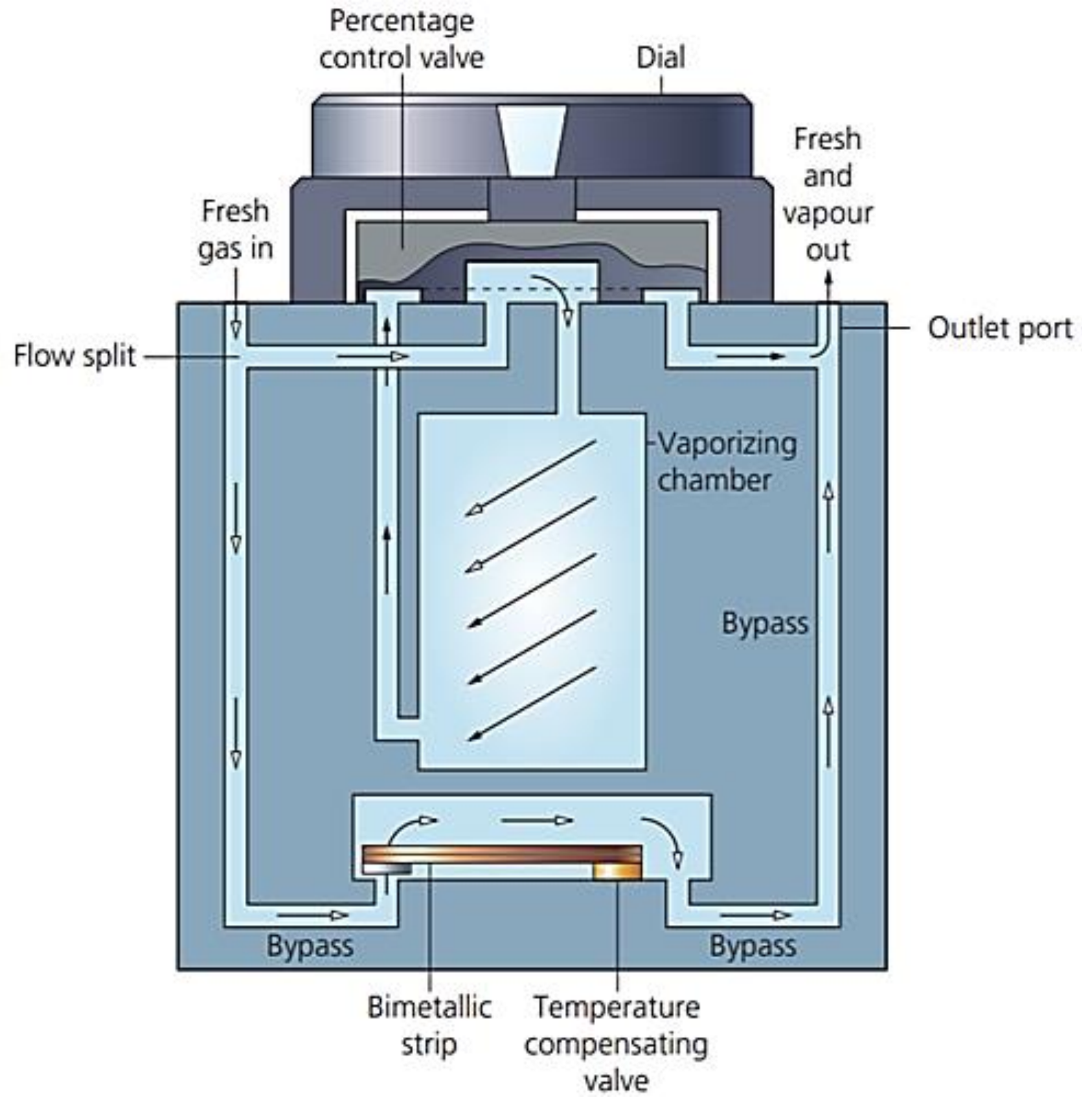


Plenum vaporizer

Components:

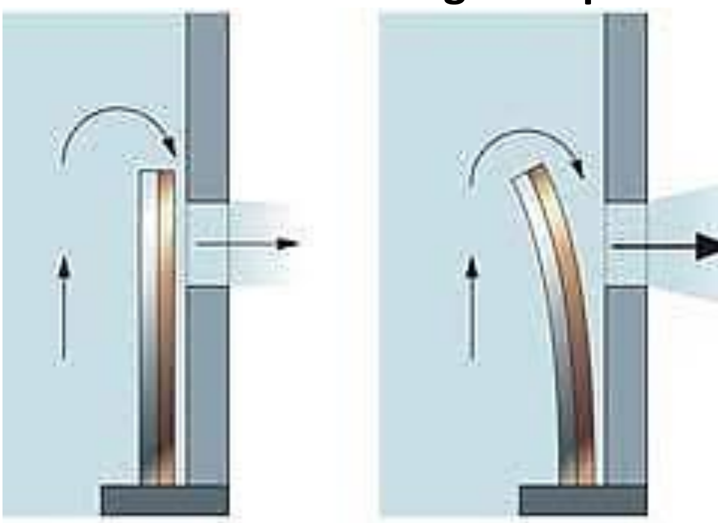
1. ***A case with the filling level indicator and a port for filling device.***
2. ***Percentage control dial on the top of the case.***
3. ***The by-pass channel and the vaporization chamber. The vaporization chamber contains wicks or baffles to increase the surface area of vaporization.***
4. ***The splitting ratio between by-pass channel and vaporization channel is controlled by a temperature sensitive valve utilizing a bimetalic strip or a expandable rod.***
5. ***the vaporizers are mounted on the back bar using interlocking Selectatec system .The interlocking rods prevents more than one vaporizer to be used at the same time, the FGF only enters the vaporizer when its switched on.***

Schematic diagram of Tec 5 plenum vaporizer



Bimetalic strip

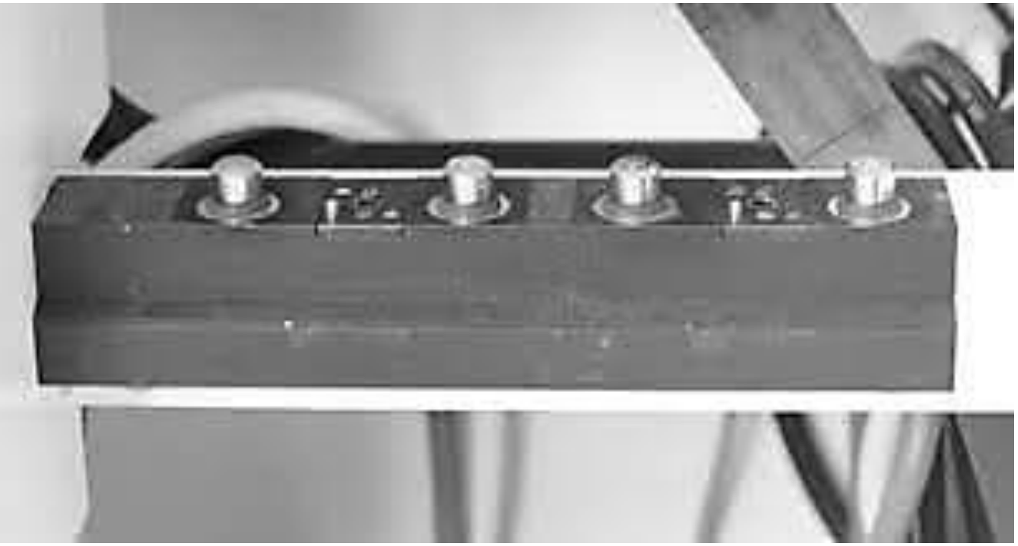
Low temp. **High temp.**



2.19 Mechanism of action of a bimetallic strip.

Selectatec back bar of anesthetic machine

Empty selectatec back bar



Selectatec back bar of anesthetic machine

Installing vaporizers on the back bar

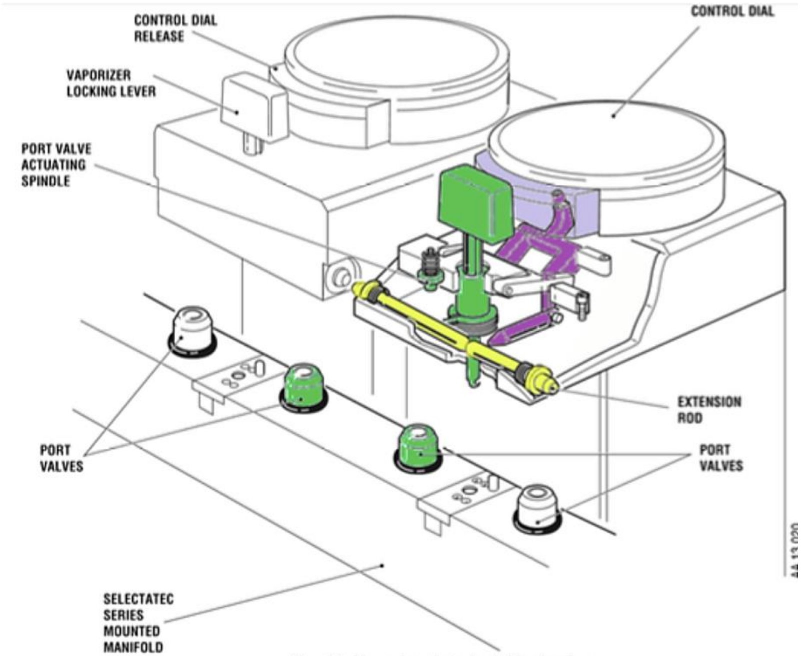


Fig. 12 Vaporizer Interlock Mechanism

Mechanism of action

1. ***The calibration of each vaporizer is agent-specific.***
2. ***FGF is split into two streams on entering the vaporizer. One stream passes through the by-pass channel and the other ,smaller stream flows through the vaporizing chamber , they unite when the gas leaves the vaporizer .***
3. ***The vaporizing chamber is designed so that the gas leaving it is always fully saturated with vapor before it rejoin the by-pass gas stream . This should be achieved despite changes in the FGF rate.***
4. ***Full saturation with vapor is achieved by increasing the surface area of contact between the carrier gas and the volatile anesthetic liquid, by means of wicks , series of baffles or by bubbling through the liquid.***

Calibration differences in vaporizers

Mechanism of action

5- The desired concentration is obtained by adjusting the percentage control dial which alters the amount of gas flowing through the vaporizing chamber.

6-In modern vaporizers the vapor concentration supplied is independent of FGFs between 0.5-15 L/min.

Mechanism of action

7-During vaporization , cooling occurs due to loss of latent heat of vaporization , lowering temperature of the liquid makes it less volatile . In order to compensate for temp. changes :

A-vaporizers are made of materials with a very high thermal conductivity like Copper , readily giving heat to the liquid anesthetic agent and thus maintaining its temp.

B- temp. sensitive valves like (bimetalic strips or bellows within the body of the vaporizer automatically adjust the splitting ratio ,thus
It allows more flow through the vaporizing chamber as the temp. decreases.

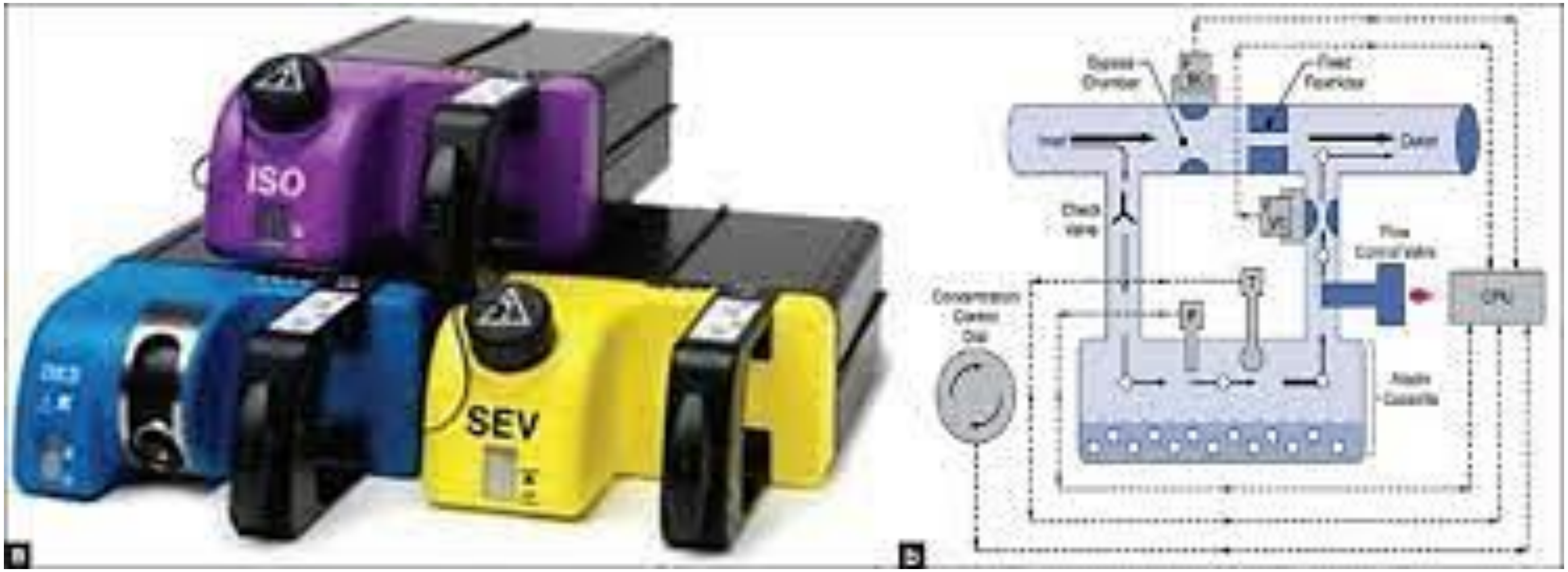
Mechanism of action

8- The amount of vapor carried by the FGF depends on both :

A- The Saturated Vapor Pressure (SVP) of each agent.

B- The atmospheric pressure. At high altitudes ,the atmospheric pressure is reduced while SVP remains the same. This leads to an increased amount of vapor. Thus unlike other volatile anesthetic agents , Desflurane vaporizers are designed so that they are both temperature and pressure compensated.

Aladin cassettes



Problems in practice and safety features

1. ***In Tec 5 vaporizers there is anti-spill mechanism that prevents the liquid to enter the by-pass channel even if the vaporizer is turned upside down ,despite that its recommended that the vaporizer is purged with FGF of 5L/min for 30 min with the percentage control dial set at 5%.***

2. ***The selectatec system increases the risk of leak as the O-ring may be accidentally removed during changing of vaporizers.***

Problems in practice and safety features

3- Minute volume divider ventilators exert back pressure during inspiratory phase, and back-flow of vapor into the by-pass channel thus raising the vapor concentration to dangerously toxic levels .

Installation of down stream Flow restrictors and long vaporizing chamber inlet ports can minimize this problem.

4- Thymol is a Halothane stabilizing agent , with time it may accumulate on the wicks causing their malfunctioning , it may also cause sticking of the bimetalic strip and other metallic parts inside of the breathing system.

Problems in practice and safety features

5- a pressure relief valve downstream of the vaporizers ,opens at 35 kPa , prevents damage to the flowmeters or vaporizers when the common gas outlet is blocked .

6- The bimetalic strip is inserted to the by-pass channel (since Tec 3 vaporizers is manufactured) , as it may be corroded if exposed to a mixture of O2 and volatile inhalational agent inside the vaporizing chamber.

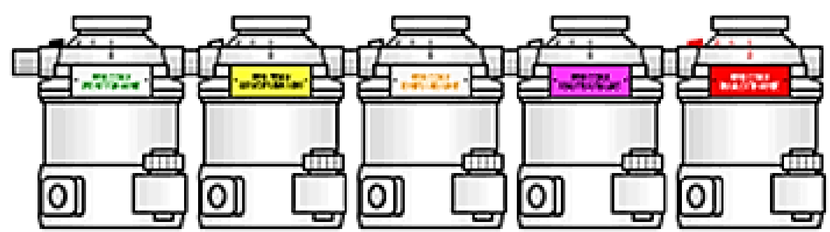
7- Presence of agent specific , filling devices or connectors , prevent:

-<u>Spillage</u> of volatile anesthetic agent which contaminates the environment or causes corrosion on the surfaces.

-<u>Filling</u> of a vaporizer with a wrong agents .

They are color and geometrically coded

Agent-specific vaporizer filling devices



Methoxyflurane Sevoflurane Enflurane Isoflurane Halothane

Vaporizer filling devices

Pour-Fill

Easy-Fill

PART-IV

Desflurane(Tec 6)vaporizers

Desflurane

- ***Is an inhalational anesthetic agent with unique physical properties making it extremely volatile.***

- ***Is saturated vapor pressure (SVP) is 644 mmHg at 20° C and a boiling point of 23.5° C at atmospheric pressure (slightly above room temperature.***

- ***These properties precludes the ordinary variable-bypass vaporizers ,thus the internal design is completely different despite the similar appearance.***

- ***The desflurane vaporizer is mounted on the Selectatec bar.***

Schematic diagram of Desflurane vaporizer

1. *Vaporizing chamber (sump) :*

-Electrically heated.

-450 ml capacity.

-Needs a warm-up time of (5-10)min.

-Operating temp. is 39C .and;

-SVP of 1550 mmHg(2 atm. Pressures).

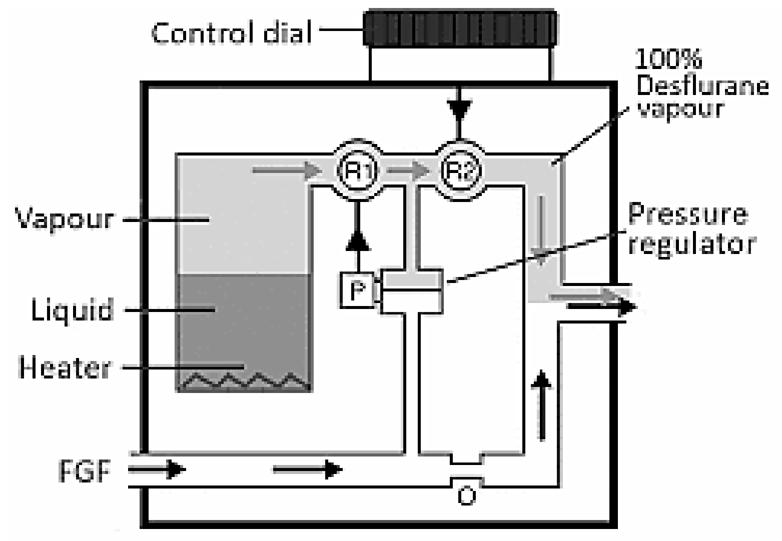
-The vaporizer will not function below this temp. and pressure.

2. *FGF channel:*

-A fixed restriction/orifice is positioned in the channel.

-Does not enter the vaporizing chamber.

-Enters the channel of the regulated concentration of Desflurane vapor before the gas mixture is delivered to the patient.



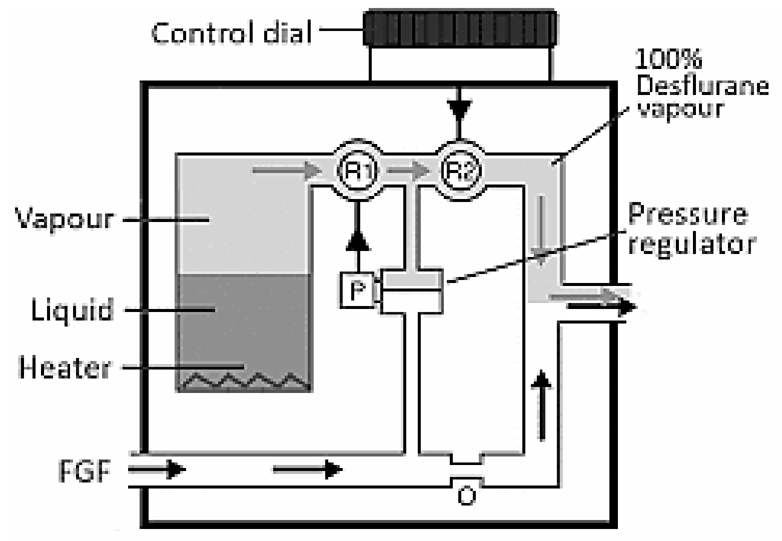
Schematic diagram of Desflurane vaporizer

3- A pressure regulator:

-A differential pressure transducer adjusts the pressure at the outlet of the vaporizing chamber.

-Senses the pressure at fixed restriction on one side and the pressure of desflurane upstream to the pressure regulator on the other hand.

-Ensures that the pressure of desflurane vapor upstream of the control valve equals the pressure of FGF at the fixed restriction



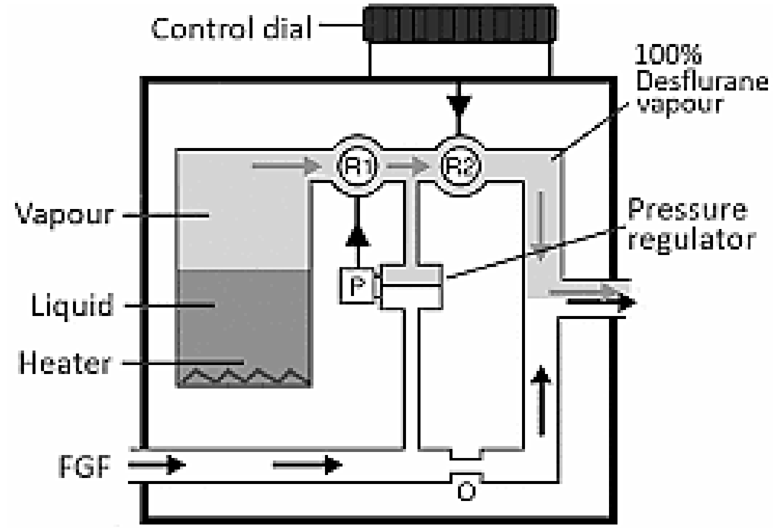
Schematic diagram of Desflurane vaporizer

4- A percentage control dial:

- A rotatory valve adjust a second restrictor.

-Controls the flow of desflurane vapor into FGF thus the output concentration

-The dial calibration is (0.0% -18%).

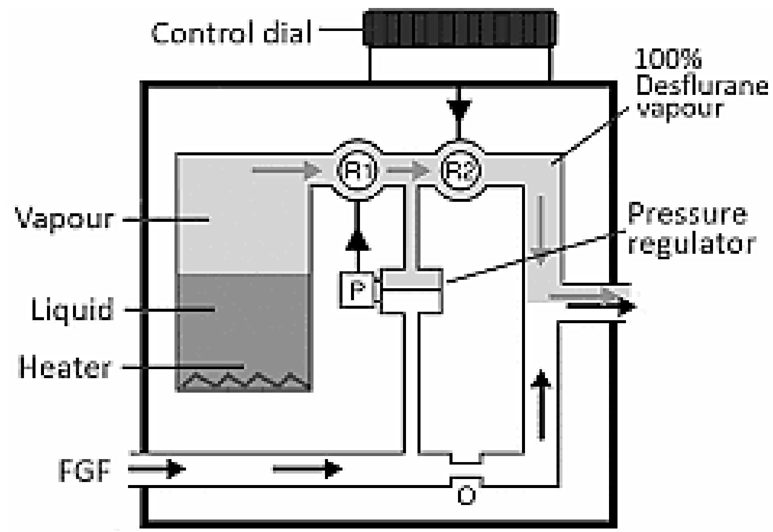


Schematic diagram of Desflurane vaporizer

4- The fixed restriction/orifice:

- Ensures that the pressure of the carrier gas within the vaporizer is proportional to gas flow.

-Enables the output concentration to be constant independent of FGF rate .

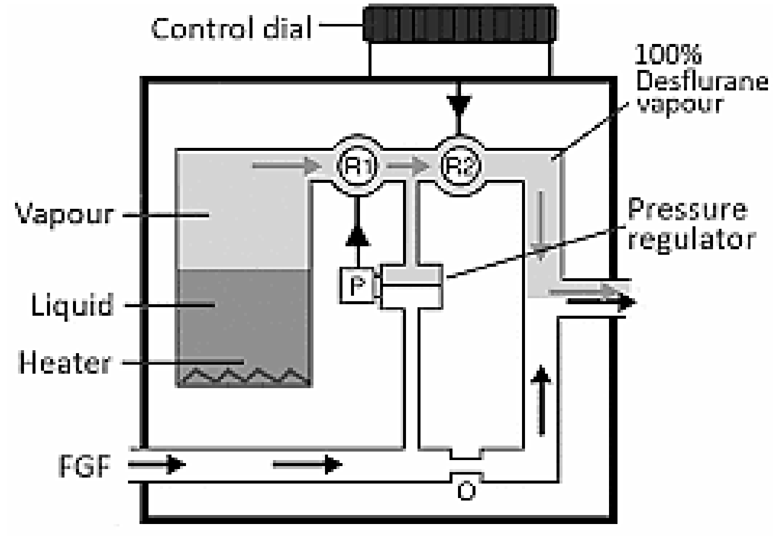


Schematic diagram of Desflurane vaporizer

5- Malfunction alarm:

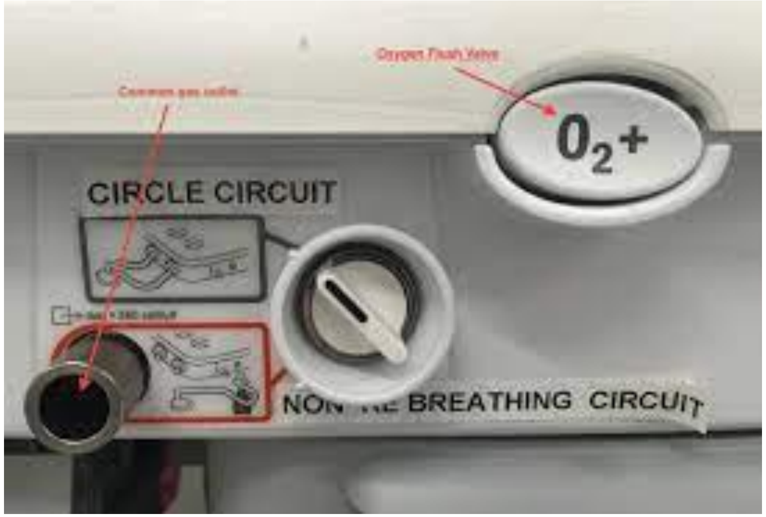
-Auditory and visual.

- Back-up 9V battery if there is mains failure.



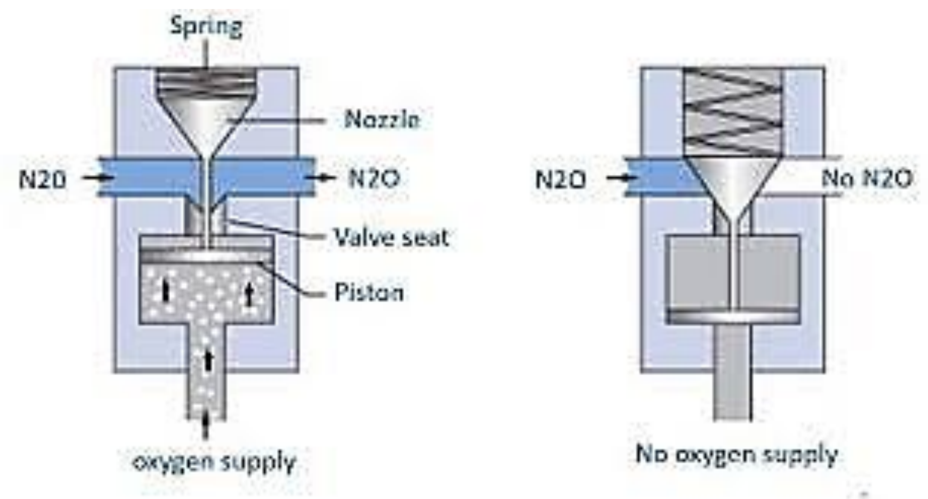
Emergency Oxygen Flush

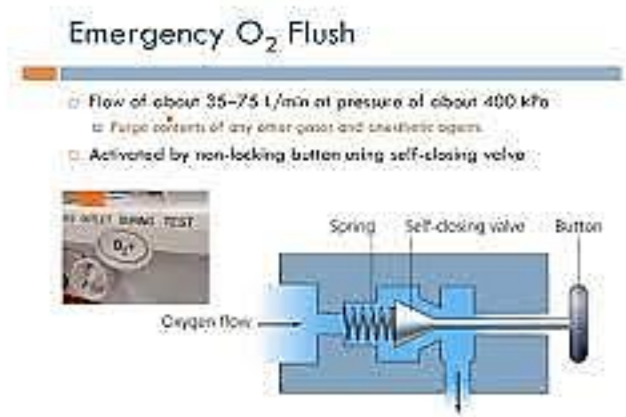
- *Is usually activated by non-locking button and using a self-closing valve.*
- *When pressed pure O2 is delivered from the Exit port (outlet) of the anesthetic machine to the patient.*
- *The flow bypasses the flowmeters and vaporizers.*
- *A flow of 35-75 L/min at a pressure of 400 kPa is expected.*
- *The button is recessed in a housing so that it prevents accidental or unwanted activation.*



Emergency Oxygen Flush

- ***Is usually activated by non-locking button and using a self-closing valve.***





Problems in practice and safety features

1. ***The high pressure increases the risk of barotrauma.***
2. ***When used inappropriately causes dilution of the anesthetic gases and vapors.***
3. ***Should not be used with Minute volume divider ventilators.***

Oxygen supply failure alarm

There are many designs available.

Characteristics of the ideal O_2 failure alarm

1. *Activation depends on O_2 pressure.*
2. *No batteries or mains power.*
3. *Gives audible signal of sufficient duration and volume to attract attention.*
4. *Gives a warning of impending failure and another warning that failure has occurred.*
5. *Interrupt flow of all other gases when it is activated.*
6. *ambient air is allowed to be delivered to prevent CO_2 accumulation.*
7. *Tamper proof.*
8. *Should not be affected by backpressure from ventilators.*

Characteristics of the ideal O_2 failure alarm

In modern anesthetic machine:

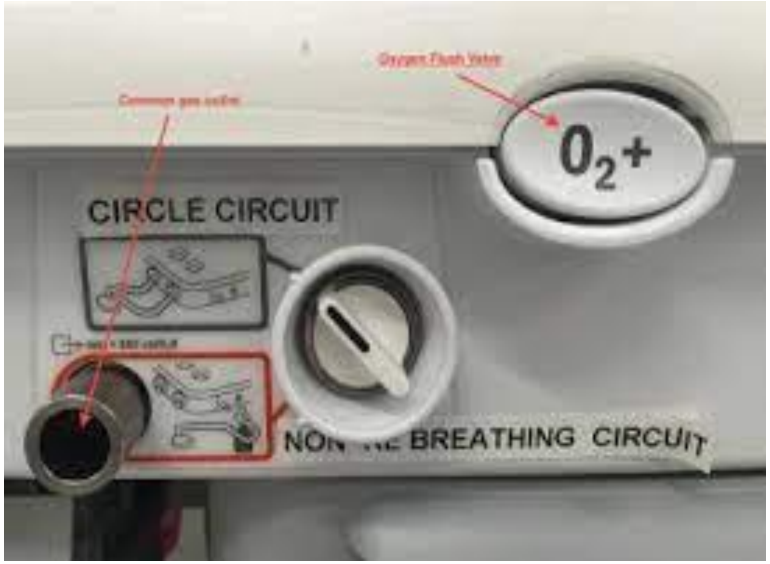
-At O2 supply pressure <200 kPa , low pressure supply alarm sounds.

-At O2 supply pressure < 137 kPa ,the (fail safe) valve interrupts the flow of all other gases.

-At O2 supply pressure < 100 kPa O2 flow starts to decrease below the flow set.

Common gas outlet

- *It is the end of the anesthetic machine.*
- *The gas mixture made at the flowmeters plus the inhalational anesthetic agent added by the vaporizers exits the machine to the to be conducted to the breathing system.*
- *It is a strong conical outlet connector with outer diameter of 22 mm and inner diameter of 15 mm.*



Other modifications and designs

1. ***Desflurane vaporizer.***
2. ***MRI proof anesthetic machine is manufactured from non-ferromagnetic material .***
3. ***In newly designed anesthetic machines, many important components are electrically and electronically controlled like electronic flowmeters ,pressure and flow sensor transducers or thermistors, FiO2 and end tidal anesthetic agents***
4. ***Direct injectors that are more efficient than traditional vaporizers.***
5. ***Syringe pumps for i.V. anesthesia***

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Other modifications and designs

6- Quantiflex Anesthetic Machine:

Has the following features:

a) ***Two flowmeters ,one for O_2 and another one for N_2O with one control knob for both gases.***
b) ***Mixture control wheel for adjustment of relative concentration of O2 and N_2O ranging between 30-100% O_2 concentration.***
c) ***Prevents delivery of hypoxic mixture.***
d) ***Used in dental anesthesia.***