Vaporisers for anaesthesia

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Outline

- Definition, development
- Physical basics
- Construction
- Modifications
- Safety
- Future

Anaesthesia vaporizer

- **Safety** of patient first.
- The anesthesia vaporizer is a **critical component** of anesthetic machine.
- It is very important to ensure that the appropriate **percentage** of anesthetic agent is being delivered.
- A **malfunctioning** vaporizer can be the cause of inappropriate depth of anesthesia and may also be the reason you “lose” a patient.
- Output +/- 15%

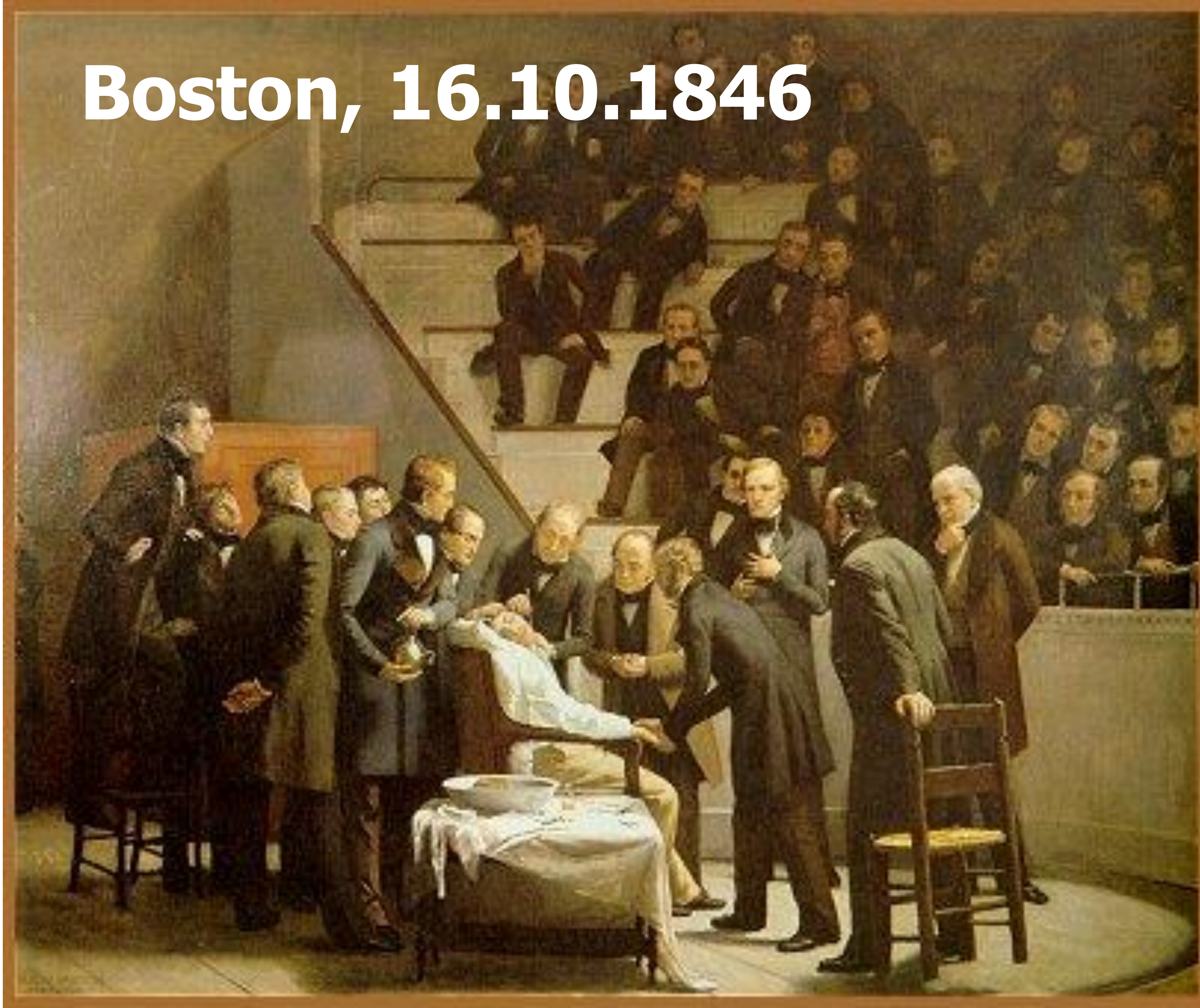
Definition

- A vaporizer is a device that transforms liquid anaesthetic to vapour and adds its clinically useful and precise, adjustable concentrations to a stream of carrier gas
- Saturated vapour pressure (SVP) of volatile anaesthetic agents at room temp is many times higher than required to produce anaesthesia

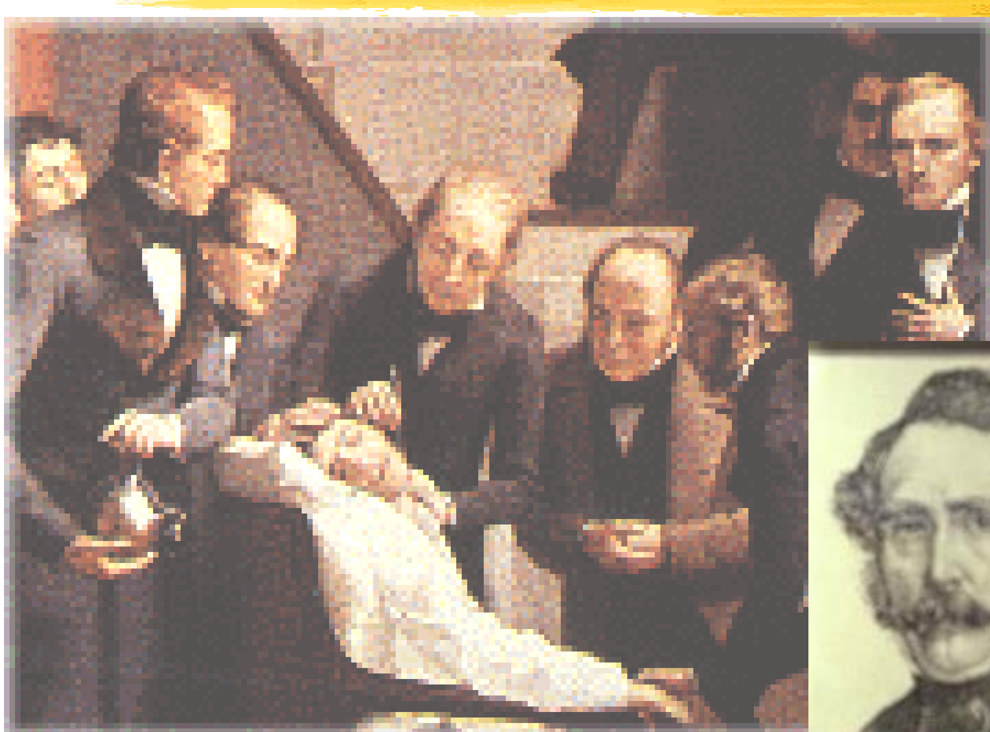
Raimundus Lullus, 1275
Paracelsus, "sweet oil of vitriol„ 16. century

lia, das ſie alle gar wunderbarlichen Sulphur geben / in dem/ ſo die Corpora Animantata geſchieden werden von den Corporibus Embryonatis. Als vom Salz / vom Salgemmen/ von den Speciebus Aluminis, von den Vitriolis, &c. Nuhn aber ein kurtze Regel will ich euch inn gemein geben / das alle Sulphura von den Vitriolatis Salibus, Stupefactiua ſeindt/ Narcotica, Anodyna, Somnifera: Vnnd aber mit einer ſolchen Proprietet / das an dem orth die Somniferiſch arth / ſo rüwig vnnd ſo mildt hingeht / daß ohn allen ſchaden ſich abzeucht / nichts auff Opiatiſche wirckung / als in Iuſquiamo, Papauere, Mandragora, &c. ſondern gar Mildt / Tugendtlich / ohn all Infectiff. Darumb ich das zum höchſten leb / das ein ſolch Somniferum Stupefactiuum ſoll von der Natur ſelbſt Decoquiert ſein / Præpariert vnnd Corrigiert. Vnnd dieweil wir Artzt alle ſehendt / das die Somnifera viel thundt/ vnnd groſſe ding thundt / vnnd das aber in den Opiaten ein ſolchs Gifft iſt / das ſie nicht zu gebrauchen ſeindt ohn die geſtalt Quintæ Eſſentiæ: So ſollen wir vnſer Zuflucht vnd Verſtandt deſter mehr ſetzen hie an das orth / dieweil wir wiſſen/ das viel kranckheiten ſeindt / die ohn Anodyna nicht mögendt geheylt werden / vnnd all jhr Cur in die Anodynen geſetzt ſeindt von Gott durch die Natur. Darumb bewegt mich daſſelbig/ dieſen Sulphur deſter baß zu beſchreiben: Wie er gefundẽ wird/ vnnd wie man jhn zu wegen bringet / werdt jhr finden inn den Alchimiſtiſchen Proceſſen. Hie ſollendt jhr aber wiſſen von dieſem Sulphur / das vnter allen der vom Vitriol am bekanntlichſten iſt / das er an jhm ſelbſt Fix iſt: Zum andern hatt er ein Süeſſe / das jhn die Hüner all eſſen / vnd aber endtſchlaffen auff ein Zeit / ohn ſchaden wieder auffſtohndt. Dieſen Sul-

Boston, 16.10.1846



Boston, 16.X.1846

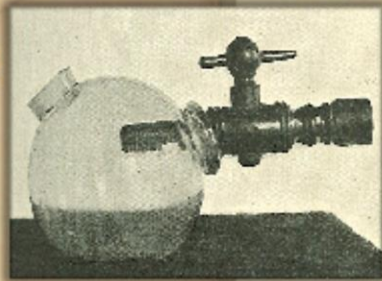


W.T.G.Morton

Ether
Draw-over
No control

REMARKS

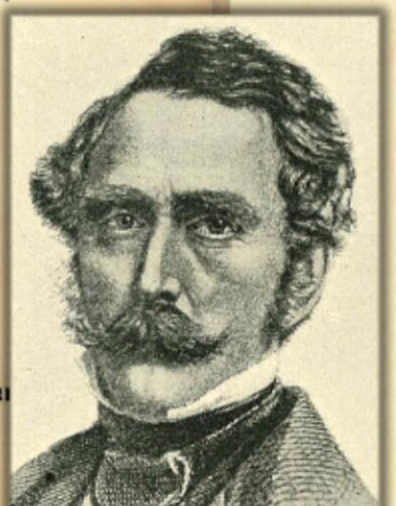
ON THE



PROPER MODE OF ADMINISTERING

SULPHURIC ETHER

BY INHALATION.



BOSTON:

DUTTON AND WENTWORTH, PRI

1847.

TO THE

SURGEONS OF THE MASS. GEN. HOSPITAL,

THIS LITTLE WORK IS RESPECTFULLY DEDICATED,

AS AN EVIDENCE

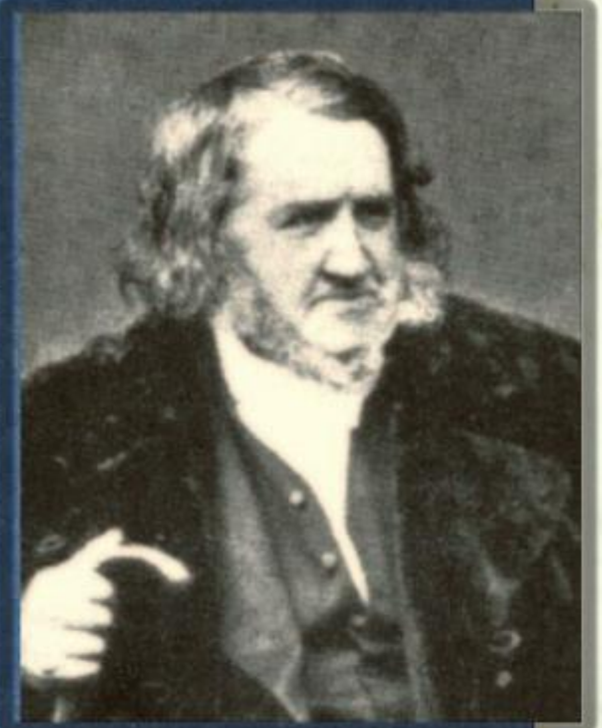
THAT THEIR EARLY AND CONTINUED INTEREST IN THE ADMINISTRATION OF SULPHURIC ETHER

IS GRATEFULLY APPRECIATED,

BY THEIR

OBT. SERVT.

WM. T. G. MORTON.



J. Y. Simpson

ANÆSTHESIA,

OR THE

EMPLOYMENT OF

CHLOROFORM AND ETHER

IN

SURGERY, MIDWIFERY, ETC.

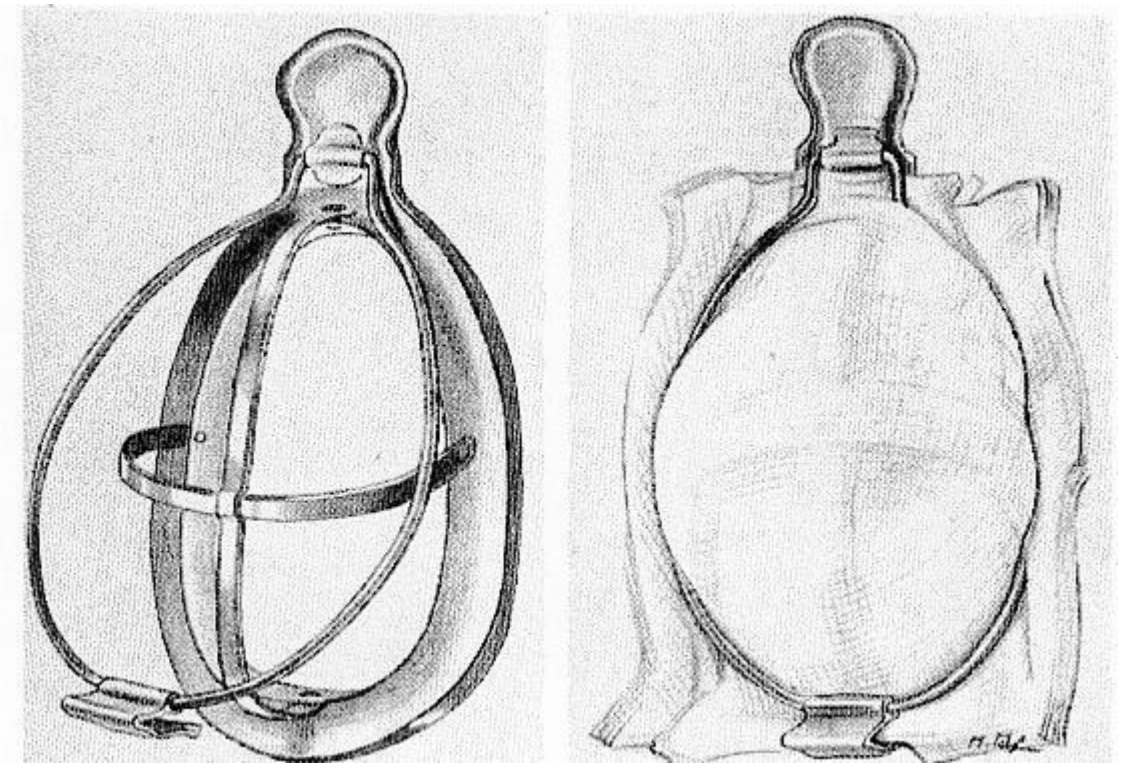
BY

J. Y. SIMPSON, M.D., F.R.S.E.,

PROFESSOR OF MIDWIFERY IN THE UNIVERSITY OF EDINBURGH, PHYSICIAN-ACCOUCHEUR TO THE QUEEN IN SCOTLAND, ETC. ETC. ETC.

PHILADELPHIA:
LINDSAY & BLAKISTON.
1849.

Carl Schimelbusch, 1890



Ether, chlorform
Draw over
Some control

Generic simple flow in vapouriser

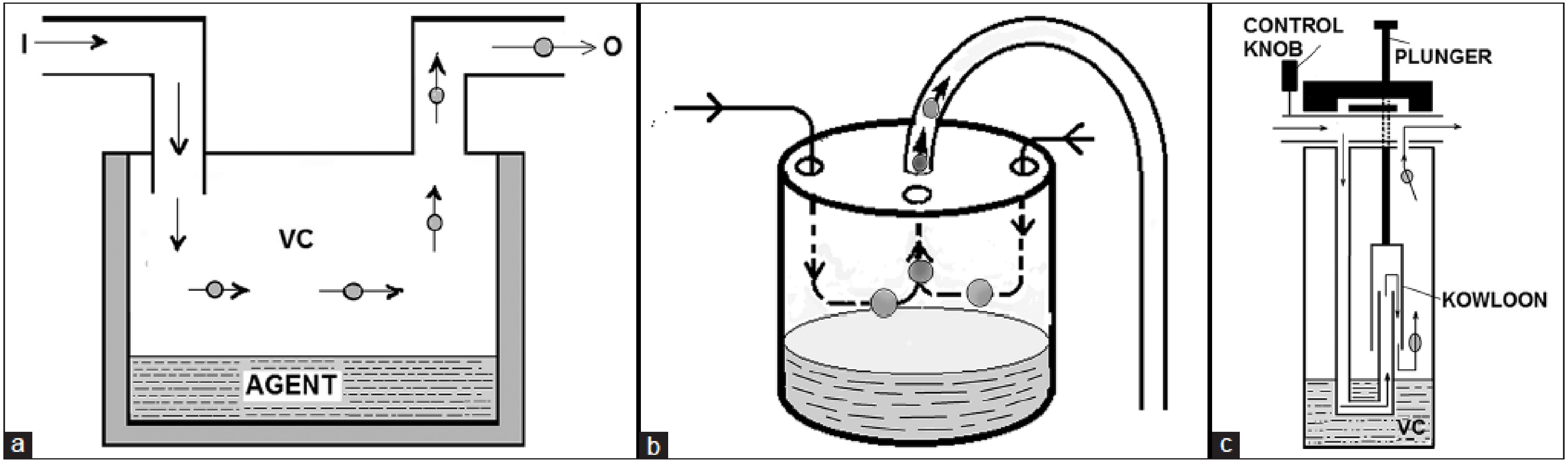


Figure 1: (a) Generic simple flow over vapouriser: I – Inlet port; O – Outlet port; vapourising chamber; Plain arrow shows fresh gas flow (FGF); Arrow with circle shows FGF carrying vapour; (b) Flagg can; (c) Boyle's bottle

A bit of physics

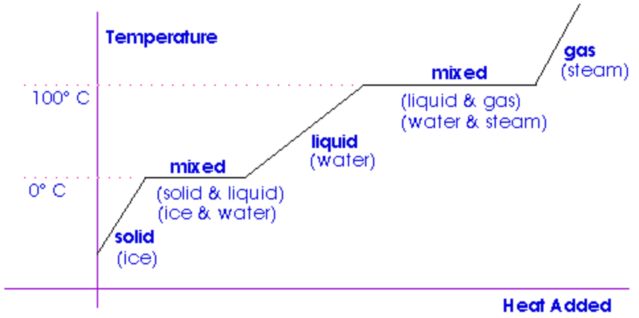
1. Gas / vapour
2. Critical temperature
3. Latent heat of evaporation
4. Boiling point
5. Saturated water pressure (SVP)
6. Partial pressure (Dalton law)

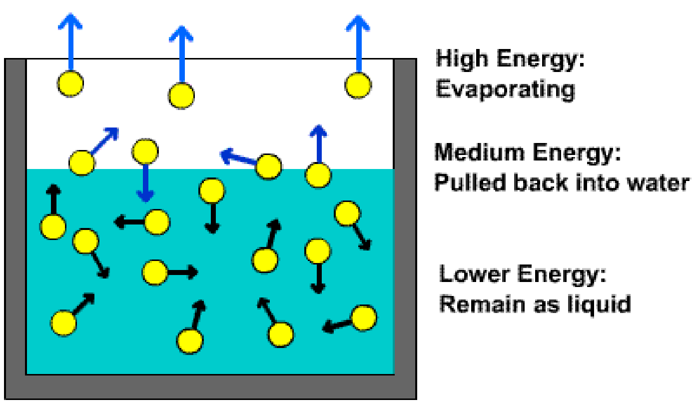
Physics of vaporisers

- **Vapor pressure:** Molecules escape from a volatile liquid to the vapor phase, creating a "saturated vapor pressure" at equilibrium. **Vapor pressure (VP) increases with temperature**. VP is independent of atmospheric pressure, it depends *only* on the physical characteristics of the liquid, and its temperature.
- **Latent heat of vaporization** is the number of calories needed to convert 1 g of liquid to vapor, without temperature change in the remaining liquid. The temperature of the remaining liquid will drop as vaporization proceeds, lowering VP, unless this is prevented.
- **Specific heat** is the number of calories needed to increase the temperature of 1 g of a substance by 1 degree C. Vaporizer – materials with high specific heats to minimize temperature changes associated with vaporization.
- **Thermal conductivity** - a measure of how fast a substance transmits heat. High thermal conductivity is desirable in vaporizer construction.

1. Gas / vapour

- Evaporation: in liquid some moleculs have enough energy to leave the liquid = evaporation
- Only on surface, requires heat energy
- Corelated with
  - a) temperature
  - b) surface
  - c) removal of vapour molecules
- Boiling point: $P_{vapour} = P_{atm}$

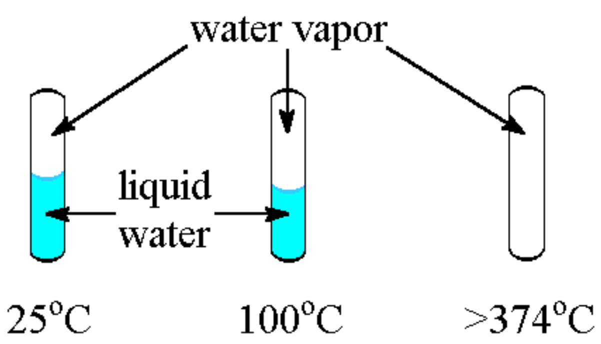




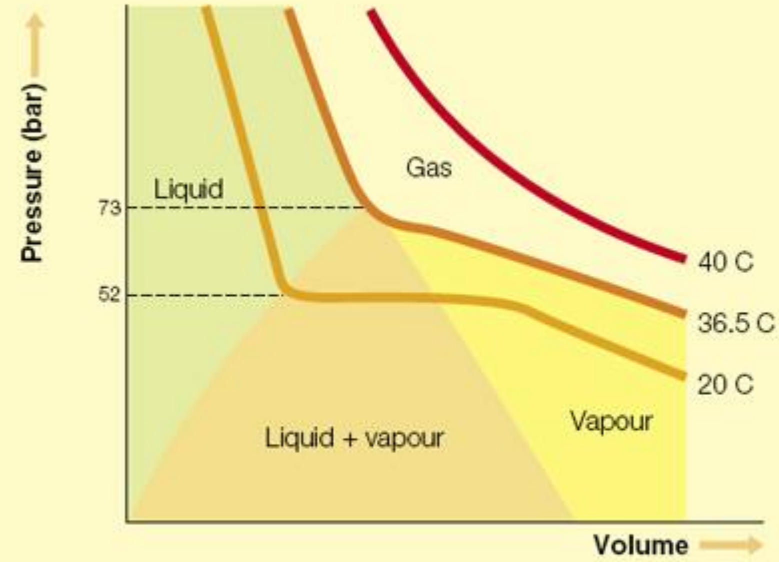
Critical temperature (CT)

- Temperature, above which a substance cannot be liquified, irrespective of pressure.
  Now it is **GAS**.
- Below CT the substance can exist as **liquid** or **vapour**.
- Gas: substance above CT; no liquid possible
- Vapour: below CT, can be pressed to liquid

2. Critical temperature

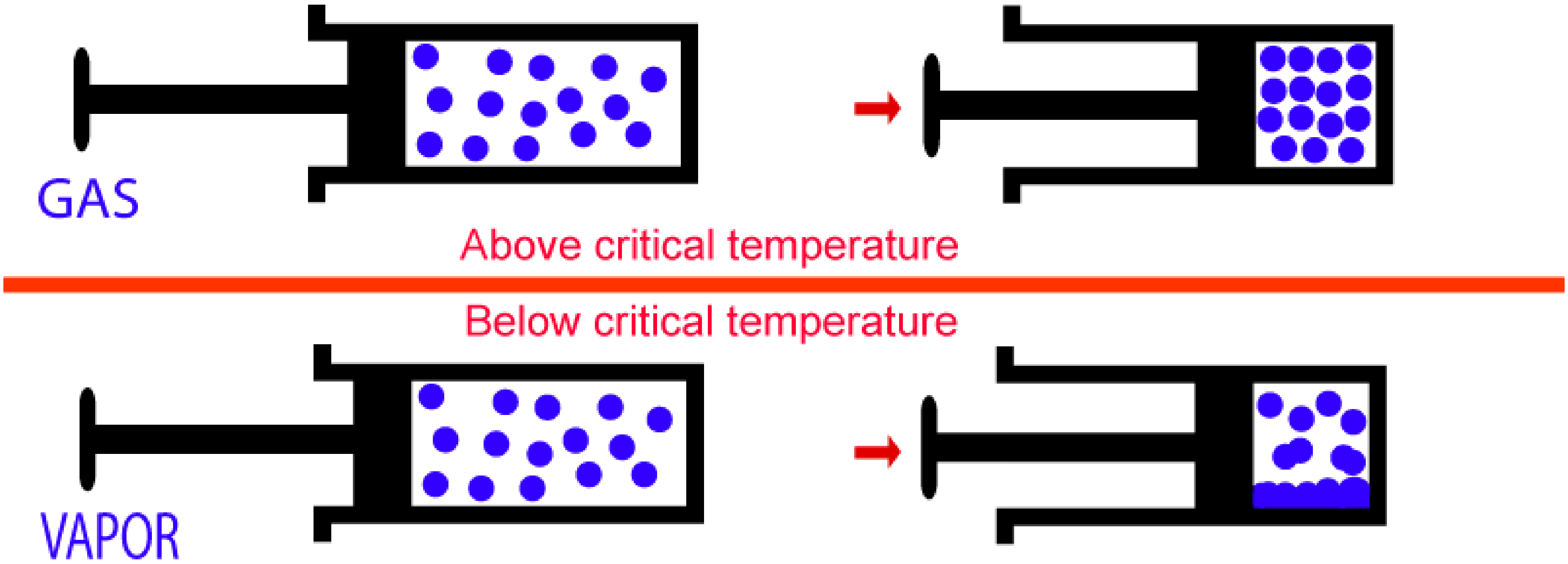


Isotherms of nitrous oxide



The isotherm at 40 C is above the critical temperature of nitrous oxide (36.5 C) and threfore obeys Boyle's law. As the volume decreases the pressure rises. At the critical temperature 36.5 C there is a critical pressure at which nitrous oxide becomes a liquid. Liquids are relatively incompressible and therefore a decrease in volume leads to a dramatic rise in pressure. At 20 C as the nitrous oxide is compressed some of it liquefies at a pressure of 52 bar (saturated vapour pressure of nitrous oxide). Further reduction in volume causes more vapour to condense with no change in pressure. When all the vapour is condensed to liquid a rapid rise in pressure is seen with further decrease in volume.

Critical temperature



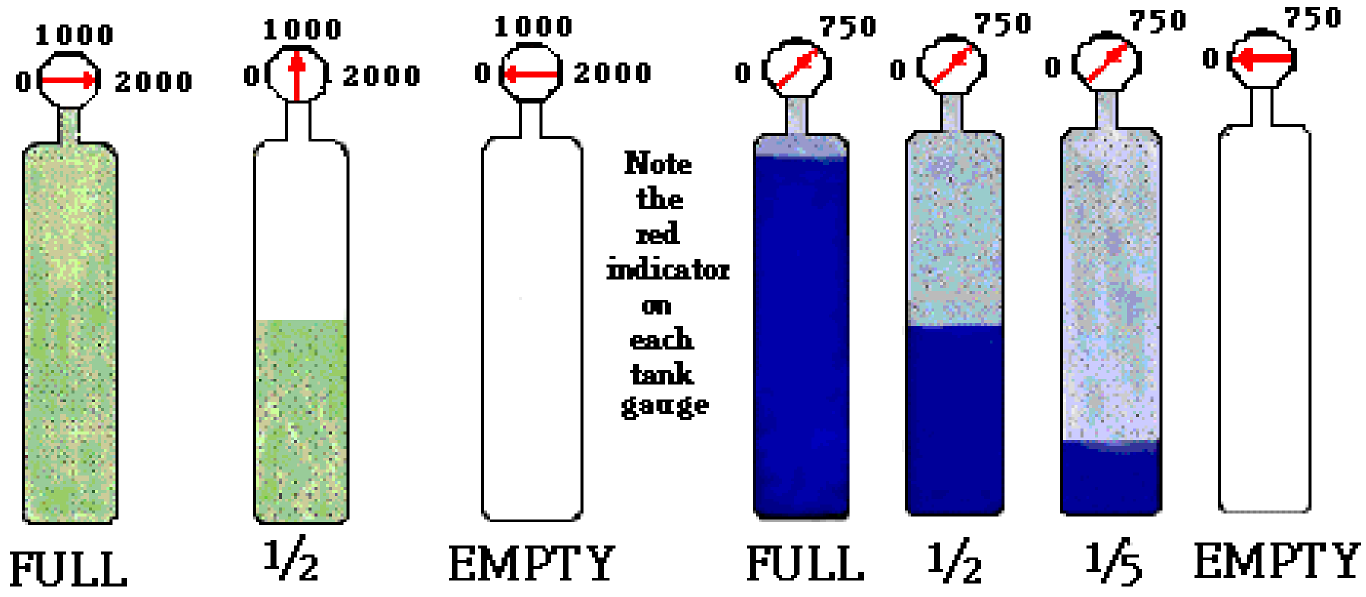
Oxygen and nitrous oxide

Oxygen: Tc -119°C

At 22°C and 15 MPa: gas

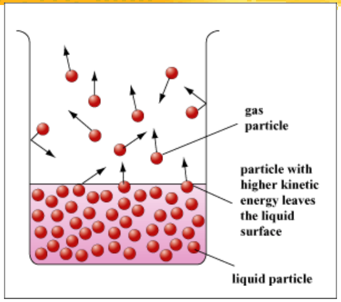
N_2O: Tc 36.5°C

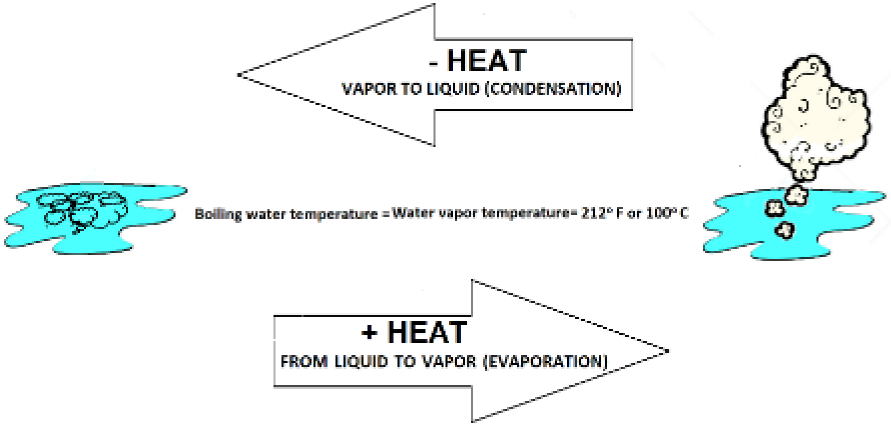
At 22°C and 5 MPa: liquid + gas

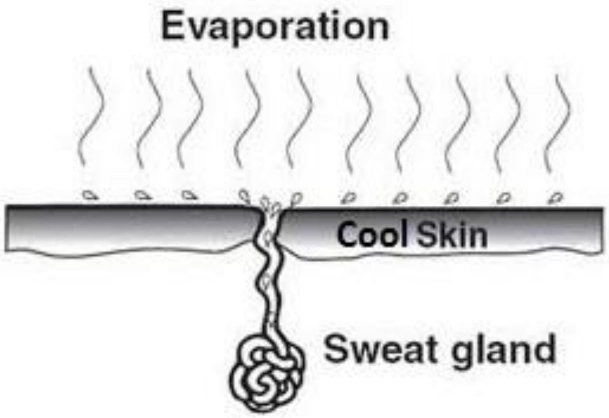


3. Latent heat of evaporation

- Moleculs leaving liquid
- Average energy falls, liquid cools
- Heat energy required to evaporate the liquid





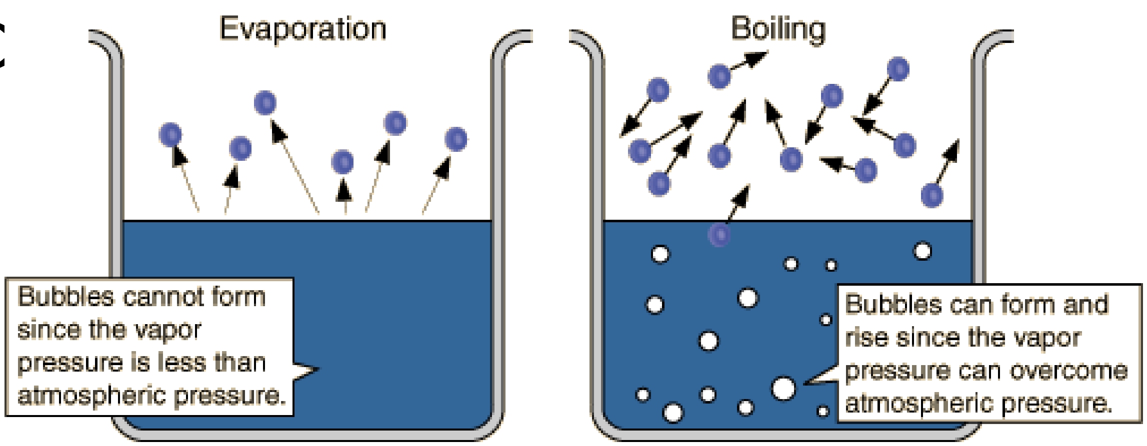


4. Boiling point

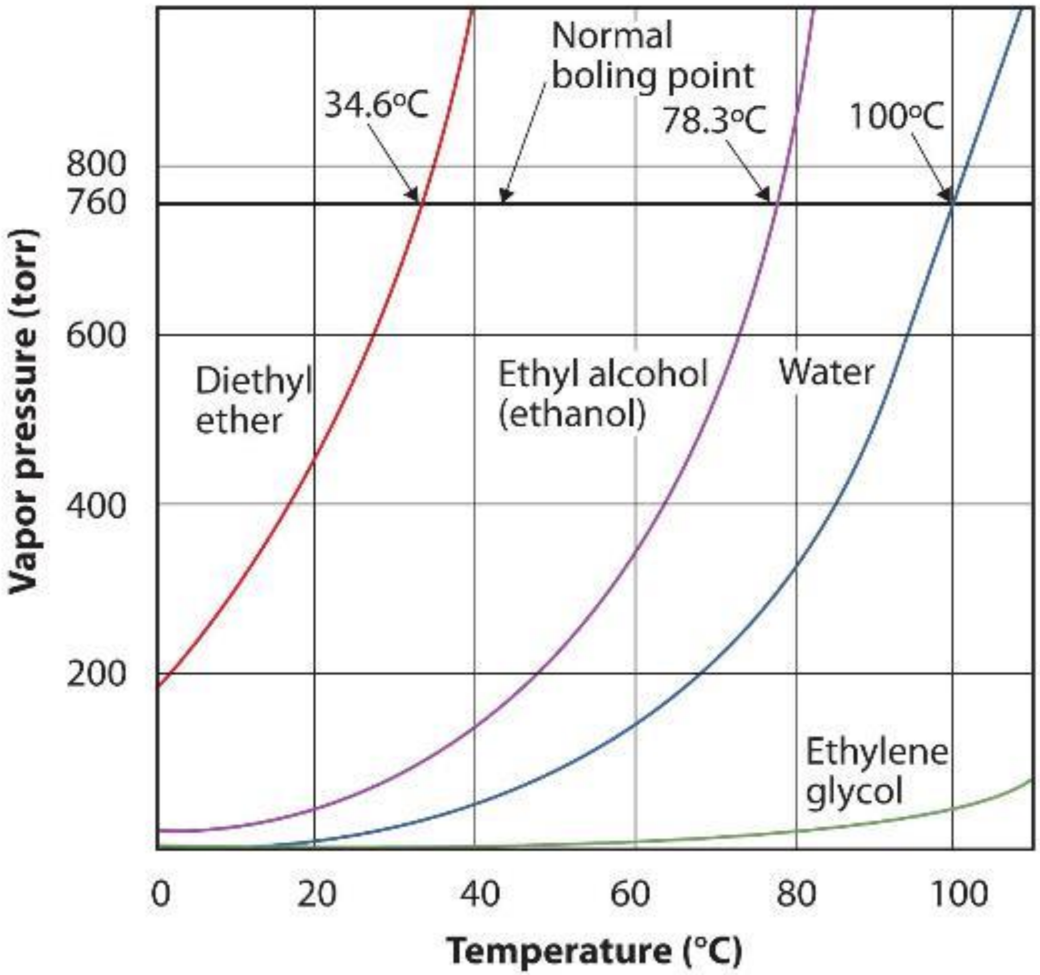
- Higher temperature ≈ quicker evaporation
- Boiling point: the pressure of vapour = atmosferic pressure
- Inside evaporation; bubbels of saturated vapour
- The closer the liquid to BP, the quicker turn to vapour

  Ether BP: 35°C

  Water BP: 100°C



Boiling point



5. Saturated water pressure (SVP)

- Evaporation in a closed container will proceed until there are as many molecules returning to the liquid as there are escaping.
- At this point the vapour is saturated; for given temperature indipendent of pressure!
- Pressure of that vapor is called the saturated vapor pressure.
- Boiling point: temperature at which SVP = P_{atm}

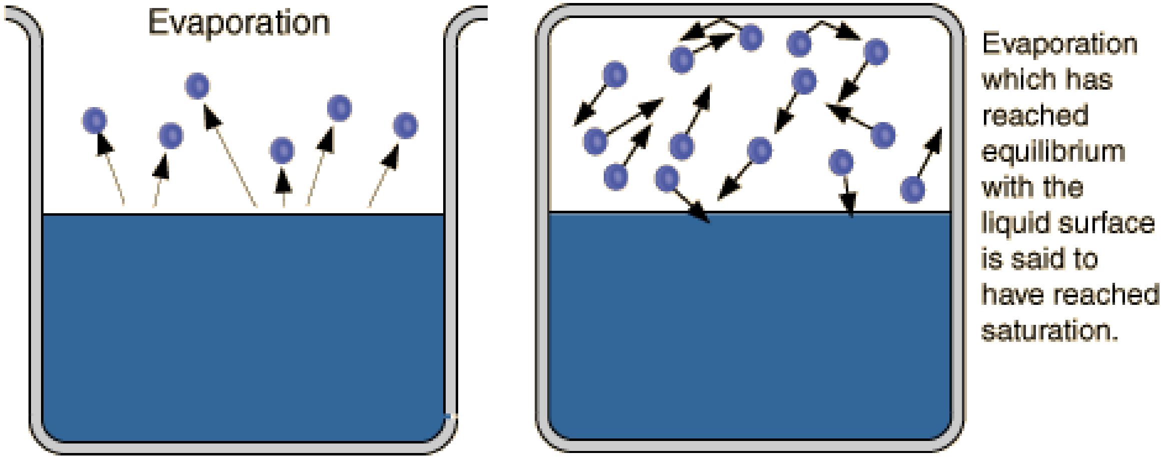
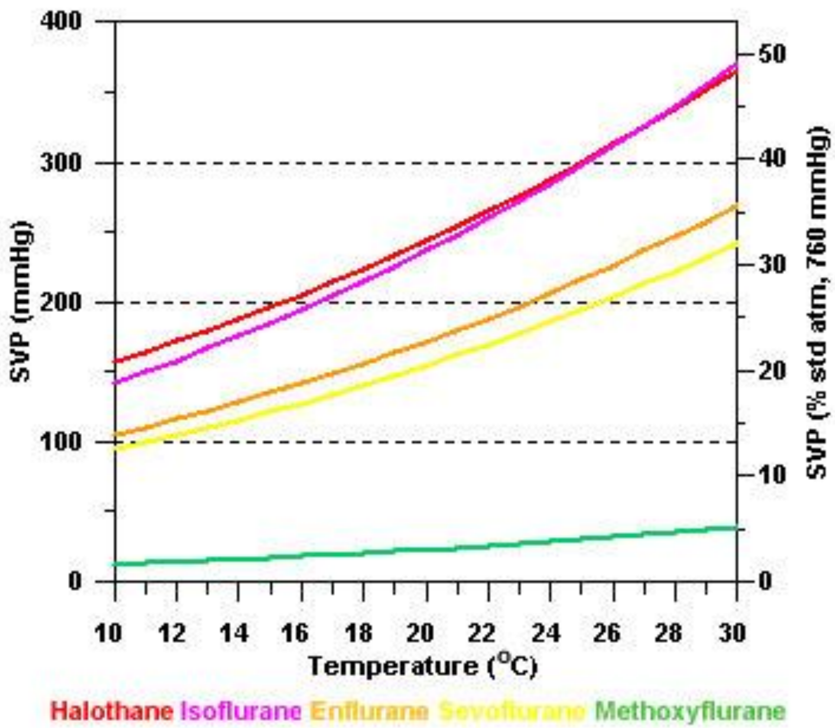
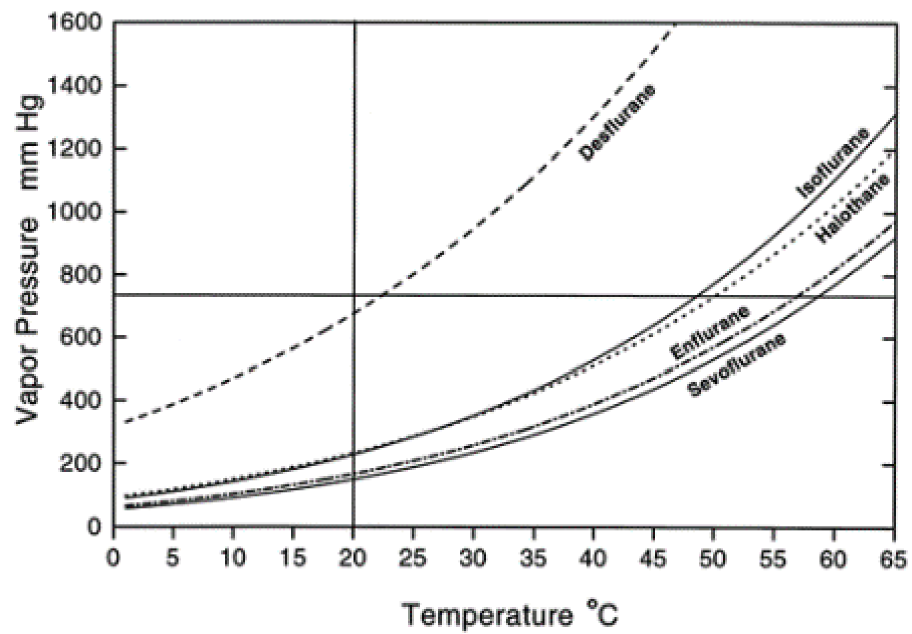


Table 1 - The saturated vapour pressures of some common volatile anaesthetics at 20°C

	SVP at 20°C (kPa)
Ether	59
Halothane	32
Enflurane	23
Desflurane	88.5
Isoflurane	33
Sevoflurane	21





SVP and anaesthesia

- To generate known concentration of inhalation agent (vapour)
- Dalton law (partial pressures)

$$P1 + P2 + P3 \ldots = P_{total}$$

- P_{part} is proportional to the volume occupied by vapour in the mixture
- Concentration of agent: saturated vapour of liquid ≈ volume% ≈ concentration
- E.g. Sevoflurane SVP at 20°C = 21 %

Concentration of anaesthetic vapour in gas

$$\text{Gas concentration} = \frac{\text{Vapour pressure}}{\text{Ambient pressure}}$$

$$\text{Sevoflurane conc.} = \frac{21.3}{101.3} = 21\%$$

This is too high concentration

SVP and temperature

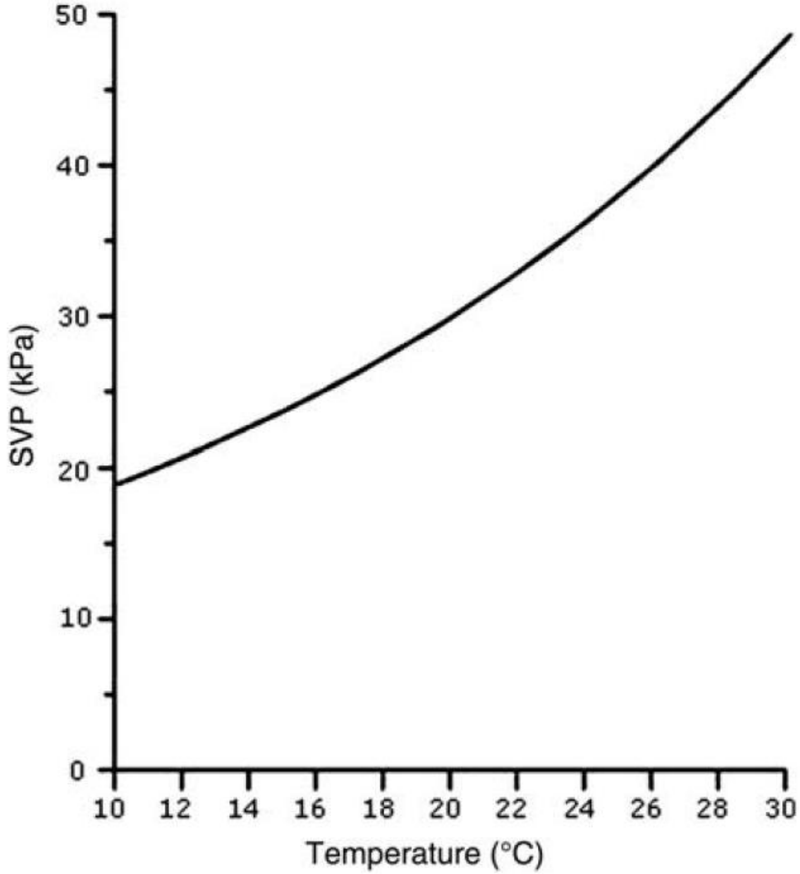
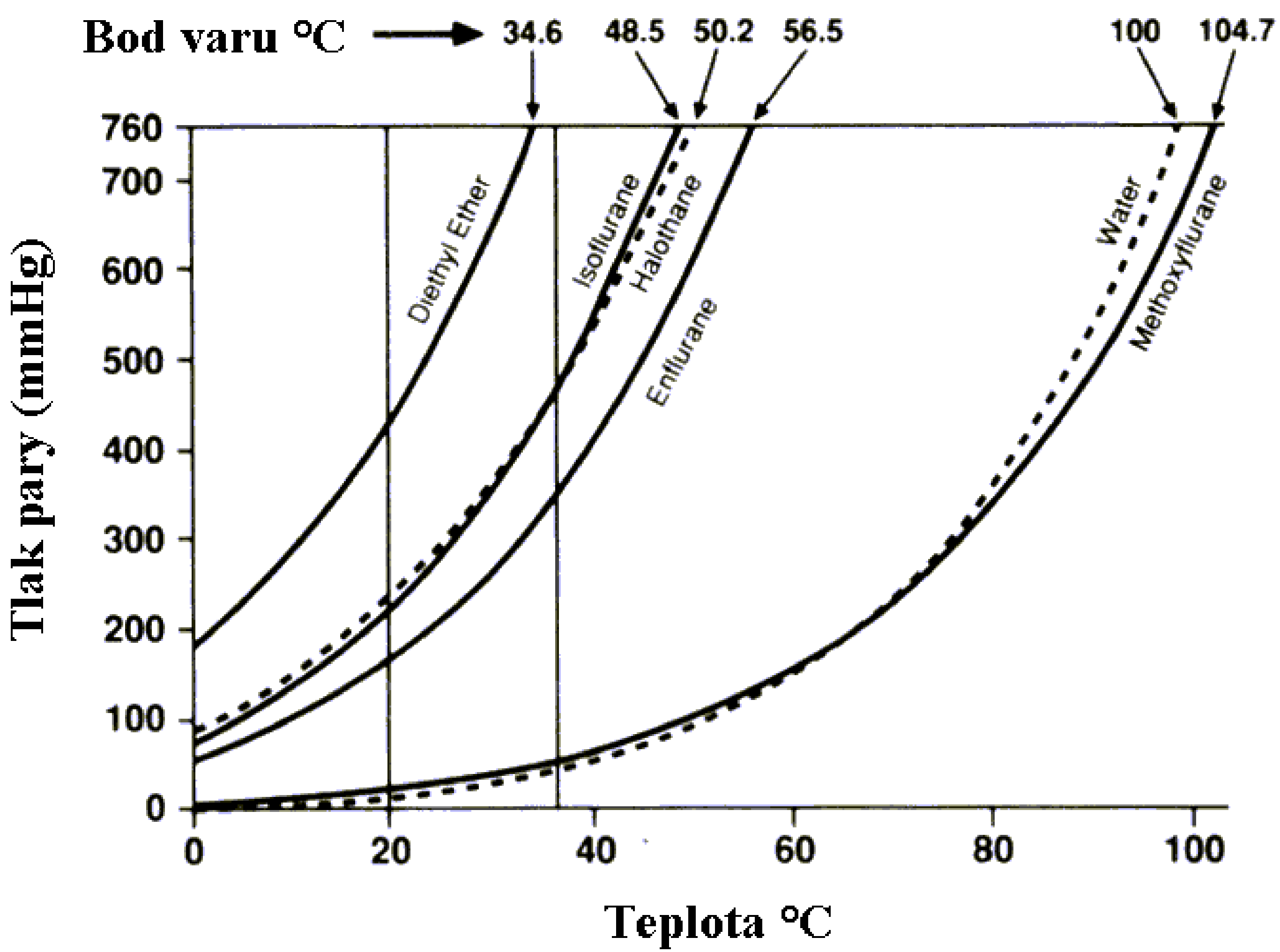


Fig 1 SVP increases non-linearly with temperature. Reproduced with permission of e-Learning Anaesthesia.

Relation between temperature and pressure of saturated vapour - volatility



Vaporisers - requirements

1. Simple, safety, user friendly
2. Precise, accurate concentration of anaesth. vapour
3. Ambient and evaporation temperature stability
4. Pressure, flow stability
5. Carrier gas indipendent
6. Agent specificity
7. Safe against
   - wrong liquid
   - tilt, leak, corrosion
   - electronic failure
8. Simple service, maintenance

Vaporiser classification

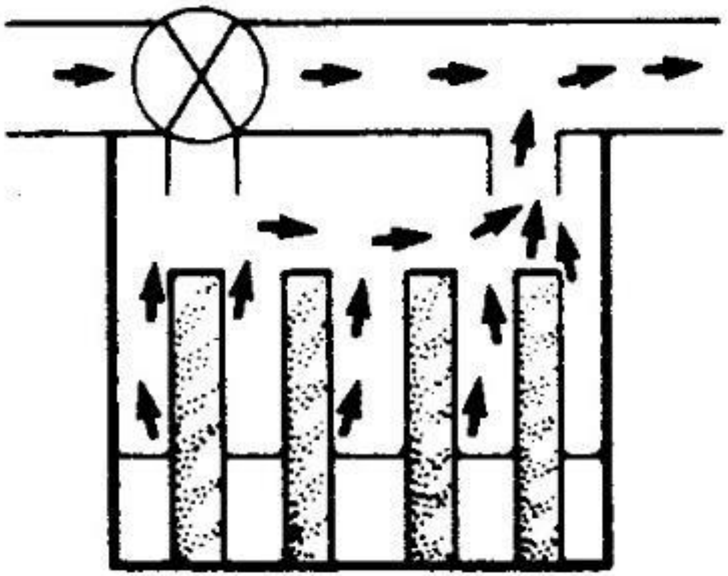
- **A. Method of vaporisation**
  1. Flow over
  2. Bubble through
  3. Injection
- **B. Resistance**
  1. Low (draw over, inhalers)
  2. Plenum
- **C. Location**
  1. Outside the circuit
  2. Inside the circuit
- **D. Regulation of concentration**
  1. Variable bypass
  2. Measured flow
  3. Electronic
- **E. Temperature stability**
  1. None
  2. By supplied heat
  3. By flow alteration
  4. Thermocompensation
     (mechanical, computerized)
- **F. Specificity**
  1. Agent specific
  2. Multiple agents

Vaporisers - development

- Ether / chloroform inhalers
- Wick vaporisers
- Draw/push over vaporiser
- Precise modern „plenum“ vaporisers
- Desfluran - chalenge

A. Evaporation

Goal: saturated vapour



Wick

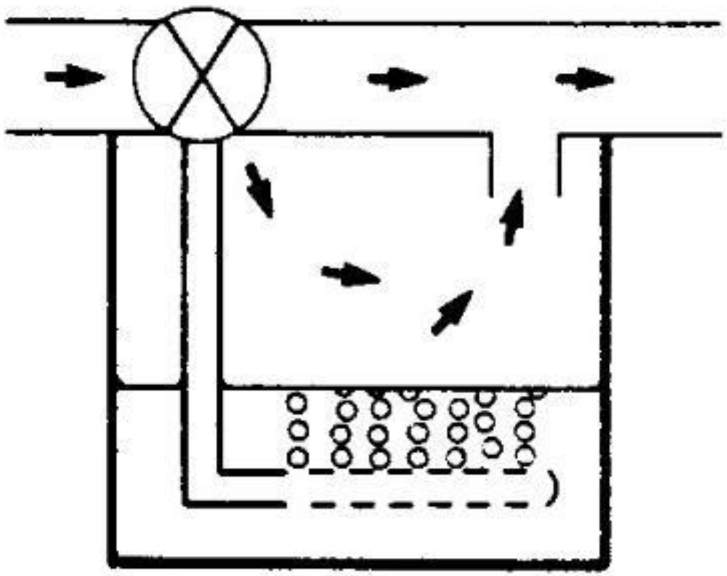


Plate with holes

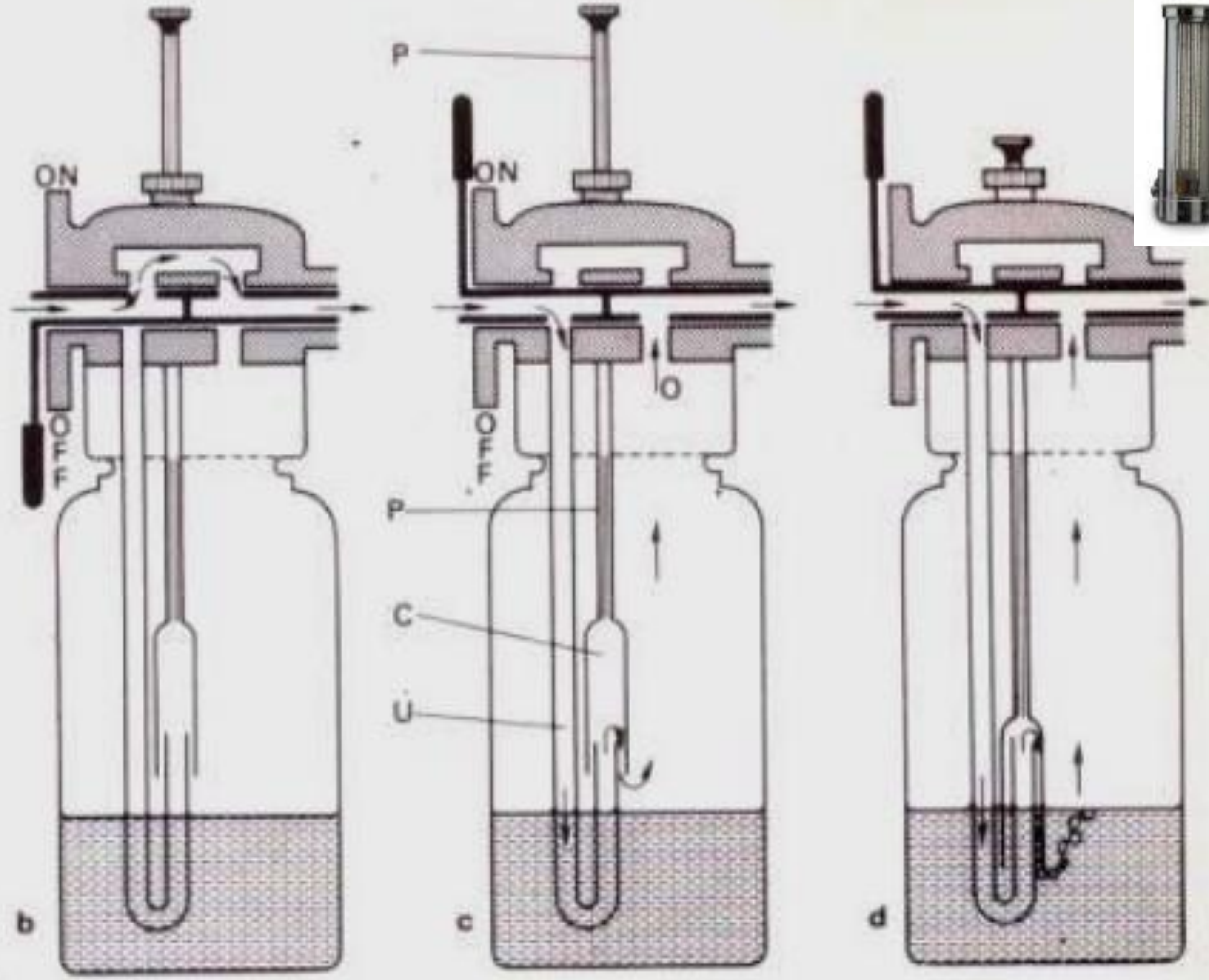
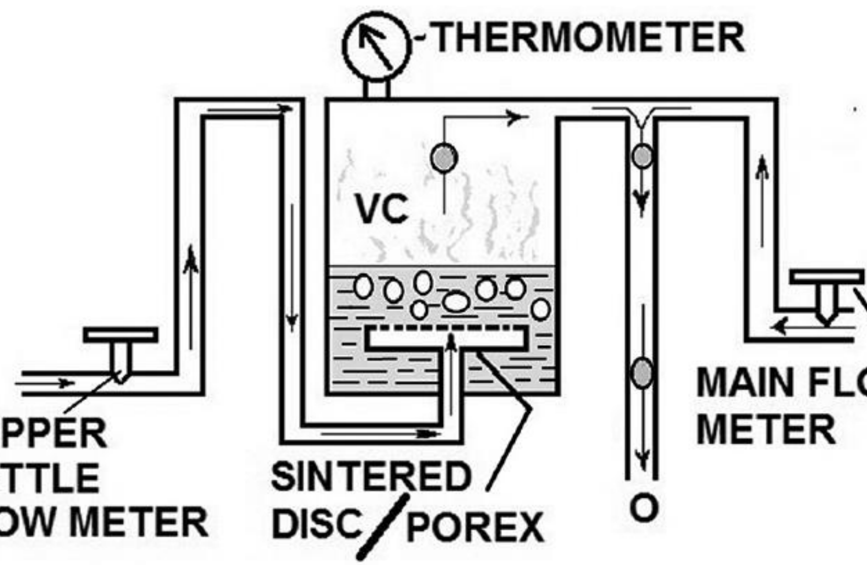


FIG. 69. (a) The Boyle's bottle. (b) Shows the control valve in the 'off' position, (c) shows the control lever fully on and the cowl (C) causing the gas to impinge on the surface of the liquid, and in (d) the cowl has been lowered so far that the gas bubbles through the liquid.

Cooper kettle

Bubble through
Agent not specific
Out of circuit
Not temp. comp.
Measured flow

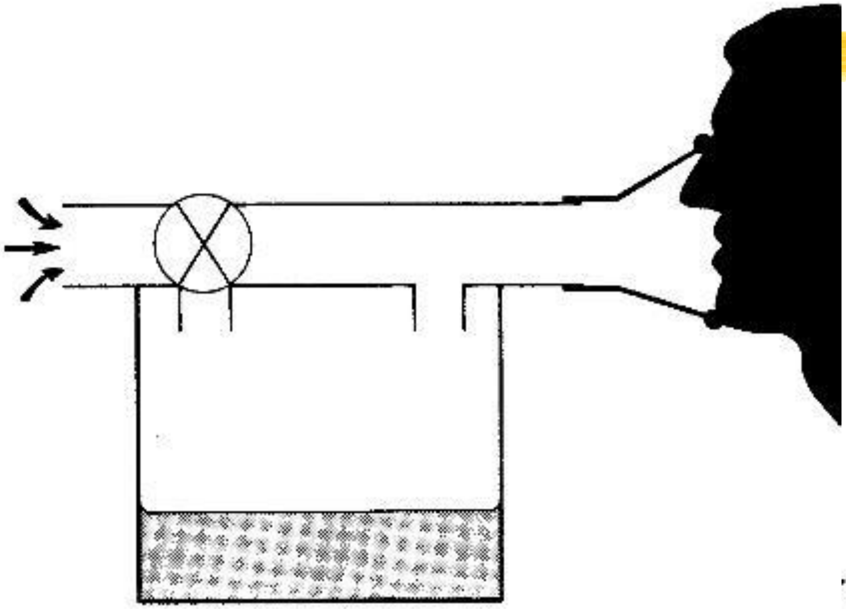


B. Resistance

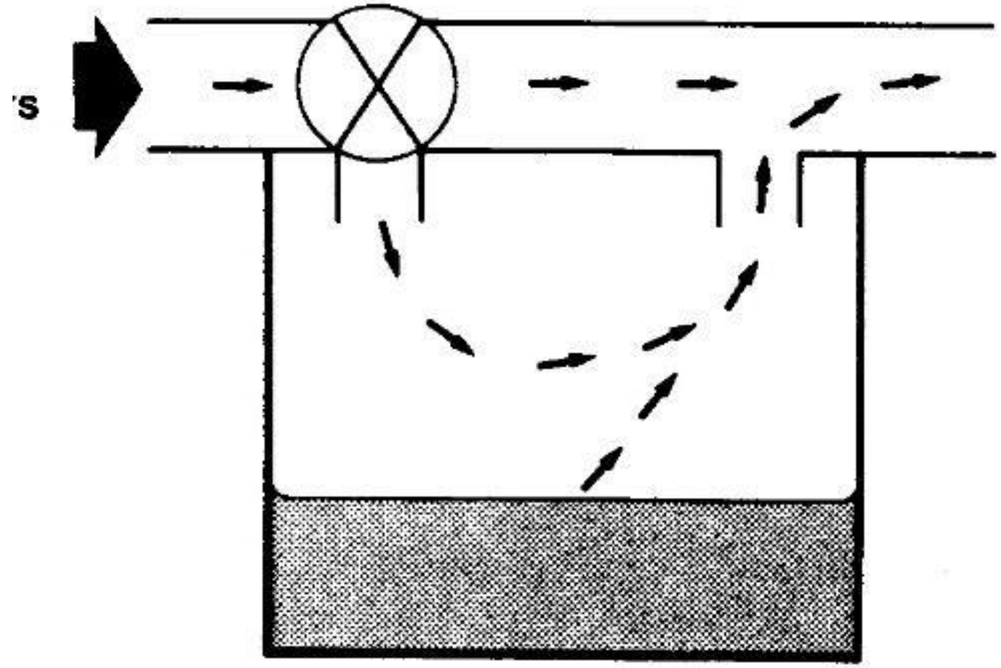
- 1. Draw-over vaporizers - a sub atmospheric pressure is developed downstream of the vaporizer (e.g. patients respiratory efforts), drawing the gas through

- 2. Plenum vaporizers - positive pressure developed upstream (by a flowmeter) so that the gas is pushed through the vaporizer

Draw over vaporiser

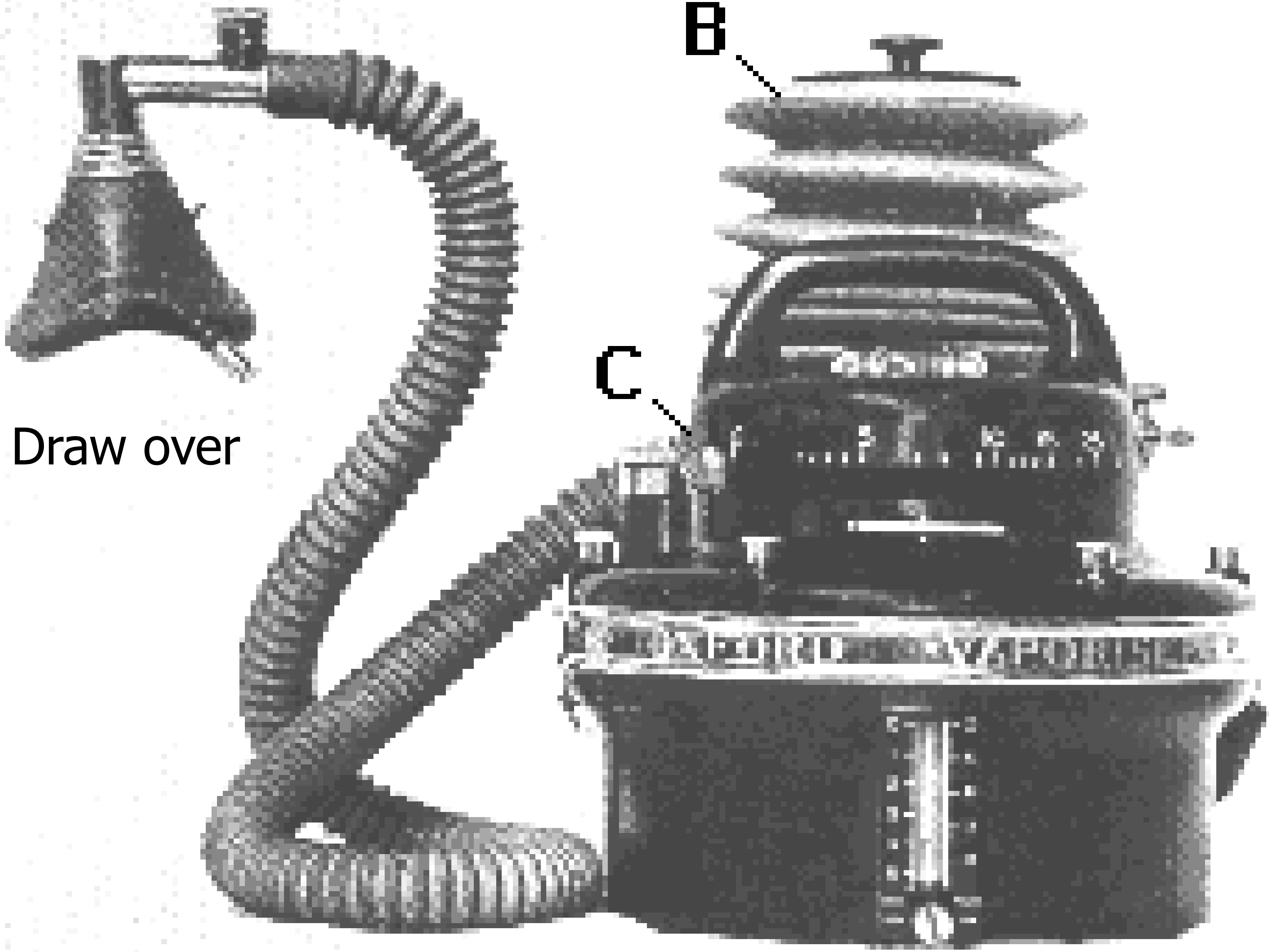


Plenum vaporizer

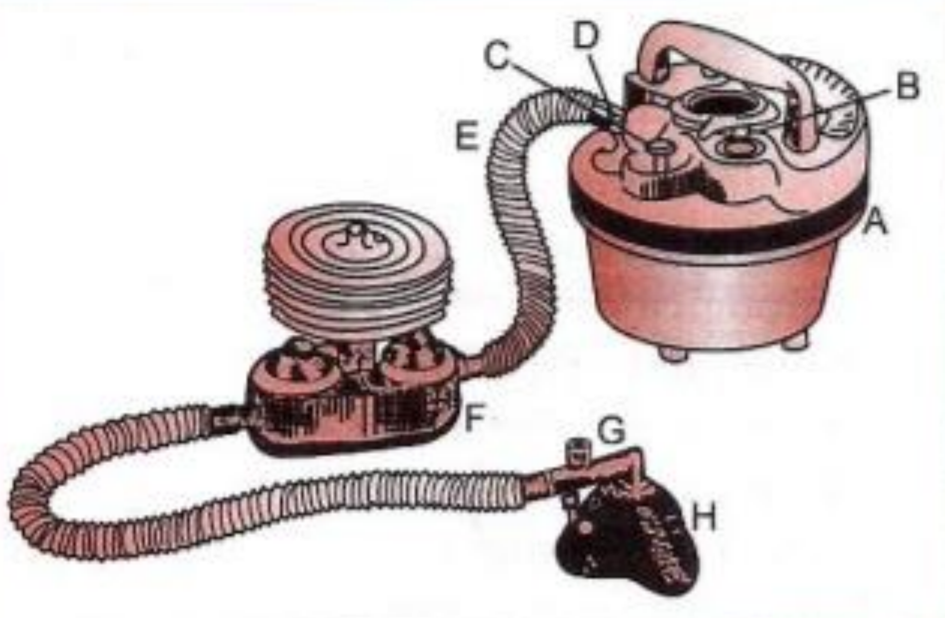


Draw over vaporisers

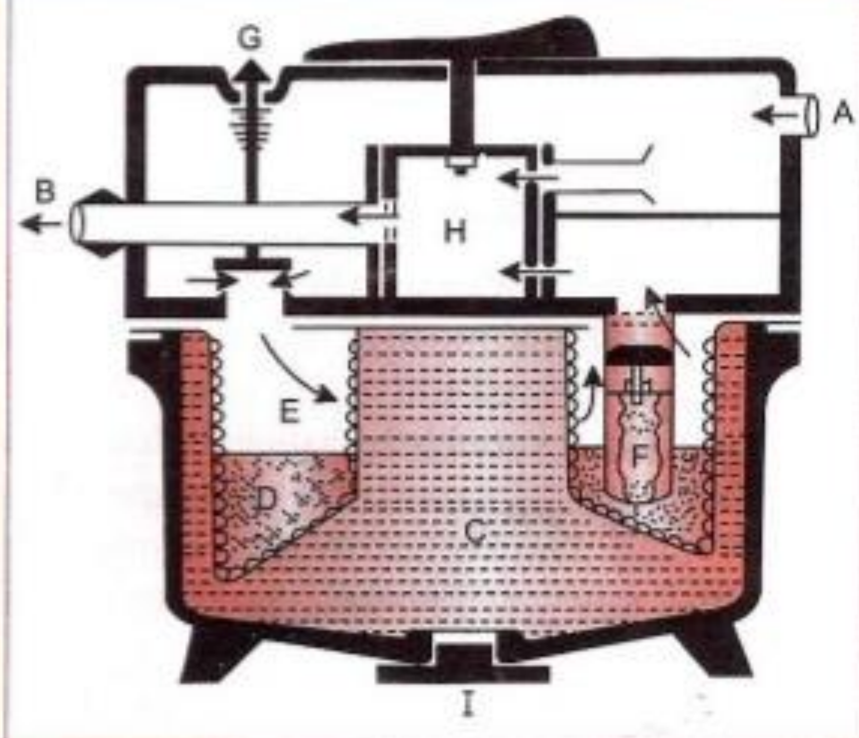
- Low resistance to flow
- Patient can „draw“ fresh gases over the volatile drug
- No pressurised gas needed
- Spontanous / mechanical ventilation
- Distant places
    - EMO (Epstein, Macintosh, Oxford)
    - Oxford miniature vaporiser


B
C
Draw over

EMO / OMV vaporisers



EMO inhaler with Oxford inflating bellows
A = Inlet, B = Temperature compensator indicator, C = Ether filler, D = Ether level indicator, E = Hose from outlet, F = Oxford inflating bellows, G = Expiratory valve, H = Face mask

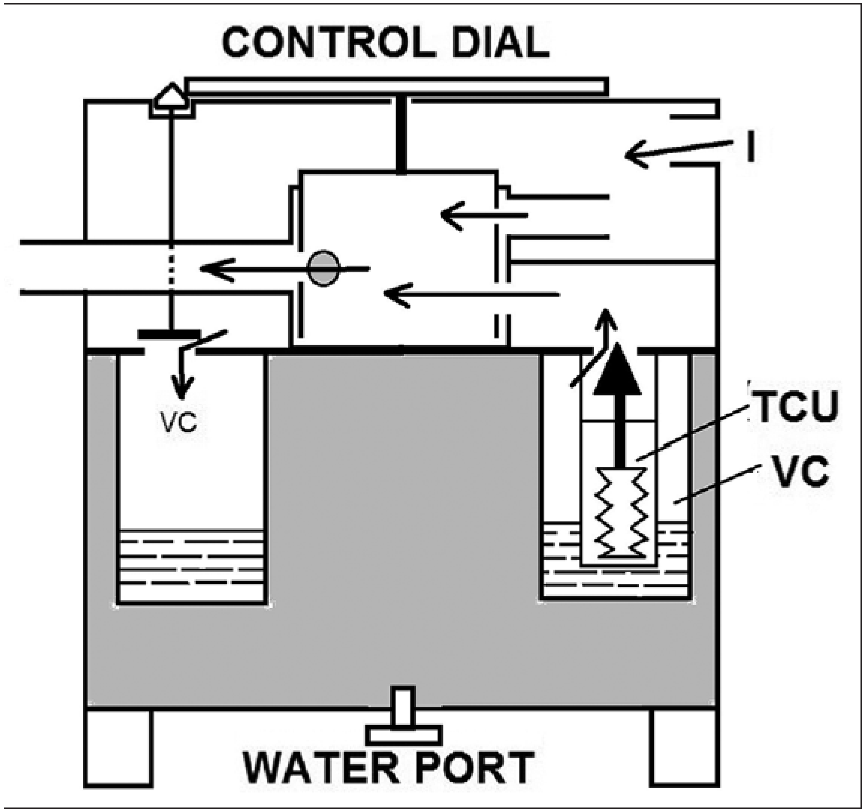


Schematic diagram of EMO inhaler
A = Inlet, B = Outlet, C = Water compartment, D = Ether, E = Vaporizing chamber, F = Thermo-compensating valve, G = Off/on valve, H = Mixing chamber, I = Water drain

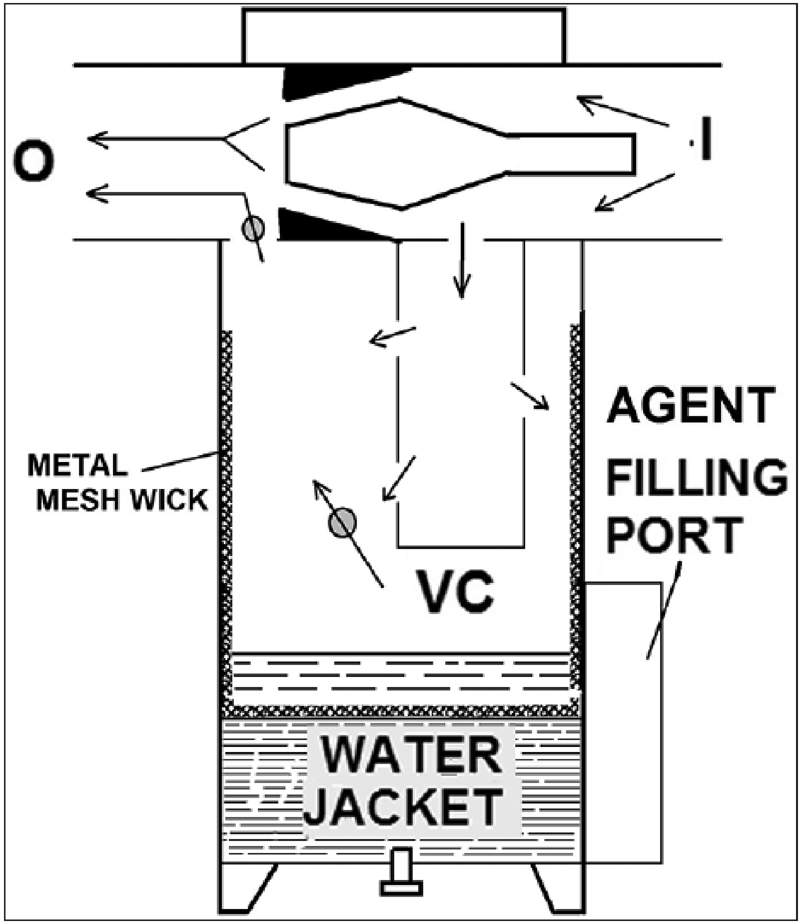
Draw over vaporisers

OMV

EMO



Epstein, Macintosh and Oxford



: Oxford miniature vapouriser

Table 1 Drawover anaesthesia

Advantages	Disadvantages
Simplicity of concept and assembly, with inherent safety	Decreasing familiarity with the technique and equipment
No need for pressurised gas supply, regulators and flow meters	Vaporiser limitations
Minimum FiO_2 is ~21%	* Filling systems not agent specific (potential advantage)
Robust, reliable, easily serviced equipment	* Basic temperature compensation, affecting performance at extremes
Low cost (purchase and maintenance)	Less easy to observe spontaneous ventilation with self inflating bag
Portable, suitable for field anaesthesia	Cumbersome in paediatric use, unless lightweight tubing is available

Flow over (plenum) vaporisers

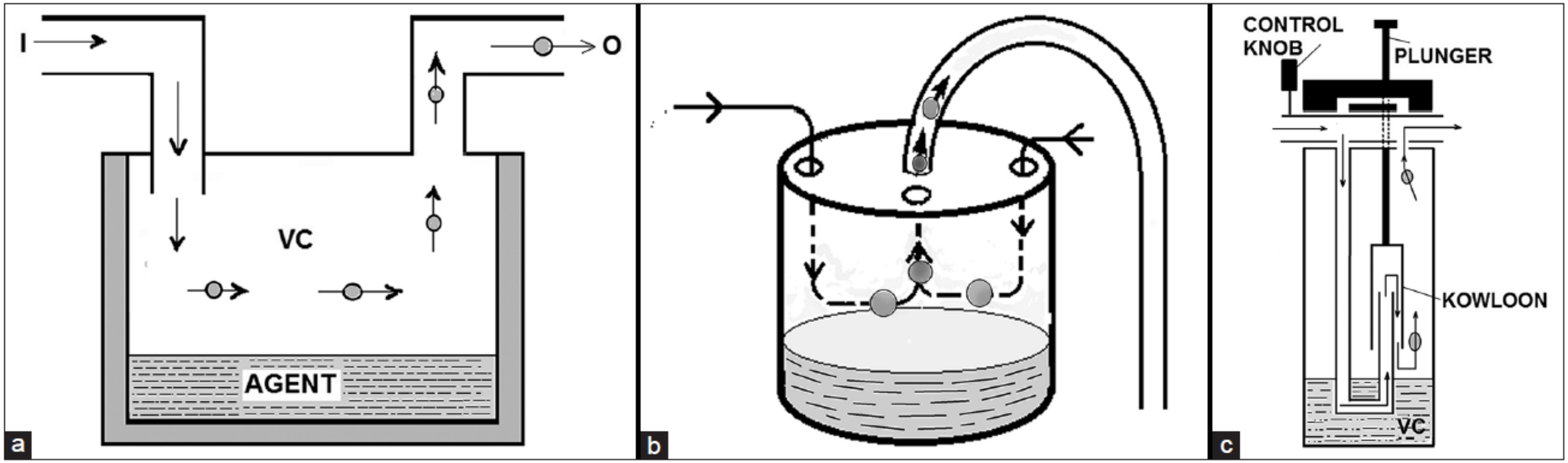


Figure 1: (a) Generic simple flow over vapouriser: I – Inlet port; O – Outlet port; vapourising chamber; Plain arrow shows fresh gas flow (FGF); Arrow with circle shows FGF carrying vapour; (b) Flagg can; (c) Boyle's bottle

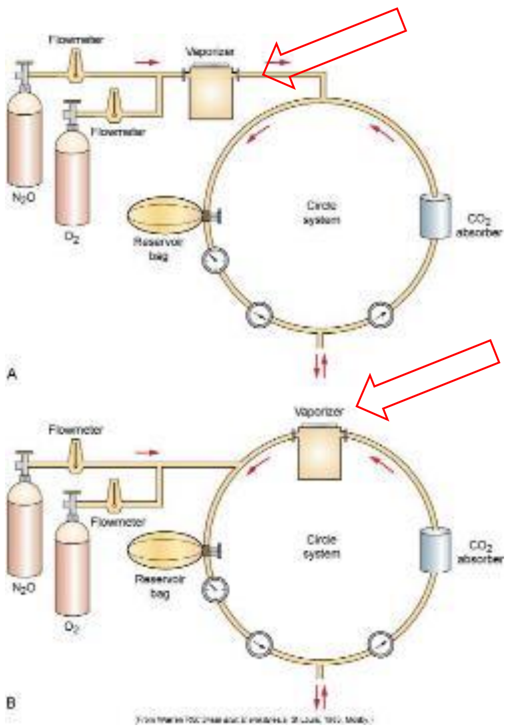
Early vapourisers

- Made general anaesthesia possible
- Problems with **effectiveness of evaporation** (SVP, concentration)
- Problem with **cooling** during vapourisation (decrease of SVP)
- **Variation** with pressure and flow

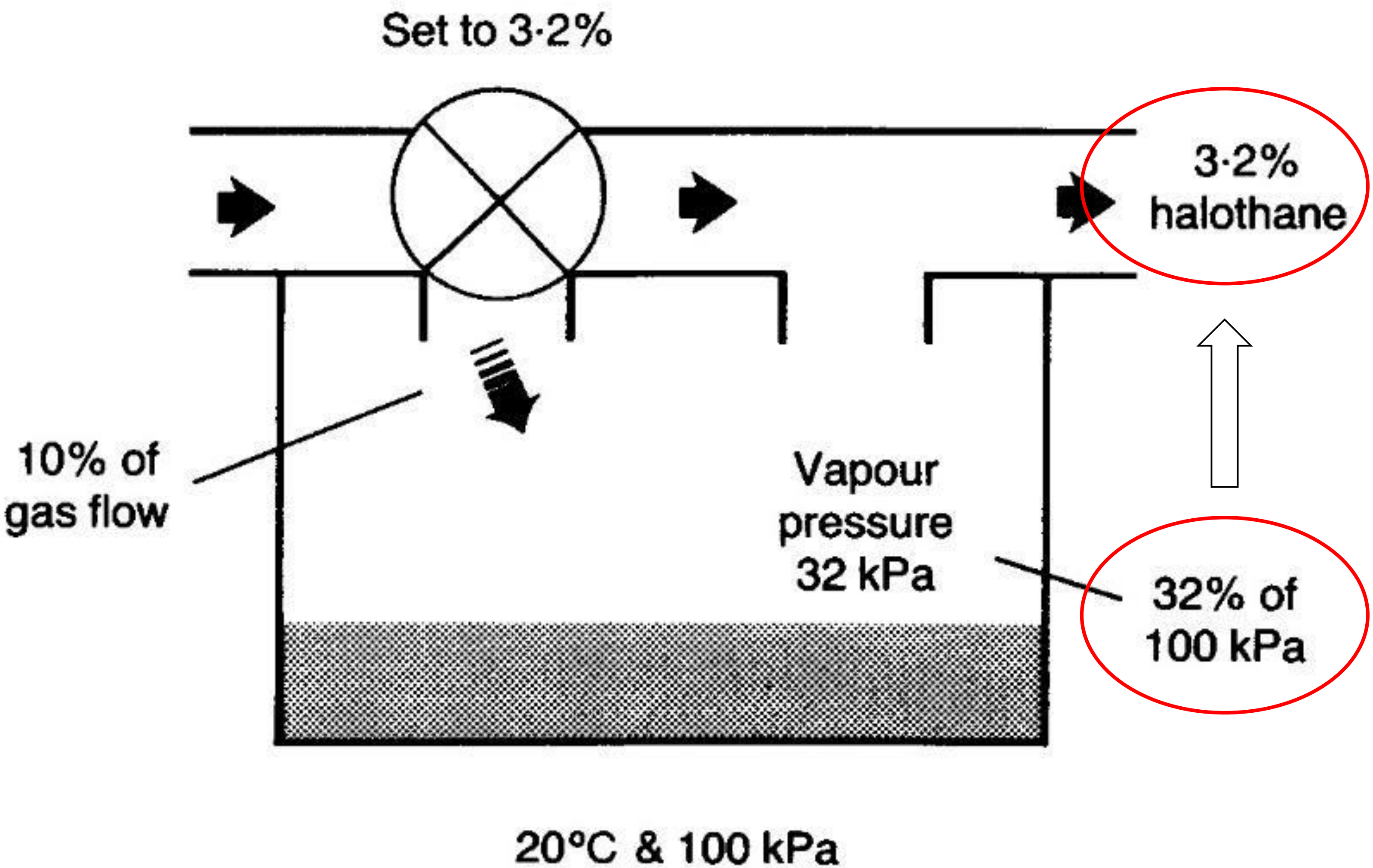
C. Location

1. In circuit – insp. or exp. arm, low resistence

2. Out of circuit – between rotameters and outlet



D. Regulation of concentration



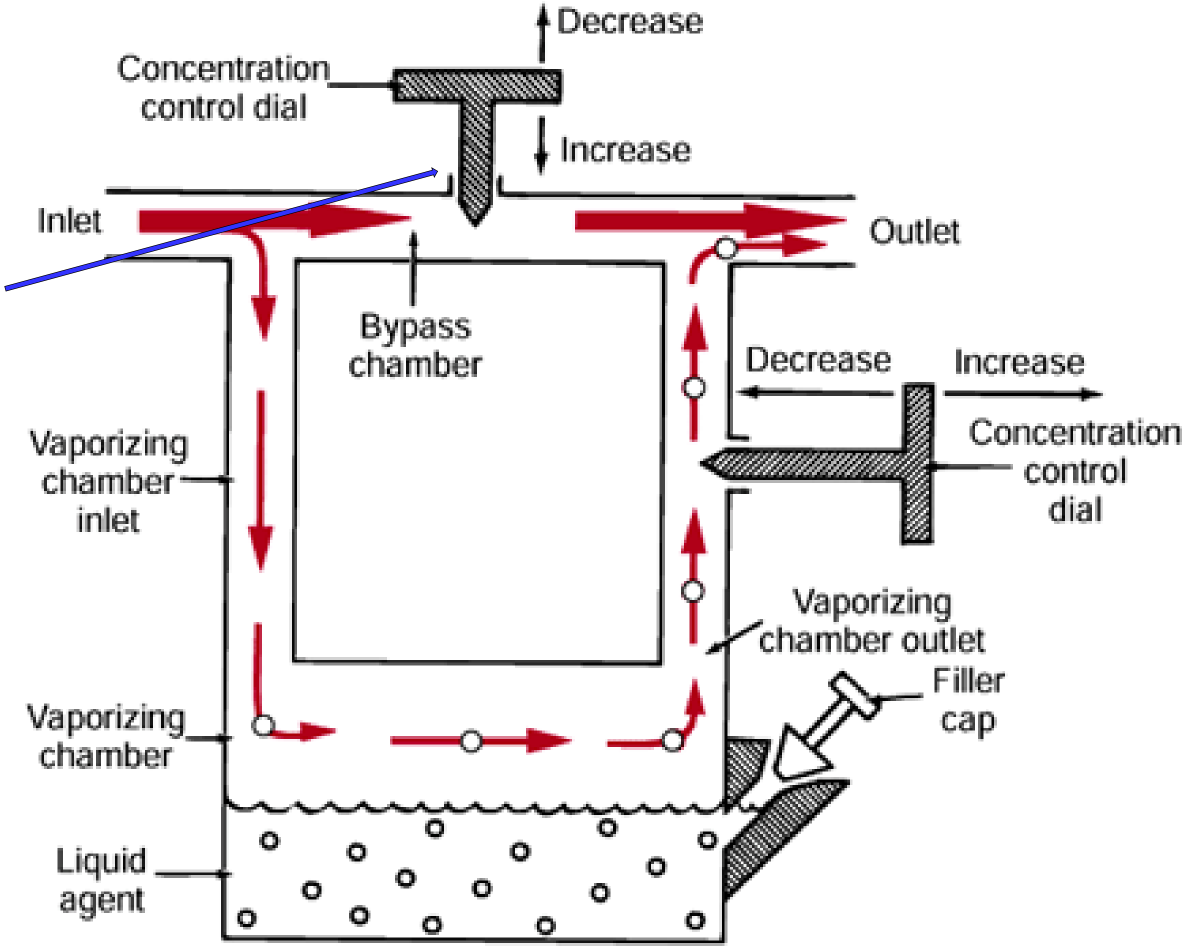
Vapor pressure of volatile agents at 20 °C (mmHg/kPa)

- Sevoflurane: 157 / 21
- Desflurane: 669 / 89
- Isoflurane: 238 / 31
- Enflurane: 172 / 23
- Halothane: 243 / 32
- N_2O: 38,8 / 5

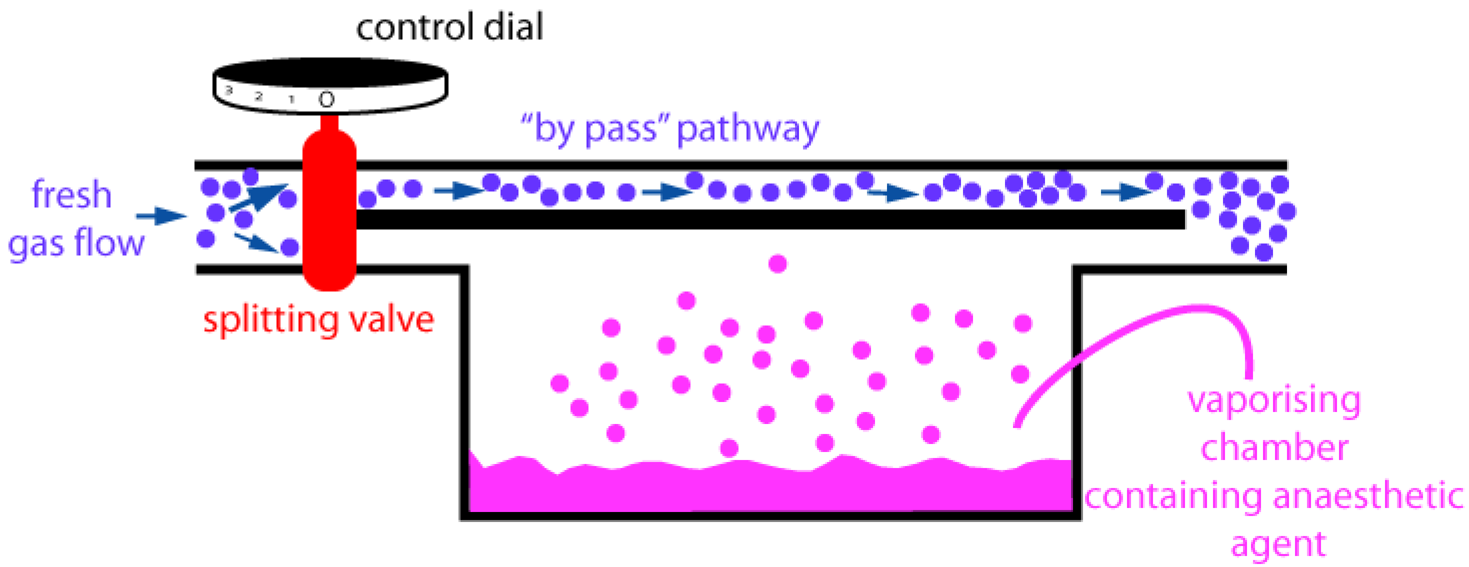
Vaporiser with variable bypass

(vapour splitting)

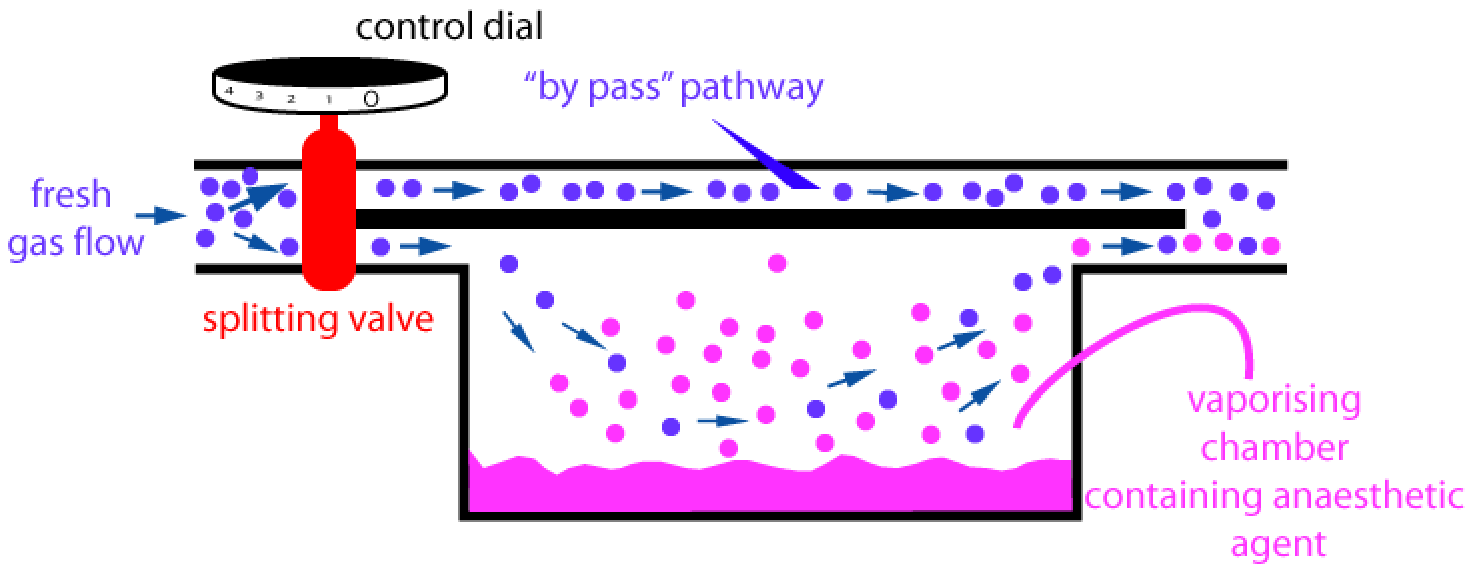
Splitting ratio



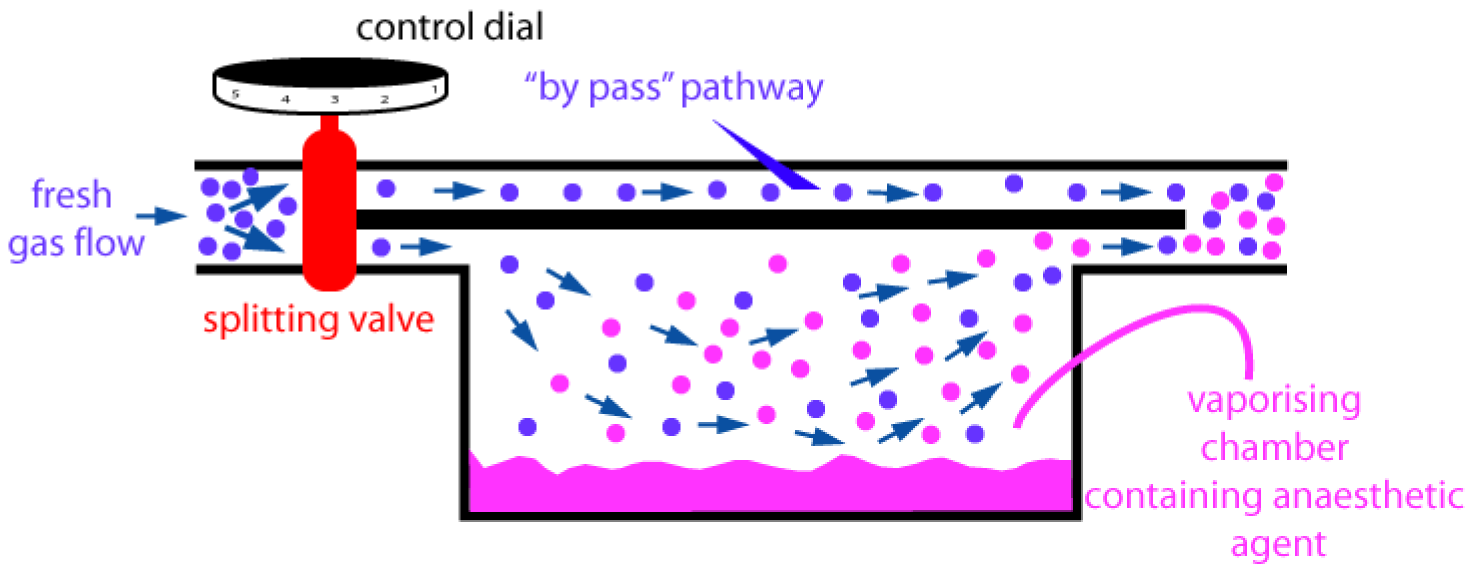
Variable bypass



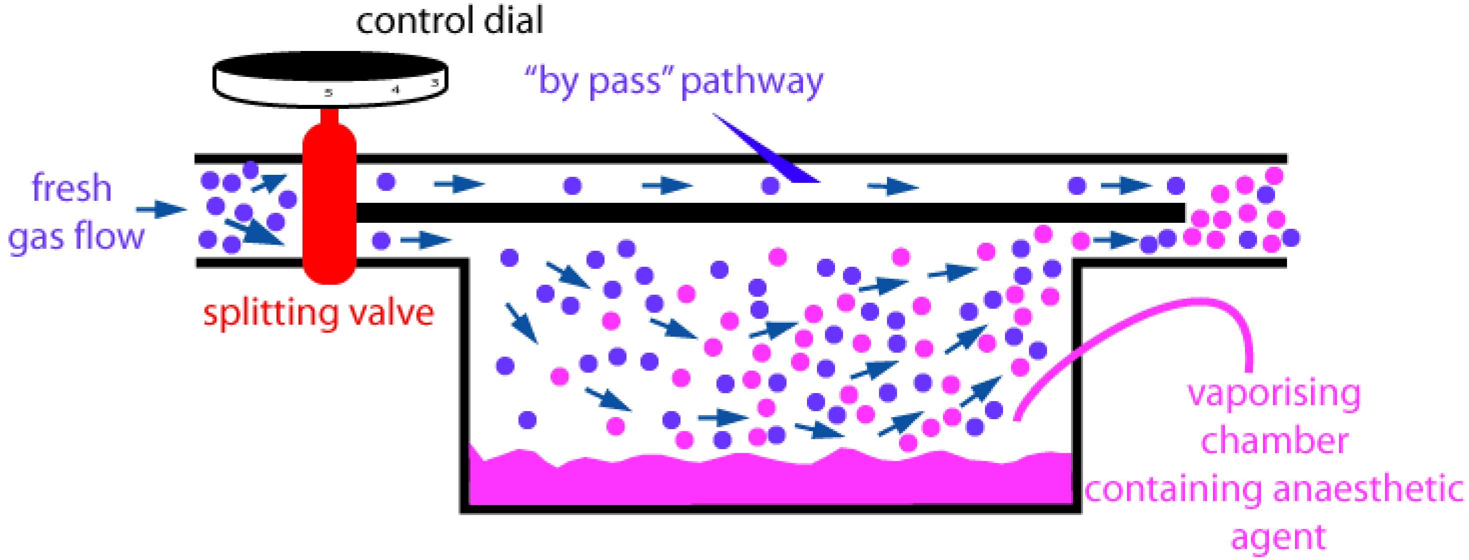
Variable bypass



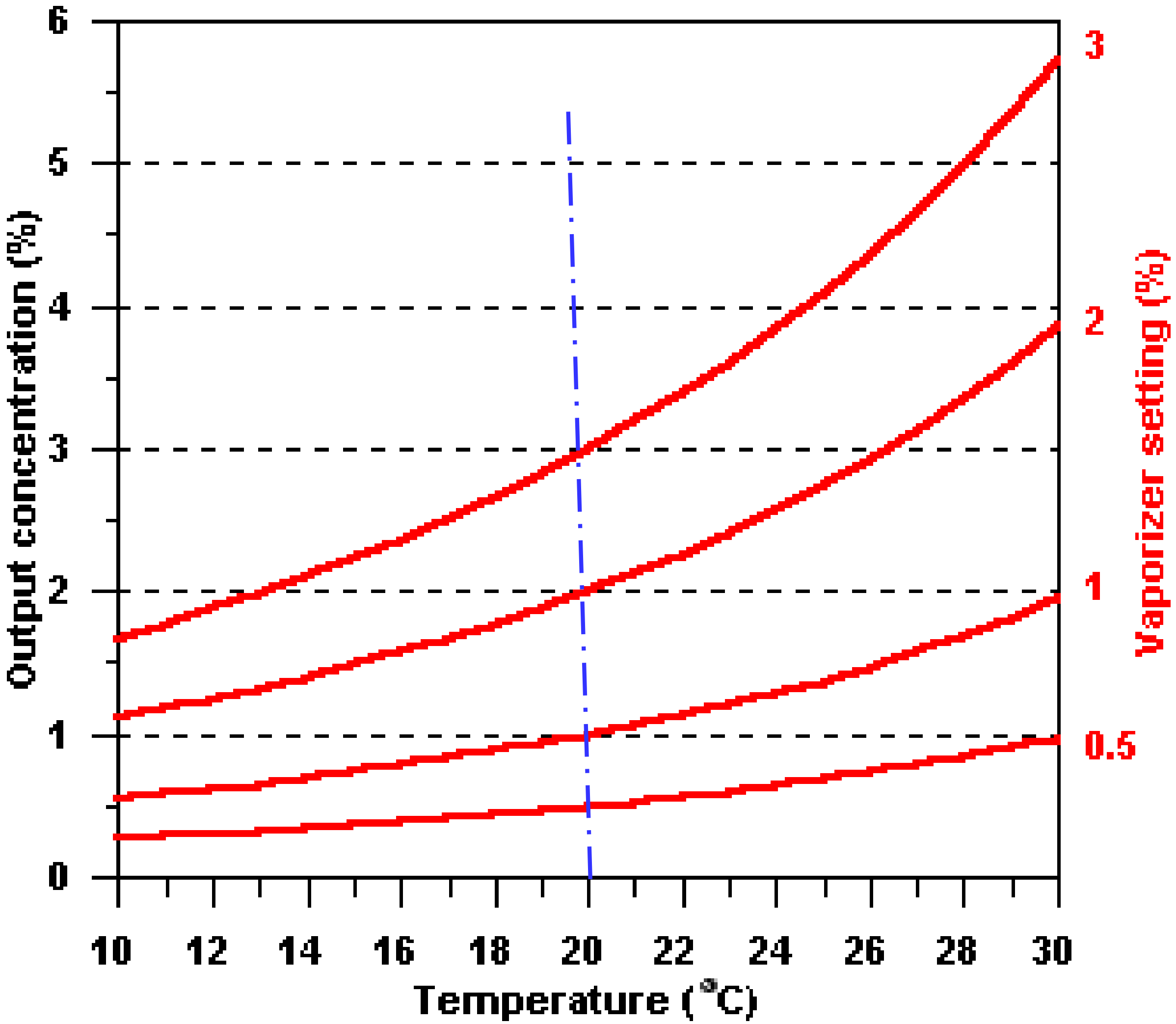
Variable bypass



Variable bypass

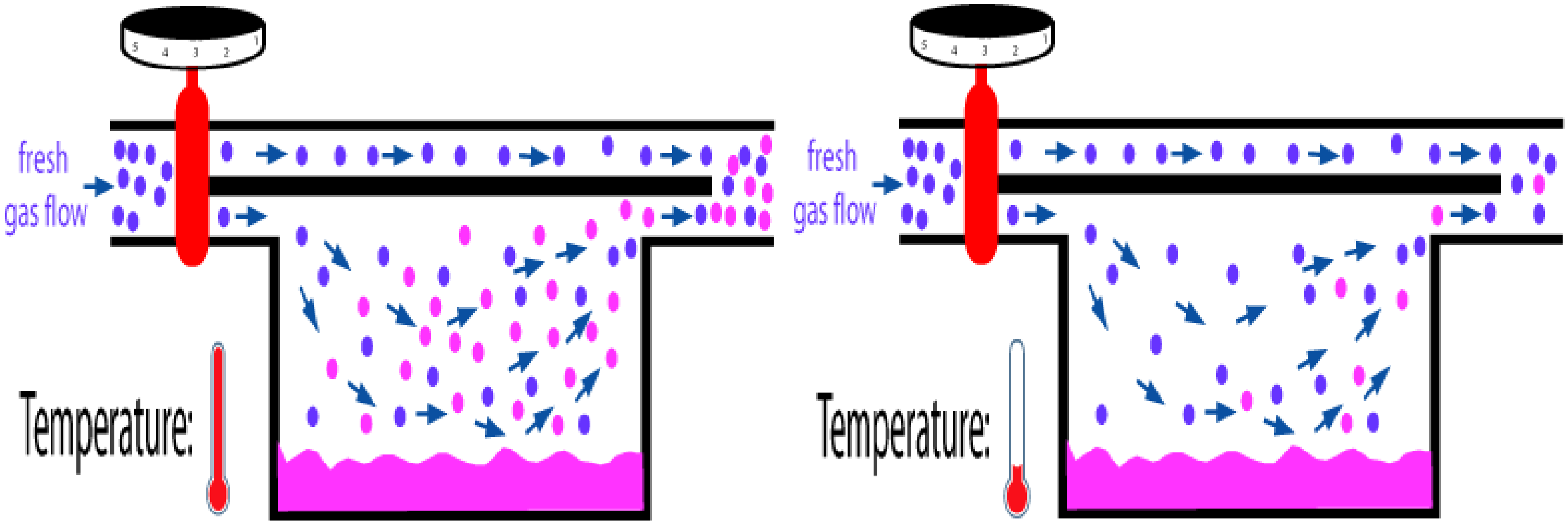


E. Temperature stability



Vaporizer setting at 20°C

According the stabilisation of temperature



Molecules consume energy to escape and become vapor

According the stabilisation of temperature

Temperature of anestetic liquid
- fluctuations in ambient temperature
- loss due to latent heat of vaporization

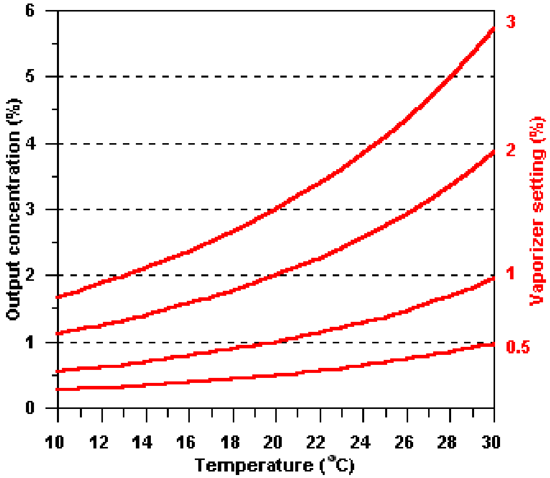
Solution

a) Temperature **stabilization**
- high heat capacity, thermal conductivity

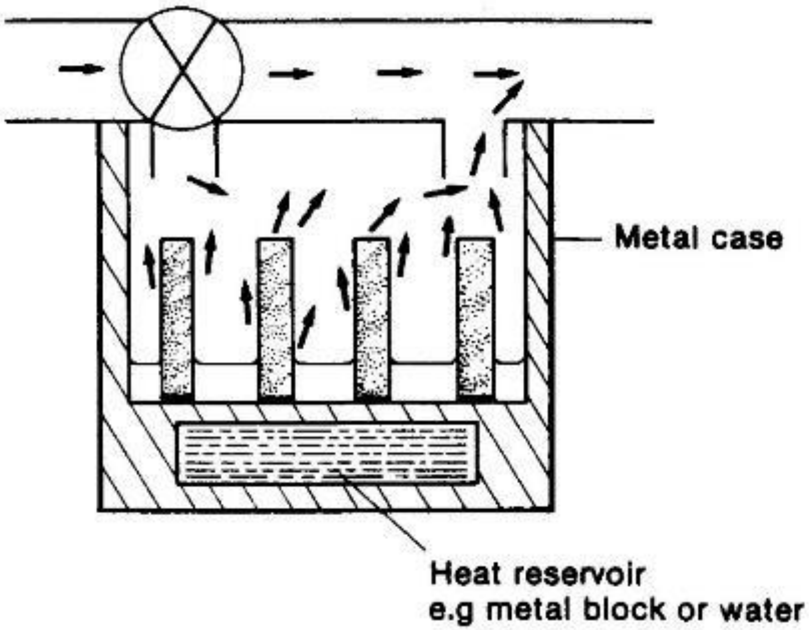
b) Temperature **compensation**

c) Correction

Corection to temperature

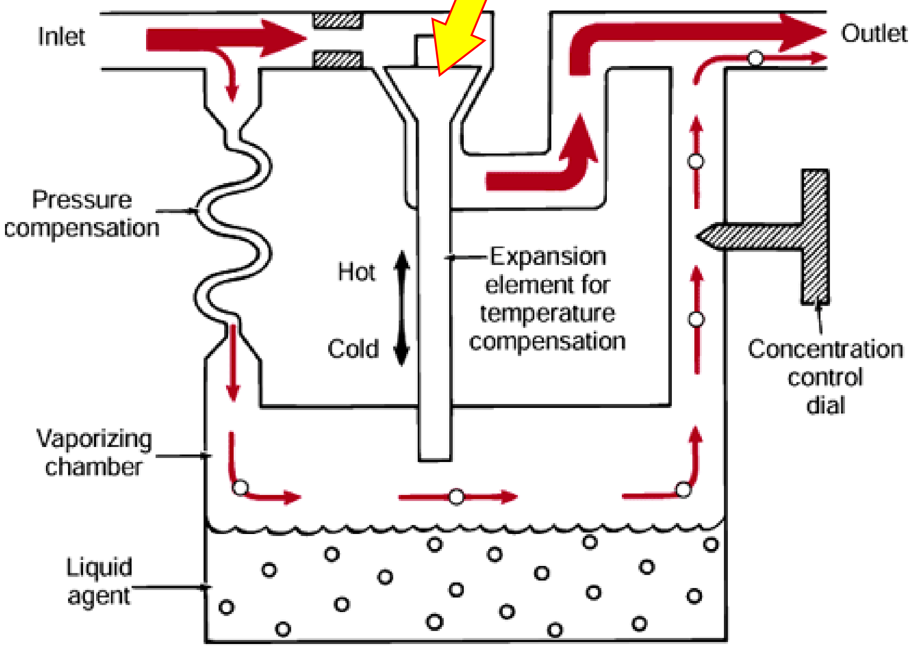


Temperature stabilisation / compensation (TCU)



Stabilizácia

TCU



F. According specificity

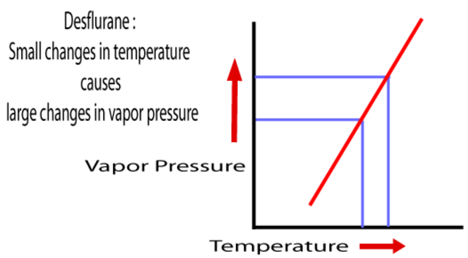
a) Universal for all agents (older types)
b) Agent specific (actual types)

Most of the current vaporisers are:

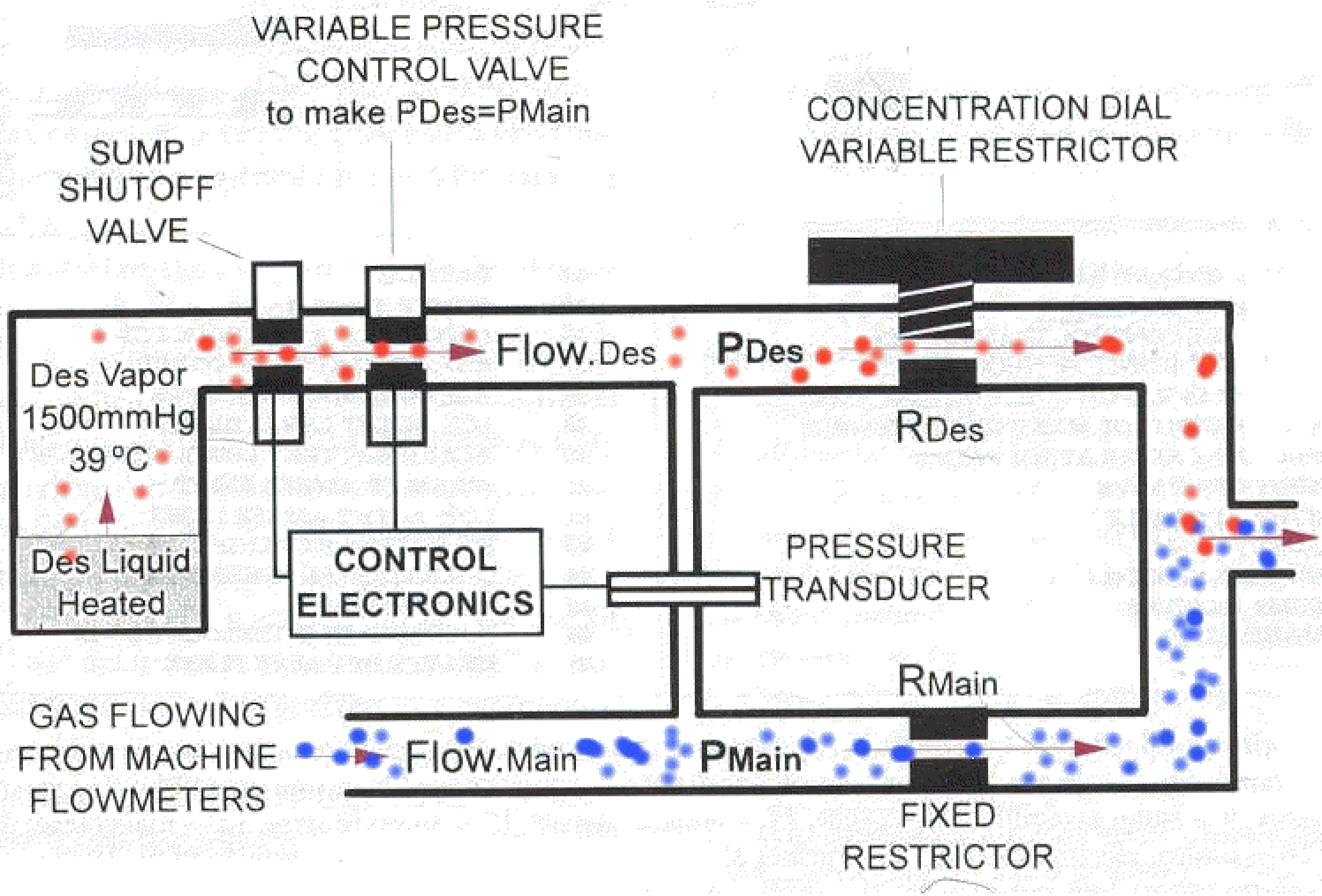
- flow-over/push-over
- variabile bypass
- temperature compensated
- agent-specific
- out of circuit

Desflurane chalenge

- Not suitable for variable bypass vaporiser
  - high SVP (88.5 kPa at 20 °C)
    - needs extreme bypass flow
  - low boiling point (23.5°C)
    - will boil, fluctuation of output



- Solution:
  1. Warming to 39 °C; SVP to stabile 194 kPa
  2. no bypass but DES injection to fresh gas flow
  3. Manual adjustment 0-12%; lock for 12-18%



VARIABLE PRESSURE
CONTROL VALVE
to make PDes=PMain
SUMP
SHUTOFF
VALVE
CONCENTRATION DIAL
VARIABLE RESTRICTOR
Des Vapor
1500mmHg
39 °C
Flow.Des
PDes
RDes
Des Liquid
Heated
CONTROL
ELECTRONICS
PRESSURE
TRANSDUCER
RMain
GAS FLOWING
FROM MACHINE
FLOWMETERS
Flow.Main
PMain
FIXED
RESTRICTOR

G. Modificatory factors for the output of vaporiser

1. Precision (+/- 0.2 vol%), many factors
2. Flow (extreme values)
3. Composition of the carrier gas (N_2O)
4. Temperature (stability 15-36° C)
5. Atmospheric pressure (inversely)
6. Intermitent back flow (pump effect)

Flow

- Higher flow – problem to achieve full saturation
- Maximalisation of surface area -
  wicks, baffles, cowls, nebulizers ...
- Modern vaporiser: stability in the range
  0,25-15 l/min

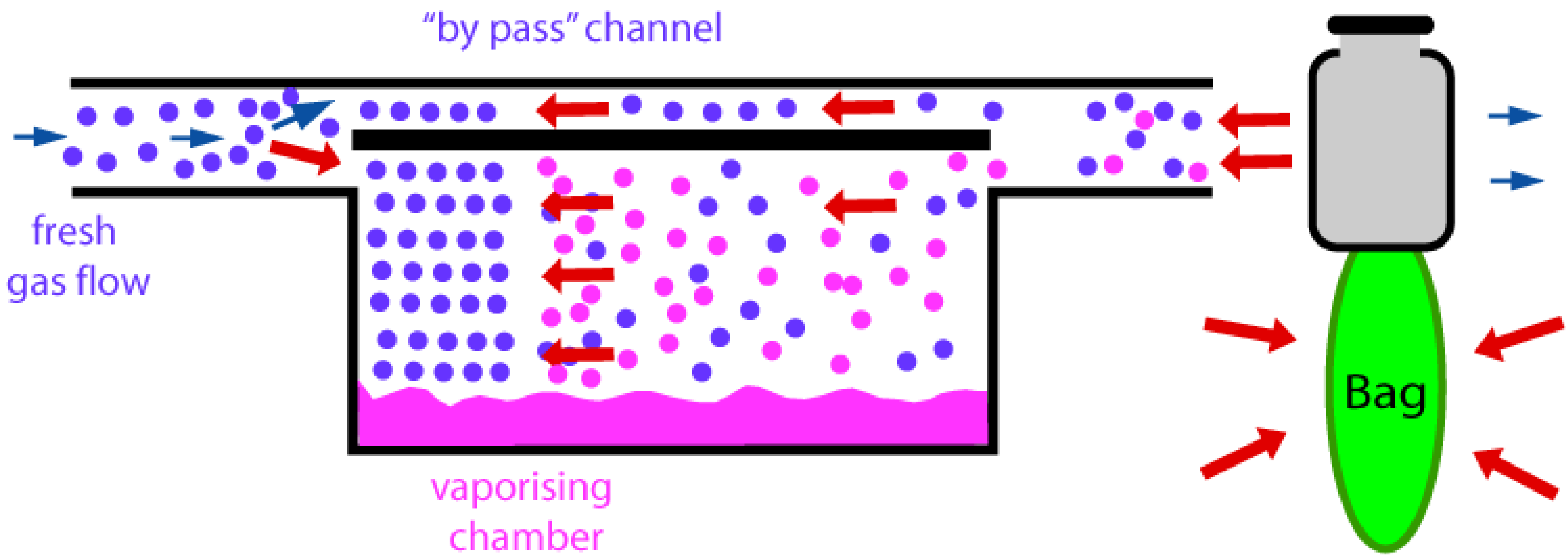
Carrier gas composition

- Viscosities of air, N_2O < oxygen
- Splitting valve – decreased flow to vaporizing chamber
- Clinicaly not significant
- The same for Desflurane vaporiser

Backpressure

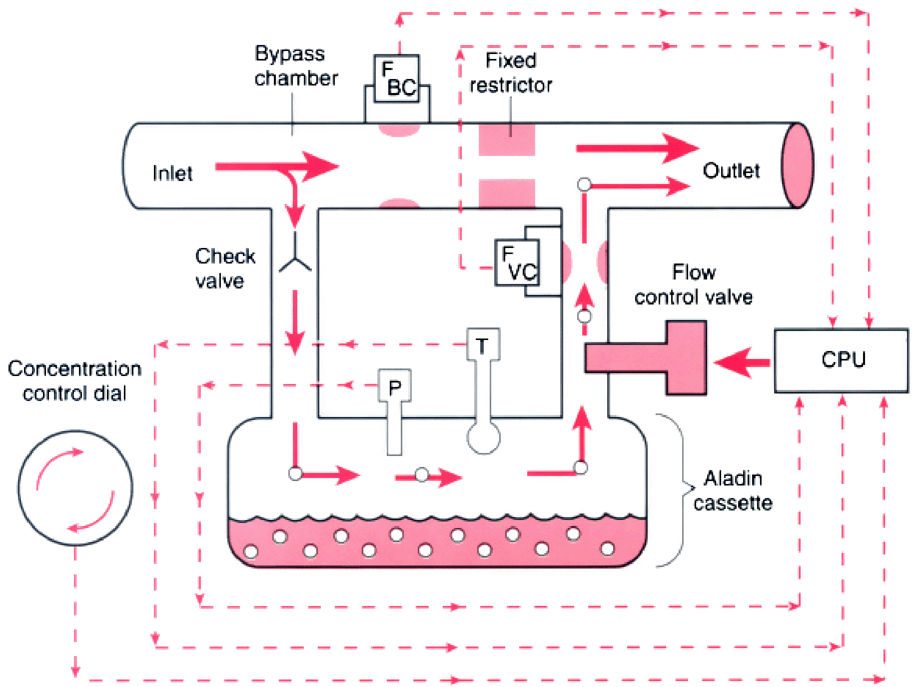
- Pumping effect
- Ventilator pressure transmitted retrograde to vaporiser
- Gas forced to vaporising chamber
  - resaturation of gas
  - saturated gas pressed into bypass channel
- Result: higher vapour concentration

Backpressure

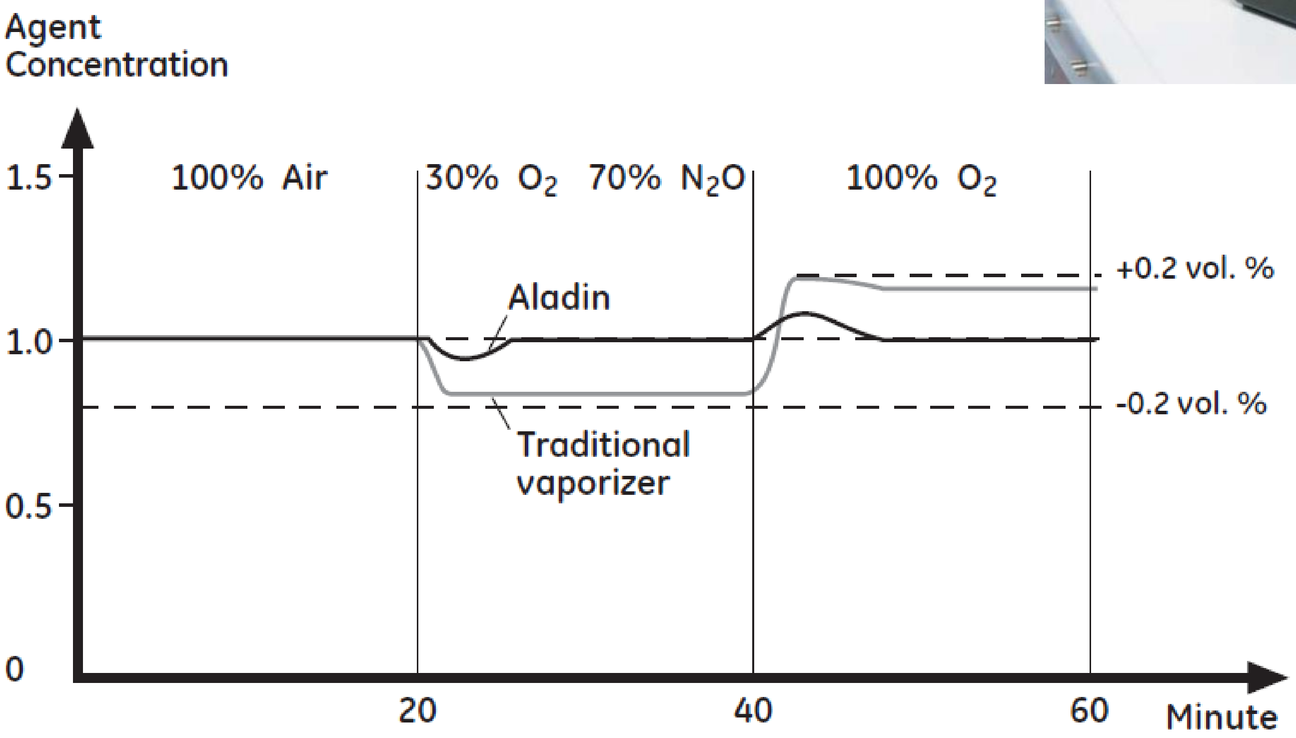


Aladin cassette vaporizer

- Datex Ohmeda, GE
- Agent specific vaporising chamber casette
- Central processing unit (in anest. machine)



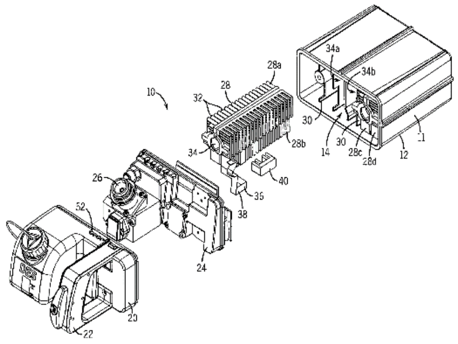
Aladin casette



* Unlike conventional vaporizers, the Aladin Cassette is able to take into account the fresh gas flow concentrations due to the S/5 ADU's integrated electronic fresh gas flow measurement.

Advantages

- Variable bypass + measured flow
- Control valve with adjustment to flow
- Measurement of
  - bypass flow
  - liquid temperature
  - chamber pressure
- Syntetic lamellae with metal plates (wick)
- Temperature stabilization (metal plates, fan)
- Carrier gas identification
- No backpressure problem

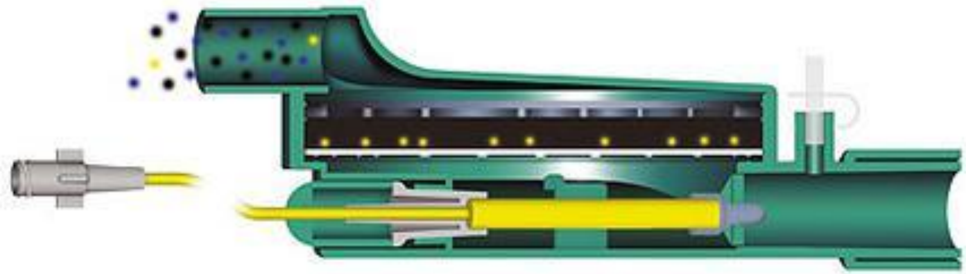


Carestation

Anaconda – vaporiser for sedation

Expiration

Air/oxygen and CO_2 passes the active carbon out into the ventilator circuit and out through the ventilator exhaust. The anaesthetic agent is adsorbed to the active carbon.



Inspiration

During inspiration the anaesthetic agent is desorbed and transported with the air/oxygen to the patient, together with agent evaporated from the evaporator.

- Air/oxygen
- Anaesthetic agent

Safety first; concerns

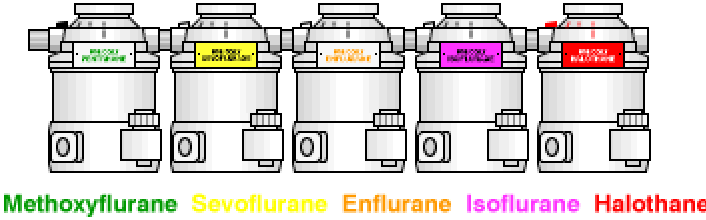
- Incorrect agent
- More than one vaporizer being used
- Reversal insertion of vaporizer
- Tilting and overfilling of vaporizer
- Leakage
- Electronic failure

Safety first; measures

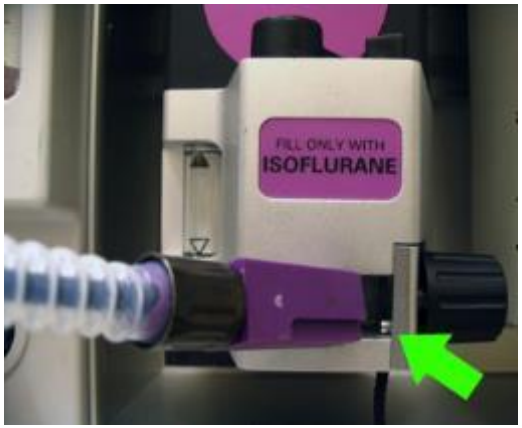
1. ISO/DP 5350 Norm for colour coding
2. Geometric coded filling devices
3. Interlock system to prevent more than one vaporizer being used (accidental overdose)
4. Carefull manipulation
5. Checklist for anaesthesia equipment (HD)

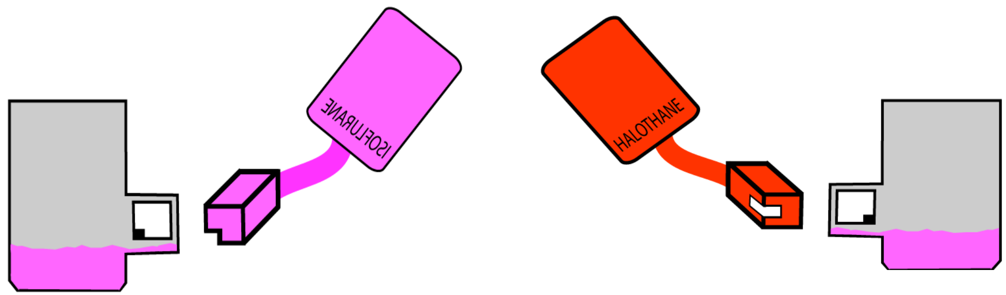
Colour coded filling devices

Anestetic	Colour
Halotane	red
Isoflurane	purpur
Enflurane	orange
Sevoflurane	yellow
Desflurane	blue

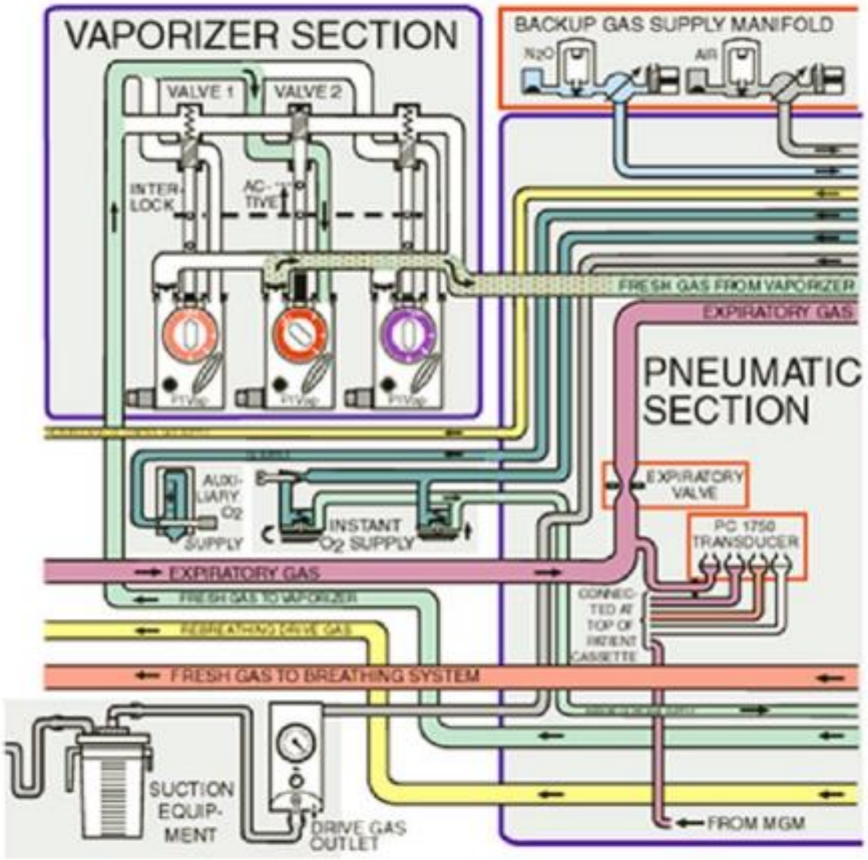


Funnel / keyed filler types





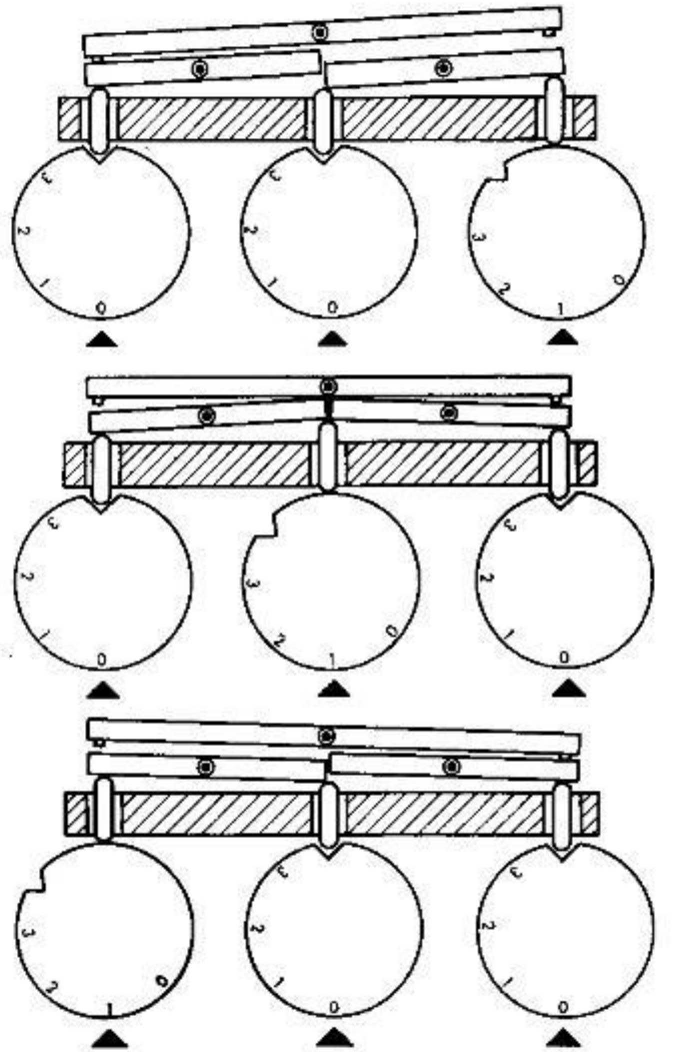
More agents?

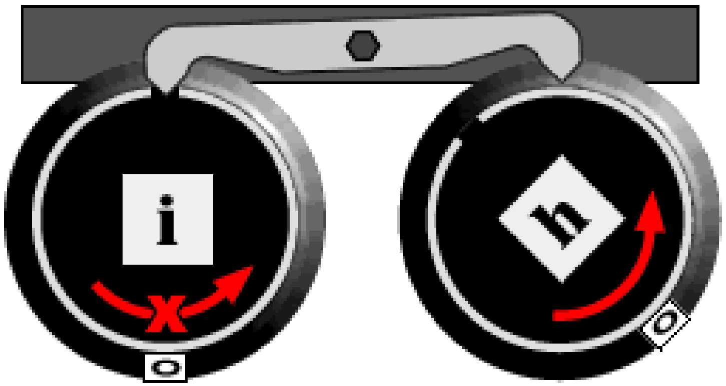

VAPORIZER SECTION
BACKUP GAS SUPPLY MANIFOLD
AIR
VALVE 1
VALVE 2
INTER-LOCK
FRESH GAS FROM VAPORIZER
EXPIRATORY GAS
PNEUMATIC SECTION
AUXI-LIARY O_2 SUPPLY
INSTANT O_2 SUPPLY
EXPIRATORY VALVE
PC 1750 TRANSDUCER
EXPIRATORY GAS
FRESH GAS TO VAPORIZER
REBREATHING DRIVE GAS
FRESH GAS TO BREATHING SYSTEM
SUCTION EQUIP-MENT
DRIVE GAS OUTLET
FROM MGM

The vaporizer interlock ensures that

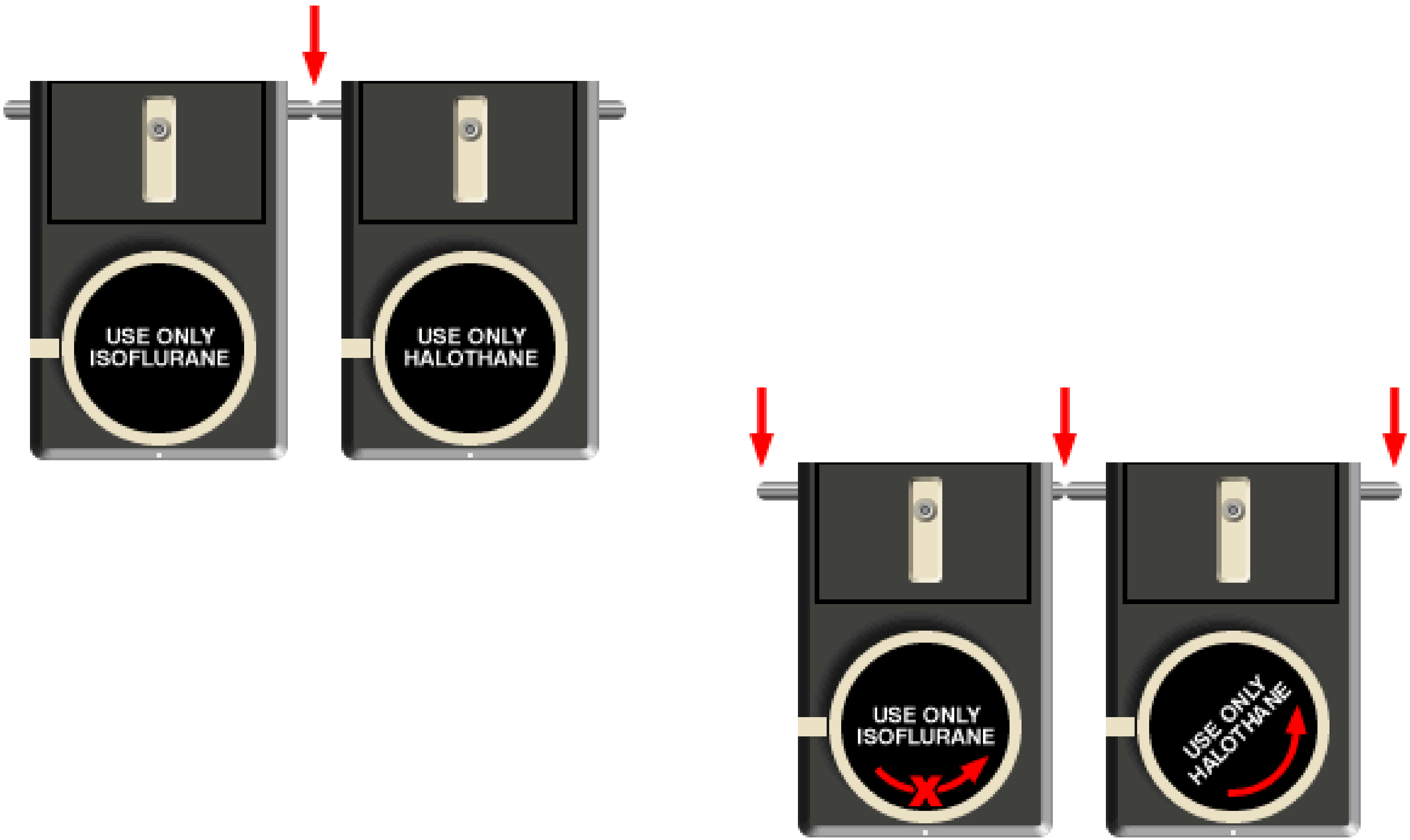
- Only one vaporizer is turned on
- Gas enters only the one which is on
- Trace vapor output is minimized when the vaporizer is off
- Vaporizers are locked into the gas circuit, thus ensuring they are seated correctly.

Interlock NAD





Interlock S


USE ONLY ISOFLURANE
USE ONLY HALOTHANE
USE ONLY ISOFLURANE
USE ONLY HALOTHANE

Maintenance

Every Two Weeks:

The vaporizer should be drained into an appropriately marked container when the agent level is low and the agent discarded. Less frequent intervals may be used when the anesthetic agent does not contain additives or stabilizing agents.

Annually:

The vaporizer should be serviced at an authorized service center. This service should include:

1) Complete *disassembly* of components.

2) *Inspection* of all parts for damage and wear.

3) Thorough *cleaning* of all metal parts.

4) *Replacement* of wicks, seals and damaged, worn or outdated items.

5) *Lubrication* where necessary.

6) Re-assembly of vaporizer and *testing* for and correction of any *leaks*.

7) Verification of the *delivered* vapor *concentrations* at different temperatures. Any re-graduation or *adjustment* where necessary.

8) Maintaining continuous service record.

Checklist for Anaesthetic Equipment 2012

AAGBI Safety Guideline

Checks at the start of every operating session
Do not use this equipment unless you have been trained

Check self-inflating bag available

Perform manufacturer's (automatic) machine check

Power supply	• Plugged in • Switched on • Back-up battery charged
Gas supplies and suction	• Gas and vacuum pipelines – 'tug test' • Cylinders filled and turned off • Flowmeters working (if applicable) • Hypoxic guard working
Breathing system	• Whole system patent and leak free using 'two-bag' test • Vaporisers – fitted correctly, filled, leak free, plugged in (if necessary) • Soda lime - colour checked • Alternative systems (Bain, T-piece) – checked • Correct gas outlet selected
Monitors	• Working and configured correctly • Alarms limits and volumes set
Airway equipment	• Full range required, working, with spares

RECORD THIS CHECK IN THE PATIENT RECORD

Don't Forget!	• Self-inflating bag • Common gas outlet • Difficult airway equipment • Resuscitation equipment • TIVA and/or other infusion equipment

This guideline is not a standard of medical care. The ultimate judgement with regard to a particular clinical procedure or treatment plan must be made by the clinician in the light of the clinical data presented and the diagnostic and treatment options available.

Zásady bezpečnosti

1. Používajte správny – zamýšľaný, odparovač!
2. Naplňte správnou látkou!
3. Nenakláňajte!
4. Kontrolujte hladinu v komore!
5. Používajte INTERLOCK systém!
6. Používajte analyzátor plynov zvlášť pri LOW / MINIMAL flow anestézii!

1. Každý deň ontrolný protokol pre anestéziu!
2. Pravidelná údržba!

Odvod plynov - scavening

Summary - vaporiser

- Anaesthesiolost has to be familiar with principles and instructions for use
- Modern vaporisers are agent specific, plenum, with variable bypass, temperature compensated.
- New generation: meeting all potential problems
- Draw over: low resistance, in circuit, less efficient; but robust, portable, suitable for „field anaesthesia“.

Future

- New inhalation agents?
- Low flow
- Closed circuit, no flow
- Computer assisted
- Anaesthesia machine integrated
- Patient adapted, feedback
- Closed loop

Thank you

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