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
Boston, 16.X.1846

Ether
Draw-over
No control

W.T.G. Morton
REMARKS
ON THE
PROPER MODE OF ADMINISTERING
SULPHURIC ETHER
BY INHALATION.

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 ADMIN-
ISTRATION OF SULPHURIC ETHER
IS GRATEFULLY APPRECIATED,
BY THEIR
OBT. SERVT.
WM. T. G. MORTON.

BOSTON:
DUTTON AND WENTWORTH, PHI.
1847.
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.
Ether, chloroform
Draw over
Some control
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 molecules 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: $P_{\text{vapour}} = P_{\text{atm}}$
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

The isotherm at 40°C is above the critical temperature of nitrous oxide (36.5°C) and therefore 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 vapor pressure of nitrous oxide). Further reduction in volume causes more vapor to condense with no change in pressure. When all the vapor is condensed to liquid a rapid rise in pressure is seen with further decrease in volume.
Critical temperature

Above critical temperature

Below critical temperature

GAS

VAPOR
Oxygen and nitrous oxide

Oxygen: Tc -119°C

N₂O: Tc 36.5°C

At 22°C and 15 MPa: gas

At 22°C and 5 MPa: liquid + gas

[Diagram showing the levels of gas pressure and color changes for different tank levels.]
3. Latent heat of evaporation

- Molecules leaving liquid
- Average energy falls, \textit{liquid cools}
- Heat energy required to evaporate the liquid
4. Boiling point

- Higher temperature $\approx$ quicker evaporation
- Boiling point: the pressure of vapour = atmospheric pressure
- **Inside** evaporation; bubbles of saturated vapour
- The closer the liquid to BP, the quicker turn to vapour
  - Ether BP: 35°C
  - Water BP: 100°C
Boiling point

![Graph showing vapor pressure vs. temperature for different substances]

- **Diethyl ether**: Boiling point at 34.6°C
- **Ethyl alcohol (ethanol)**: Boiling point at 78.3°C
- **Water**: Boiling point at 100°C
- **Ethylene glycol**: Boiling point at 200°C

The graph illustrates the relationship between vapor pressure (in torr) and temperature (in °C) for these substances.
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 independent of pressure!
- Pressure of that vapor is called the saturated vapor pressure.
- Boiling point: temperature at which SVP = P$_{\text{atm}}$
Table 1 - The saturated vapour pressures of some common volatile anaesthetics at 20°C

<table>
<thead>
<tr>
<th>Anaesthetic</th>
<th>SVP at 20°C (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ether</td>
<td>59</td>
</tr>
<tr>
<td>Halothane</td>
<td>32</td>
</tr>
<tr>
<td>Enflurane</td>
<td>23</td>
</tr>
<tr>
<td>Desflurane</td>
<td>88.5</td>
</tr>
<tr>
<td>Isoflurane</td>
<td>33</td>
</tr>
<tr>
<td>Sevoflurane</td>
<td>21</td>
</tr>
</tbody>
</table>

![Graph showing the relationship between temperature and saturated vapour pressure for different anaesthetics.](image-url)
SVP and anaesthesia

- To generate known concentration of inhalation agent (vapour)
- Dalton law (partial pressures)
  \[ P_1 + P_2 + P_3 \ldots = P_{\text{total}} \]
- \( P_{\text{part}} \) is proportional to the volume occupied by vapour in the mixture
- Concentration of agent: saturated vapour of liquid \( \approx \) volume\% \( \approx \) concentration
- E.g. Sevoflurane SVP at 20°C = 21 %
Concentration of anaesthetic vapour in gas

\[
\text{Gas concentration} = \frac{\text{Vapour pressure}}{\text{Ambient pressure}}
\]

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 independent
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 - challenge
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
- Spontaneous / mechanical ventilation
- Distant places
  - EMO (Epstein, Macintosh, Oxford)
  - Oxford miniature vaporiser
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

EMO

CONTROL DIAL

TCU

VC

WATER PORT

OMV

AGENT FILLING PORT

METAL MESH WICK

VC

WATER JACKET

Epstein, Macintosh and Oxford

: Oxford miniature vapouriser
<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simplicity of concept and assembly, with inherent safety</td>
<td>Decreasing familiarity with the technique and equipment</td>
</tr>
<tr>
<td>No need for pressurised gas supply, regulators and flow meters</td>
<td>Vaporiser limitations</td>
</tr>
<tr>
<td>Minimum $\text{FiO}_2$ is $\sim 21%$</td>
<td>* Filling systems not agent specific (potential advantage)</td>
</tr>
<tr>
<td>Robust, reliable, easily serviced equipment</td>
<td>* Basic temperature compensation, affecting performance at extremes</td>
</tr>
<tr>
<td>Low cost (purchase and maintenance)</td>
<td>Less easy to observe spontaneous ventilation with self inflating bag</td>
</tr>
<tr>
<td>Portable, suitable for field anaesthesia</td>
<td>Cumbersome in paediatric use, unless lightweight tubing is available</td>
</tr>
</tbody>
</table>
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 resistance

2. Out of circuit – between rotameters and outlet
D. Regulation of concentration

Set to 3.2%

10% of gas flow

Vapour pressure 32 kPa

32% of 100 kPa

20°C & 100 kPa
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
- N₂O: 38.8 / 5
Vaporiser with variable bypass
(vapour splitting)
Variable bypass
Variable bypass
Variable bypass
Variable bypass
E. Temperature stability

Vaporizer setting at 20°C
According to 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

Molecules consume energy to escape and become vapor
According the stabilisation of temperature

Temperature of anesthetic 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
Correction to temperature

![Image of a vaporizer with temperature scale and concentration output graph]
Temperature stabilisation / compensation (TCU)

Stabilizácia
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 challenge

- 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 stable 194 kPa
  2. no bypass but DES injection to fresh gas flow
  3. Manual adjustment 0-12%; lock for 12-18%
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 (N₂O)
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\textsubscript{2}O < oxygen
- Splitting valve – decreased flow to vaporizing chamber
- Clinically 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 cassette
- Central processing unit (in anest. machine)
Aladin cassette

* 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
- Synthetic lamellae with metal plates (wick)
- Temperature stabilization (metal plates, fan)
- Carrier gas identification
- No backpressure problem
Anaconda – vaporiser for sedation

Expiration
Air/oxygen and CO2 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.
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

<table>
<thead>
<tr>
<th>Anesthetic</th>
<th>Colour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Halotane</td>
<td>red</td>
</tr>
<tr>
<td>Isoflurane</td>
<td>purpur</td>
</tr>
<tr>
<td>Enflurane</td>
<td>orange</td>
</tr>
<tr>
<td>Sevoflurane</td>
<td>yellow</td>
</tr>
<tr>
<td>Desflurane</td>
<td>blue</td>
</tr>
</tbody>
</table>
Funnel / keyed filler types
More agents?
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
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

<table>
<thead>
<tr>
<th>Power supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Plugged in</td>
</tr>
<tr>
<td>• Switched on</td>
</tr>
<tr>
<td>• Back-up battery charged</td>
</tr>
</tbody>
</table>

Gas supplies and gauges

| • Gas and vacuum pipelines – ‘tug test’ |
| • Cylinders filled and turned off    |
| • Flowmeters working (if applicable) |
| • Manifold/wedge 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 |
| • TVA 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.

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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

- Anaesthesiologist 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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