

Principles of anaesthetic vaporizers

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Abstract

Vaporizers are an integral part of modern-day anaesthesia, allowing the delivery of safe concentrations of volatile anaesthetic agent. Over time, vaporizer design has improved to be closer to the ideal. Today, vaporizers can be classified as 'variable bypass', where a portion of the fresh gas flow passes through the vaporizing chamber, or 'measured flow', where the flow of volatile agent is separately measured as it passes under pressure into the fresh gas flow. Understanding the operation of vaporizers, and the basic principles and designs behind this, is important to enable correct usage, handling and maintenance of vaporizers in everyday anaesthesia.

Keywords Aladin cassette; Dräger DIVA; draw-over; measured flow; plenum; vaporizer; variable bypass

Volatile inhalational agents have been in use since the dawn of anaesthesia; from Schimmelbusch masks to electronically controlled vaporizers, we have been striving to develop the perfect vaporizer. The characteristics of this ideal include:

- performance unaffected by:
 - fresh gas flow
 - volume of agent
 - temperature (both ambient and of the agent)
 - pressure (both ambient and back pressure)
- low resistance to flow
- lightweight
- hard-wearing
- economic
- minimal servicing
- corrosion resistant
- safe to use.

To understand why and how these requirements are met, we must understand some basic principles.

Physical principles

A vapour is made up of molecules of a high kinetic energy, which have broken the bonds between their counterparts and escaped the surface of a liquid. The molecules leave and return to the liquid randomly, eventually equilibrating, at which point the vapour is fully saturated. These molecules exert a pressure on

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Learning objectives

After reading this article, you should be able to:

- describe the basic physical principles with respect to vaporizers
- describe how plenum vaporizers work, their limitations and sources of error
- describe the newer, electronically controlled vaporizers.

their surroundings; at equilibrium this is known as saturated vapour pressure (SVP).

The higher the temperature, the greater the energy in the molecules; therefore, more molecules escape the liquid, and SVP increases. When SVP is equal to atmospheric pressure the liquid boils. As molecules leave the liquid, the energy in the liquid is reduced (latent heat of vaporization) so reducing the temperature of the liquid (see [Box 1](#)).

Vaporizer design

Vaporizers allow potent inhalational anaesthetic agents to be used at safe concentrations. They are designed to give an accurate concentration of vapour under normal temperature and pressure conditions, at commonly used gas flow rates.

If SVP of isoflurane at 20 °C is 32 kPa, assuming an atmospheric pressure of approximately 100 kPa, concentration at full saturation would be 32%; but 1 MAC (minimum alveolar concentration) is only 1.15%. To obtain these lower concentrations, the fresh gas passing into the vaporizer is split: only a small proportion passes into the vaporization chamber, the rest bypasses via a separate channel. A dial controls the *splitting ratio*, thereby controlling the concentration of the agent passing to the patient (see [Figure 1](#)). When the dial is in the 'off' position, all gas bypasses the vaporizing chamber.

How are accurate concentrations of volatile agent ensured? In older vaporizers, such as the Boyle's bottle, the rate of gas flow affected the concentration of volatile agent achieved at the patient end, known as *flow-dependence*. At high flows the gas leaving the chamber would not be fully saturated; at low flows the pattern of flow alters from laminar, to turbulent, or a mixture;

Definitions

Saturated vapour pressure

The pressure exerted by the vapour phase of a substance when in equilibrium with the liquid phase (kPa).

Latent heat of vaporization

The energy required to change a liquid to a gas, without changing the temperature of the liquid (J/kg).

Specific heat capacity

Amount of heat required to raise the temperature of 1 kg of a substance by 1 Kelvin (J/kg/K).

Thermal conductivity

Rate of heat flow through a substance (J/s).

Box 1

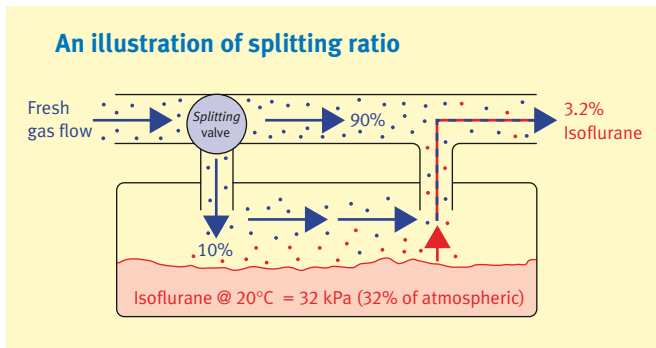


Figure 1

in these situations there is an increase in resistance, which alters the splitting ratio. Small changes in resistance are also caused by use of different carrier gases, with different densities and viscosities, such as N_2O (which also dissolves in volatile agents, reducing the flow leaving the chamber).

Full saturation of gas flow through the vaporizing chamber can counter flow-dependence (less so at low flows). To do this, the surface area of the vaporizing chamber is increased. In the Boyle's bottle, a cowl was lowered, on a separate control from the splitting ratio, to ensure all the gas bubbled through the anaesthetic agent. This method is still used in some more modern vaporizers by bubbling the gas, via a sintered disc, through the volatile agent. In some designs, typically the 'Tec' series, porous wicks increase the available surface area for vaporization. A helical design and the presence of baffles to divert the gas close to the wicks also improve efficiency of vaporization. If the vaporizer is overfilled, some of this surface area is lost, which may reduce output.

Some other physical factors can also affect the accuracy of vaporizers:

Temperature

There are two mechanisms to counter heat loss due to latent heat of vaporization. A *heat sink* is provided (Figure 2a), of good thermal conductivity (Box 1), to allow transfer of heat from the surroundings to the vaporization chamber. With the Boyle's bottle, and the Epstein, Macintosh, Oxford vaporizer (EMO), this is a water bath, with a high specific heat capacity of 4.18 J/g/K (Box 1). More modern vaporizers have a jacket of a dense metal, such as copper, with a lower specific heat capacity, but a much greater mass. Other vaporizers have a heating element.

The above measures only reduce the rate of heat loss. To maintain the concentration of volatile agent at a lower temperature, more gas must pass through the vaporization chamber. This is managed by *temperature-compensating devices* (Figure 2b, c). There are two common forms of these:

- Bimetallic strip – two closely apposed metals of differing co-efficients of expansion; bends on temperature change, altering flow through the vaporization chamber. Since Tec 3, this has been found in the bypass chamber, to avoid corrosion.
- Invar (alloy) rod, with a low coefficient of expansion, surrounded by brass, of a high coefficient. This is connected only at the base, and dipped into the volatile agent. As the brass contracts, the invar rod is pushed up to reduce flow through the bypass channel. This is found in the Bleas Datum vaporizer.

Altitude

Vaporizers are calibrated at atmospheric pressure. At high altitude, air pressure decreases whilst SVP remains the same. However, it is a greater proportion of the surrounding air pressure. This will alter the concentration of volatile agent but not the partial pressure and, therefore, the clinical effect, which is a function of the partial pressure, will remain the same.

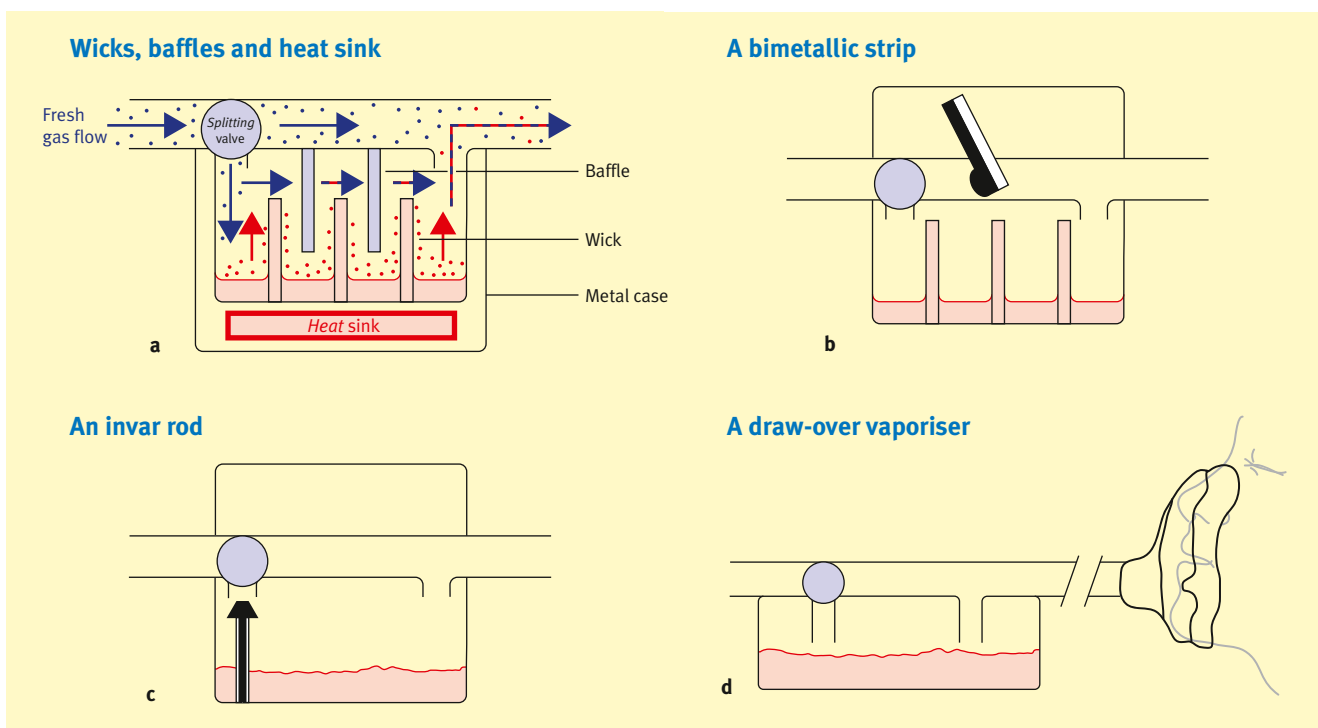


Figure 2

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