By Adam Hollingworth

Principles of Vaporisers

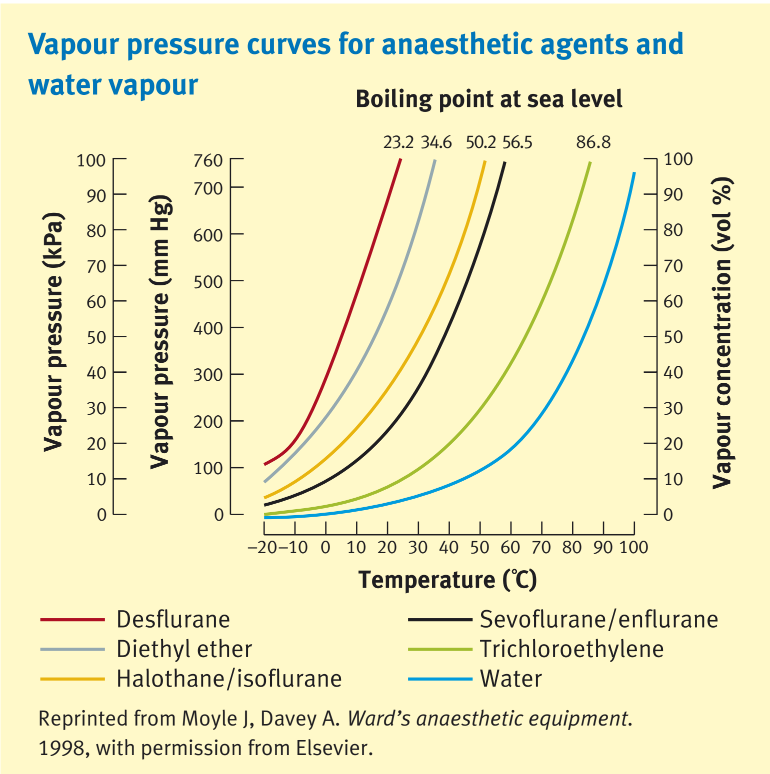
Physics

- all matter = solid, liquid or gas
- vapour is not a state of matter
- ANZCA defines vapour: substance in gaseous form below it's critical temperature
- critical temp = temp above which substance cannot be returned to it's liquid state no matter how high the pressure
- critical pressure = pressure required to liquefy a vapour at it's critical temperature eg O_2 = 49.7 atm

Saturated vapour pressure

- SVP = pressure exerted on the container wall when liquid & vapor are in equilibrium
- volatile agents exist as liquids <20C
- molecules which gain enough energy to escape liquid exist as vapour

- SVP depends on:
    - ambient temp
    - characteristics of liquid
- when SVP = atmospheric pressure ⟹ liquid boils
- modern vaporisers not designed to work with volatiles near their boiling points due to steep nature of temp/vapour pressure curve:



- temp of des vap (39C) has to be above boiling point ⟹ produce a gas under pressure
    - ↳ this is then pressure reduced & injected into fresh gas flow
    - ↳ ie no variable bypassing chamber
    - ↳ see later

Latent Heat of Vaporisation
- eg water = 0.58kcal/g
- for molecules to change from liquid to vapour they require energy - usually in form of heat
- amount of heat required = latent heat of vaporisation
- that heat is lost via ↓in temperature
- ∴ vaporisation ⟹ cooling of volatile agent ⟹ ↓SVP ⟹ ↓ed degree of further vaporisation
- ∴ temp compensation in vaporiser is v impt

Specific Heat Capacity
- eg water 4.18 kJ/kg/C
- SHC = amount of heat required to ↑temp of 1kg of substance by 1kelvin (k)
- SHC of a liquid volatile agent governs amount of energy required to maintain the liquid at a certain temp
- when designing vaporisers the materials used should have a high SHC so temp changes caused by vaporisation are minimised

Thermal Conductivity
- = rate at which heat flows through a substance
- vaporisers made of materials with high thermal conductivity eg copper
  - ↳ helps conduct heat from atmosphere ∴ keep volatile agent stable

Basic Principles of Vaporisers
- fresh gas flow enters vaporiser & divided into 2 streams of flow:
  - 1 into vaporising chamber
  - other into bypass channel
  - ↳ ratio of 2 streams is known as splitting ratio
- gas leaving vaporising chamber goes through network of wicks & baffles ⟹ fully saturated c agent
  - ↳ ↑s surface area & encourages vaporisation
- dial (adjusted by user) alters splitting ratio ∴ final conc of volatile agent leaving vaporiser outlet

Ideal Vaporiser
- performance unaffected by:
  - change in gas flow
  - volume of liquid agent
  - ambient pressure
  - ambient temp
  - latent heat of vaporisation
  - pressure changes related to resp
  - tilting or topping
- low resistance to flow
- lightweight and durable
- economical, safe, minimal servicing
- corrosion & solvent resistant
- unable to fill with incorrect agent
- will not allow administration of 2 agent simultaneously

Variables
Temperature
- ↑temp ⟹ ↑SVP of volatile agent inside vaporising chamber
- @35C SVP of isoflurane = double that at room temp

↳ ∴ amount of vapour added at the outlet ↑s when temp is high

- modern vaporisers are temp compensated:
  - temp sensitive valve automatically adjusts the splitting ratio relative to the temp
    ↳ bellows or bimetallic strip
  - ∴ when temp↑ed ⟹ valve will automatically ↑gas flow to bypass chamber
  - temp ↓ed ⟹ ↑gas flow to vaporiser chamber

Flow Rate

- early vaporisers poor saturation:
  - at very high flows due to lack of mixing in vap. chamber
  - at low flows due to lack of turbulence
- modern vaps = flow compensated to allow accurate delivery
  ↳ use wicks & baffles which ensures accuracy between <1 & >10 litres

Carrier gas composition

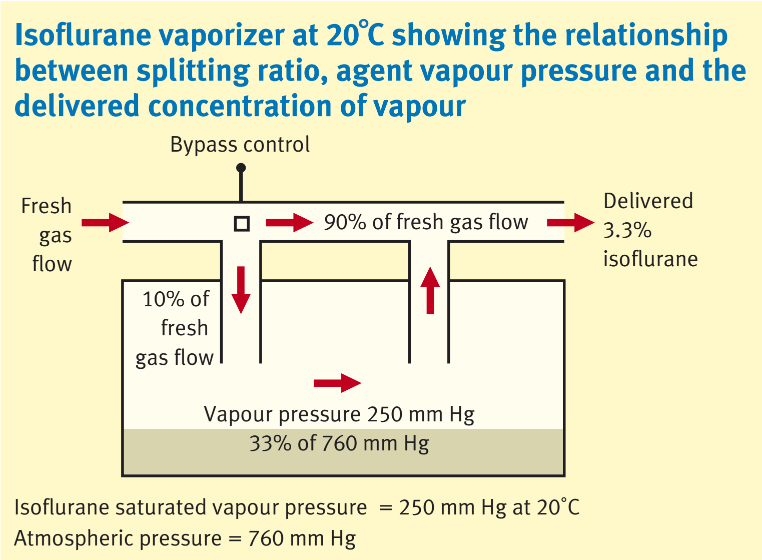
- vaporisers are calibrated for use with O2
- gases other than O2 ⟹ altered turbulent or laminar flow at splitting valve
  ↳ altered volatile concentrations delivered

Intermittent Back Pressure (Pumping Effect)

- back pressure into vaps during ventilation can cause pressure to build up in vap chamber
  ↳ esp in minute volume dividers
- as vent cycles ⟹ ↓pressure ⟹ pressurised vapour in vap chamber ⟹ flow out of correct outlet or retrograde through inlet & into bypass gas
- retrograde flow ⟹ ↑↑conc agent to pt and is called pumping effect
- methods to avoid pumping effect:
  - pressurising valve downstream of vap
  - bypass channel & vap chamber of equal volume
  - long inlet tube into vap chamber

Altitude

- output of a plenum vap is calibrated to atmospheric pressure
- if vap used at lower pressure (ie ↑ed altitude) ⟹ output no longer = dialled percentage
- SVP in vap chamber is unaffected by ambient pressure (only effected by temp):
  - ∴ isoflurane SVP = 250mmHg at 20C regardless of altitude
- but output represents greater percentage of total air pressure:
  - sea level ⟹ 5486m = 760 ⟹ 380mmHg
    - ∴ setting of 2% isoflurane ⟹ now gives 4%
- but note Daltons & Boyles law:
  - 2% of 760mmHg (15.2) = same as 4% of 380 (15.2) ∴ partial pressure delivered is the same
  - depth of anaesthesia is dependant on alveolar pp not vapour concentration ∴ even though double concentration delivered clinical effect is not changed



How much Liquid Agent Used per Hour

- formula:
  - 3 x fresh gas flow (FGF) (L/min) x volume % = ml liquid used/hr
- typically 1ml of liquid volatile ⟹ 200ml vapour
  - ↳ which is why tipping is so hazardous!

Modern Vaporisers

Anti-Spill Mechanism

- Tec 5 gen vaps have an antispill device
- this prevents volatile agents entering bypass chamber even if vap turned upside down
  - ↳ but vap should still be purged for 30mins following such an event
- Drager 2000 series - has a transparent lever which isolates vap chamber completely when removed from back bar

Selectatec mechanism

- when vap switched on ⟹ interlocking extension rod protrudes ⟹ prevents simultaneous use of another vap
- disadv = ↑ed risk of leaks

Preservatives

- halothane contains thymol
- thymol =
  - means vap needs regular servicing as interferes with function
  - modern agents do not contain thymol

Specific Vap filling device

- agent specific colour & shape-coded device
- stop wrong agent going into wrong vap

Temp Compensated

- valve adjusts splitting ratio

Pumping Effect

- prevented by:
  - downstream valve
  - long vap chamber
  - equal vap/bypass chamber volume

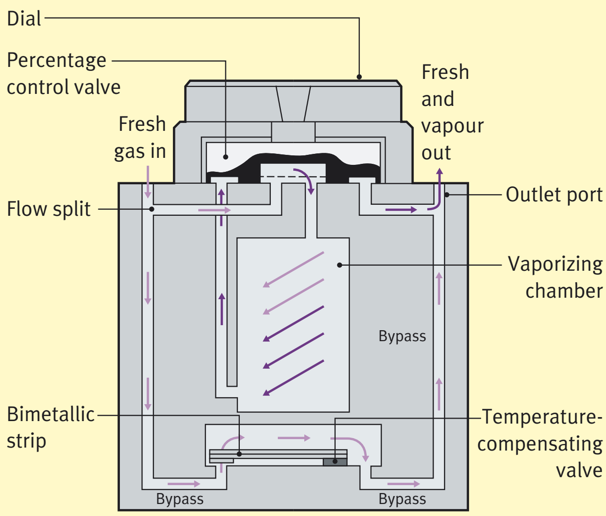
Classification of vaporisers

- 4 main types:
  - plenum
  - draw-over
  - gas blenders
  - computer controlled

Plenum Vaps

- = most frequently used
- chars:
  - unidirectional
  - agent specific
  - variable bypass
  - +ve pressure
  - should be used outside breathing system - high resistance to flow ∴ need pressurised fresh gas
- advs over draw-over devices:
  - more efficient
  - more reliable
- eg is Ohmeda TEC 7 (only cosmetic changes to TEC5):
  - flow & temp compensated
  - no pumping effect
  - consistent output over flow rages
  - easy control dial
  - glass strip indicating level of volatile agent
  - anti spill
  - mount on selectatec manifold
  - easy fill filter - can fill while vaporiser still in use

Schematic diagram of a Tec 5 plenum vaporizer



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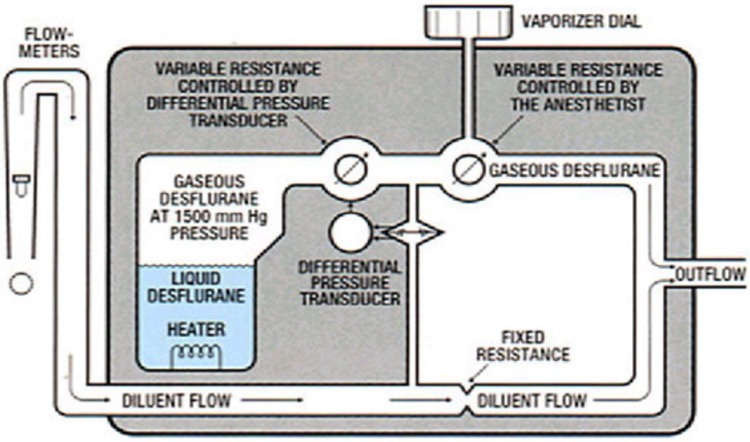
Draw over Vaporisers

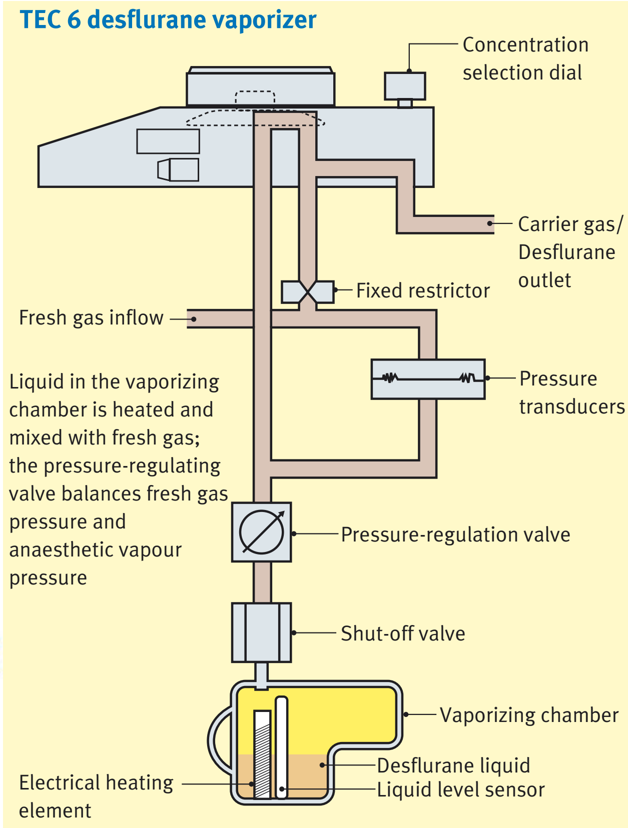
- same basic principles as for plenum vaporiser but:
  - ↓ed flow resistance ∴ can be used inside breathing circuit
    ↳but expired vapour builds to high conc & close monitoring needed
  - relatively inefficient
- fresh gas is drawn through vap due to -ve pressure downstream (from vent or pt)
- flow through vap is governed by pts minute volume
- output varies with flow: ↑flow ⟹ ↓output
- ∴ calibration across wide range of MVs needed
- eg OMV (oxford miniature versatile vaporiser):
  - simple, robust, portable, versatile ∴ military or developing countries

- can use for all agents - just need to change dial
- can be used in draw over or continuous flow anaesthesia
- contains
  - small reservoir of glycol in metal heat sink to compensate for temp changes
    ↳ as no temp compensating valves
  - metal mesh wicks to ↑output but avoid significant ↑ed resistance

Gas Blender (TEC 6)

- desflurane is extremely volatile & would exist in an unpredictable mixture of liquid & vapour form in an operating theatre ∴ needs specific vaporiser
- des boiling point is 23deg ∴ heat it past its boiling point to ensure predictable vapour present
- requires electrical source of energy as it heats des to 39C at pressure of approx 2 atmos (1500mmHg)
- no bypass channel:
  - stream of vapour (under pressure) flows out of vap chamber
  - this blended with background gas stream
- 2 pressures created:
  - 'back pressure' proportional to fresh gas flow is created by fixed flow restrictor downstream from fresh gas inlet
  - des conc is set by a dial which controls a variable restrictor downstream from vap chamber
- ∴ differential-pressure transducer needed to balance mix:
  - continually senses pressure in 2 channels:
    - vapour upstream of variable restrictor
    - backpressure from fresh gas flow
  - transducer controls a pressure regulation valve which sits in vapour channel between chamber and variable restrictor
    ↳ permits flow required to balance pressure in 2 compartments
- TEC 6 takes 5-10mins to be operational after switched on to allow heating of des
- other TEC 6 features (compared to TEC 5):
  - stop point on control dial at 12% - need to press a switch to go higher, safety due to airway irritability
  - tilt detector - shut off if >15deg
  - agent specific filling mechanism
  - des can be added without turning off vap
  - LCD indicator of volume of volatile
  - audible alarm when des running out
  - audible alarm for mains power failure
  - 9v batt back up
  - Drager - des vap can only be removed from backbar only if dial set to T - isolates des to prevent spilling





Aladin Cassette

- new method used with Ohmeda S/5 unit
- contains a central processing unit which measures & adjusts gas flow as required
- conc of agent is adjusted by regulating flow of gas through the cassette by throttle valve
    - ↳ ↑flow thru cassette ⟹ ↑conc of volatile to pt
- both flows are electronically measured
- each cassette is magnetically coded for specific agent
- no heating or pressurisation required for vaporisation