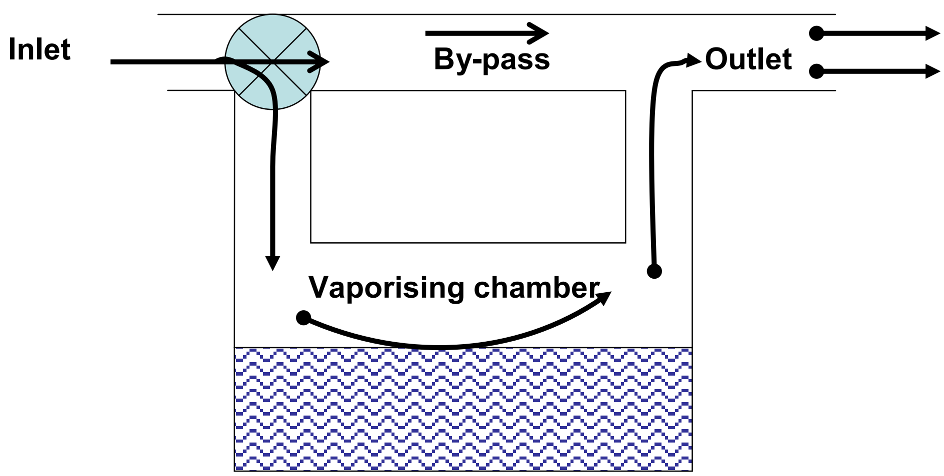
VAPORISERS

1. **What are vaporisers?**

   The purpose of an anesthetic vaporiser is to produce a controlled and predictable concentration of anesthetic vapour in the carrier gas passing through the vaporizer.



   Most vaporisers are of the plenum type, which consists of a vaporising chamber containing the liquid anaesthetic, and a bypass. Gas passing through the vaporising chamber vaporises the volatile anaesthetic and is then mixed with the anesthetic-free gas bypassing the chamber, the proportion of vapor-containing gas and bypass gas being controlled by a dial.

2. **What do you understand by plenum vaporiser? Give examples.**

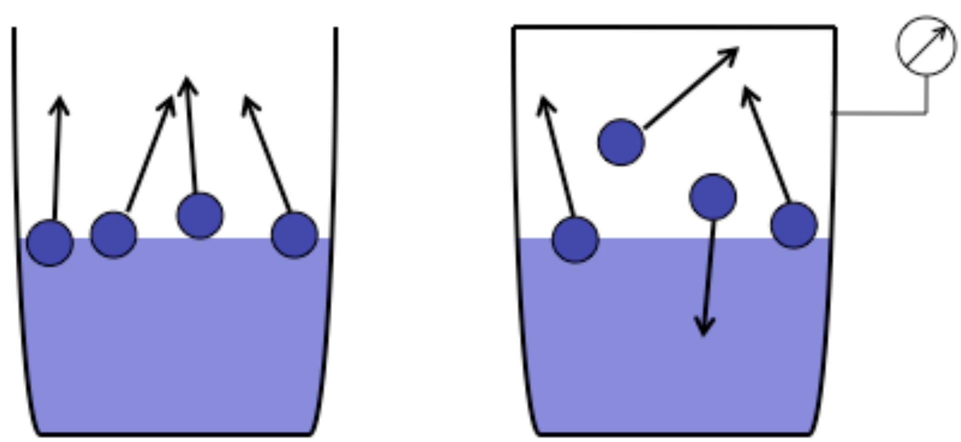
   The term plenum is derived from the plenum system of ventilation in which gas is forced into the system. All the modern vaporisers are plenum vaporisers.

3. **What physical principles are involved in the process of vaporisation?**

Molecules of liquids are in constant motion, but they also have a mutual attraction for each other.

When a liquid has a surface exposed to air or other gases, some of the molecules will escape from the surface when their energy exceeds that of their mutual attraction for other molecules. This process is called **evaporation**. Raising the temperature of the liquid can increase rate of evaporation; the molecules move faster and possess more energy.

In an enclosed atmosphere some of the escaped molecules will impinge on the surface and re-enter the liquid state. The molecules that remain in the gaseous state in the enclosure exert a pressure and this pressure is known as **Vapour Pressure** and when there is equilibrium between the molecules leaving and re-entering the liquid state, the vapour pressure is considered to be at a maximum and is called **Saturated Vapour Pressure (SVP)**.



Evaporation   Vapour Pressure

If external heat is supplied to the liquid, a point is reached when the SVP equals the ambient atmospheric pressure and at this stage vaporisation not only occurs at the surface but also in the bubbles that develop within the substance. The liquid is boiling, and the temperature is its **Boiling Point (BP)**.

From these two points become evident:

1. The SVP is dependent on the temperature and not the ambient pressure. SVP drops with drop in temperature.
2. Boiling point is dependent on the ambient pressure. At high altitude there is significant depression in boiling point.

4. What is a Boyle's bottle and why is it not an efficient vaporiser?

Boyle's bottle is one of the earliest and possibly the simplest type of plenum vaporizer.

Boyle's bottle is made of glass (the other common one made of glass is Goldman vaporizer) which has poor thermal conductivity, does not allow rapid thermal equilibration causing the liquid anaesthetic to cool down and the SVP to drop and so the output from the vaporiser drops i.e. the concentration delivered is far less than that set on the concentration dial.

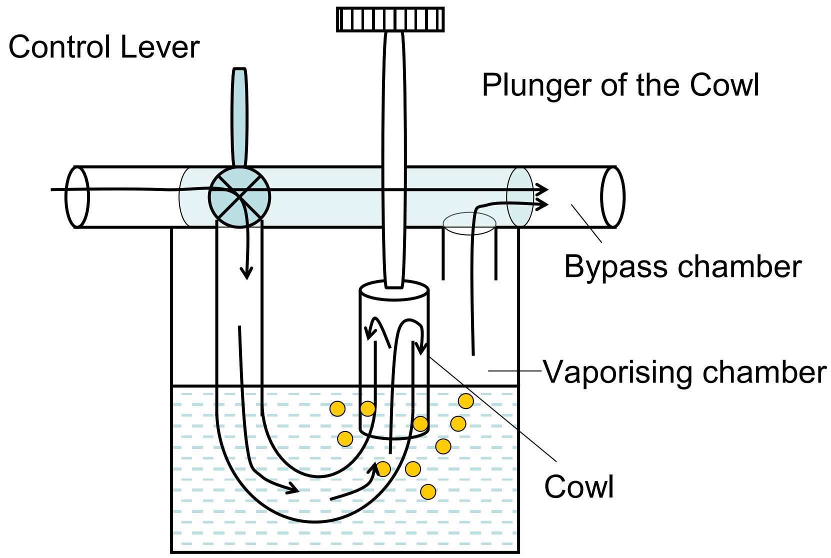
Boyle's Bottle

Goldman Vaporiser

There are no wicks to increase the surface area or bimetallic devices for temperature compensation either.

5. **What are the methods by which the efficiency of the Boyle's bottle can be increased?**

   The efficiency of the bottle can be increased by pushing the plunger down so that the cowl either lies near the surface of the liquid or is dipped into the liquid causing bubble through which effectively increases the surface area and the concentration.



The other method is to supply external heat by surrounding the glass bottle in a hot water bath. This will keep the temperature of the liquid constant.

6. What is flow dependence and what are the factors that affect flow dependence?

Output of the variable bypass vaporisers depends on the fact that gas emerging from the vaporizer is fully saturated, if this does not occur then the output from the vaporizer will depend on the flow rate i.e at higher flow rates the output may be less than the dial settings (greater dilution)

Factors that affect flow dependence are

- Volatility of the anaesthetic agent
- Splitting ratio
- Temperature compensation
- Available Surface area

7. How can flow dependence be minimised?

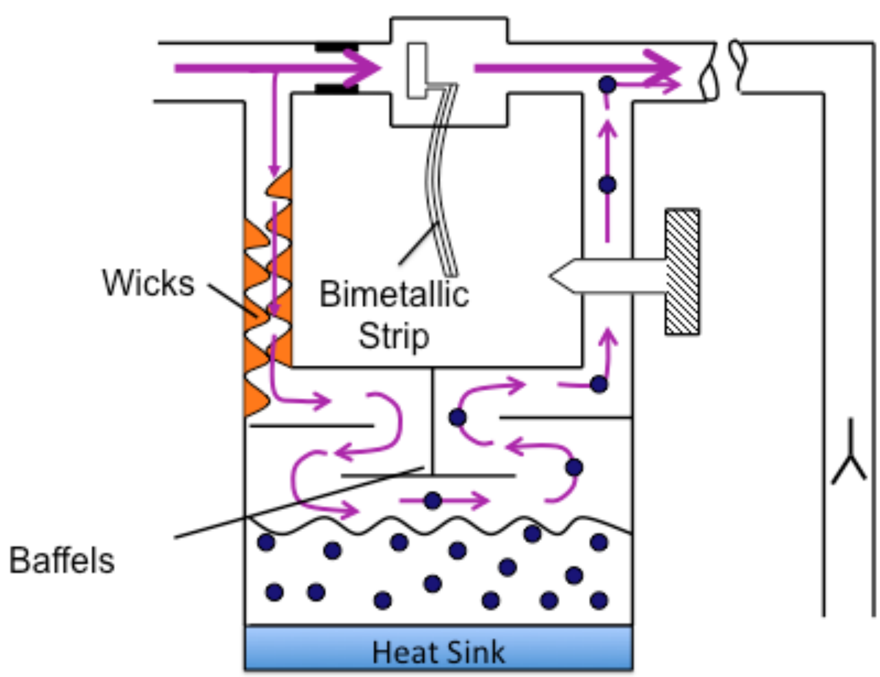
The main reason why the output from vaporisers reduces is the drop in temperature due to loss of latent heat of vaporisation. As the temperature drops so does the saturated vapour pressure.

The methods by which this can be minimised is:

1. Maintain constant temperature
2. Increase the vaporisation
3. Allow enough time for the fresh gases to pick up anaesthetic vapours

Maintaining constant temperature:

- Use material with high thermal conductivity for construction of the vaporisers.
- Use of temperature compensation devices to alter the splitting ratio, greater percentage of flow through vaporising chamber when the temperature of the liquid anaesthetic drops.



Increasing the Vaporisation:

- Large surface area for vaporisation, by using wicks or bubble – through, to maintain SVP in the vaporising chamber.
- Using Measured flow vaporizers.

Allow enough time for the fresh gases to pick up anaesthetic vapours:

- Use baffles

8. How does the temperature affect the output from vaporisers? What are the various methods used in the vaporisers to minimise these output changes?

Latent heat of vaporisation is the number of calories needed to convert 1 g of liquid to vapour, without temperature change in the remaining liquid. Thus, if this heat is not supplied externally then, the temperature of the remaining liquid will drop as vaporisation proceeds, lowering the Vapour Pressure.

Thermal conductivity - a measure of how fast a substance transmits heat. High thermal conductivity is desirable in vaporiser construction.

Relative thermal conductivity at 0^oC	
Good conductors	Poor conductors

Silver	428	Liquid state:	
Copper	403	N_2O	1.5
Gold	319	CO_2	1.45
Aluminium	236	Glass	1.0
Nickel	94	Water	0.561
Iron	84	Asbestos	0.11
Bronze	53	Paper	0.06
Lead	36	Wool 0.05	
Stainless steel	25	Polystyrene	0.035
		Gaseous State	
		O_2	0.0245
		N_2O	0.015

The vaporisers are constructed of metals with high thermal conductivity. This helps to reduce the heat loss from the liquid itself and the metal acts like a heat reservoir/sink and thus delay and reduce temperature fluctuations.

Other method of preventing this heat loss is to surround the vaporiser with a heated water bath (not very practical) or heat up the liquid anaesthetic itself.

9. How is temperature compensation achieved? Describe the various temperature compensation devices?

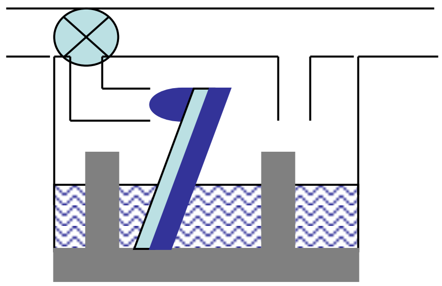
The output of modern vaporizers is linear over 20-35^{o}C, due to

- Automatic temperature compensating devices that divert greater amount of the carrier gas flow into the vaporising chamber as liquid volatile agent temperature decreases
- Wicks in direct contact with vaporising chamber walls, increasing surface area and vaporisation.

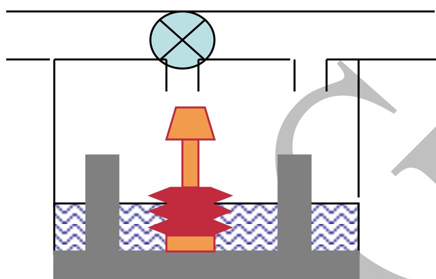
- Body of the vaporisers constructed of metals with high specific heat and thermal conductivity

There are various types of temperature compensation devices like,

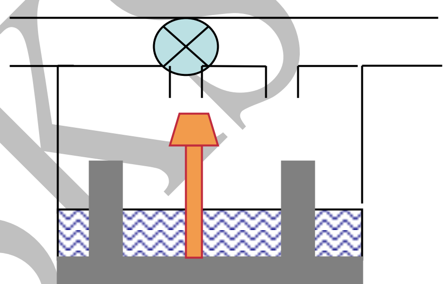
- Bimetallic strips (Tec vaporizers)



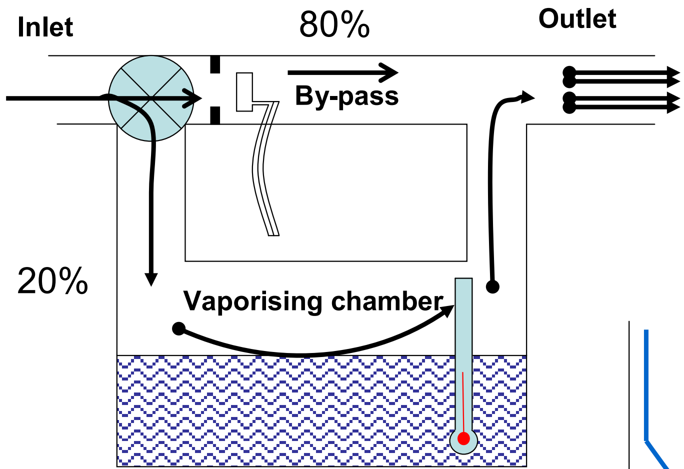
- Bellows (Vapamasta)

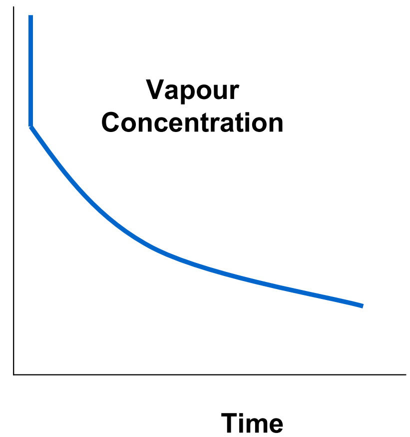


- Bimetallic Metal rod (Drager Vapor)

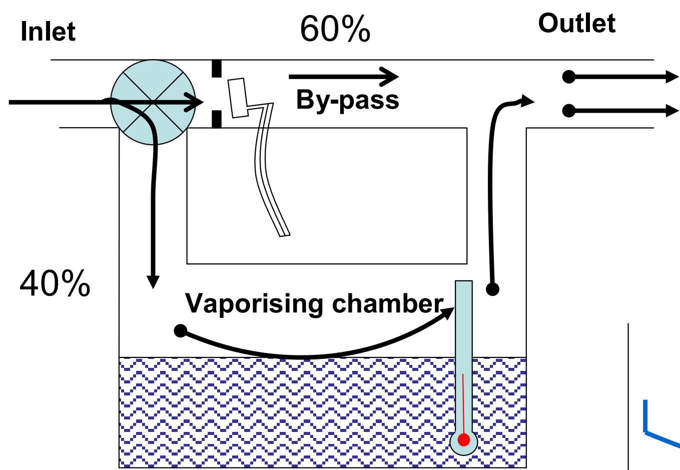


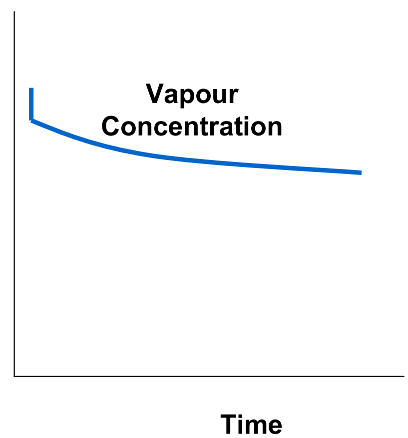
Whatever may the type of temperature compensating devices be, the working principle remains the same. They are made of two dissimilar metals, which have different expansion co-efficient.





As vaporisation increases the liquid anaesthetic cools down, reducing the SVP, this reduces the output (vapour concentration) from the vaporising chamber. If the amount of fresh gas flow through the bypass chamber is not reduced, then the mixture of gases will be diluted (less amount of volatile anaesthetic vapours in larger fresh gas flows).





On cooling the temperature compensating devices either bends (Bimetallic strips) or shrinks (Bimetallic rod/ bellows) to alter the splitting ratio.

In simple words, they reduce the flow through the bypass chamber and increase the flow into the vaporising chamber. We therefore have lesser amount of fresh gas flows and more of volatile anaesthetic vapours, this helps to maintain a constant concentration of volatile anaesthetic as set on the dial of the vaporiser.

10. How are Tec Vaporisers classified?

All Tec Vaporisers can be classified as:

- Plenum Vaporisers

- Method for regulating output concentration
    - By variable bypass

- Method of vaporization
    - By flow-over

- Temperature compensation
    - By flow alteration (using Bimetallic strip/rod or Bellows)

- Agent specificity
    - Agent specific

- Location
    - Outside the breathing system

11. What are the differences between Tec-4, Tec-5 and Tec-7 vaporiser?

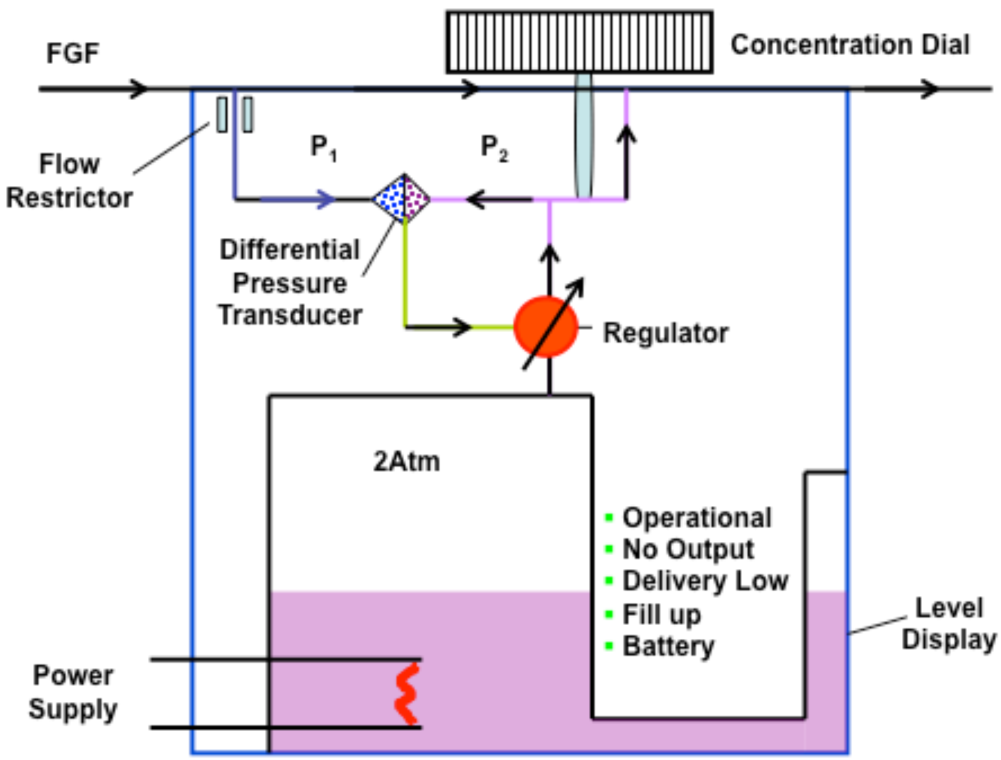
Element	**TEC 4**	**TEC 5**	**TEC 7**
Nominal working range Flow (L/min) Ambient Temp (^{O}C)	 0.25 -15 18-35	 0.25 -15 18-35	 0.25 -15 18-35
Capacity (mls) With dry wicks With wet wicks	 135 100	 300 225	 300 225
Dimensions (mm) Width Depth Height	 105 145 225	 114 197 237	 114 197 237
Temp-compensated (ambient and cooling effect)	Yes	Yes	Yes
Pressure	Yes	Yes	Yes

compensated			
Key filler option (Fraser Sweatman pin safety system)	Yes	Yes	No, Filler part of the bottle
Selectatec option	Standard	Standard	Standard
Non spill	Yes	Yes	Yes
Allowable tilt	180^{O}	180^{O}	180^{O}
Integral interlock	Yes	Yes	Yes
Safety 'off/isolation' facility	Yes	Yes	Yes
Safety 'lock on' facility	Yes	Yes	Yes
Resistance to gas flow Vaporiser 'on' Carrier gas O_2 5L/min@21°C kPa cm H_2O	2.06-2.84 21-29	1.47-1.96 15-20	1.47-1.96 15-20
Additional features			Wick assembly made of spiral Teflon reinforced internally with steel wire spiral

12. Explain the principle behind Tec 6 Desflurane vaporizer and why is it so different from the other Tec vaporisers?

The Tec 6 vaporizer has two independent gas circuits arranged in parallel.

Desflurane is heated to 39-40°C; this creates a pressure of 2 Atm in the vaporising chamber.



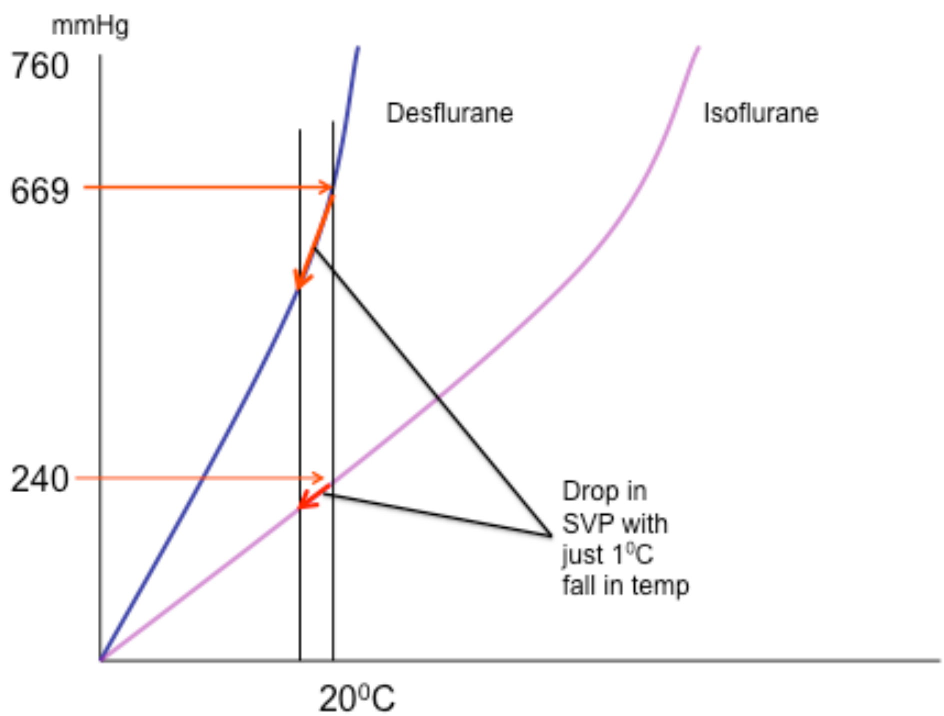
The flow from the vaporising chamber is controlled by the ***variable resistance (Pressure regulating Valve)***, which in turn is regulated by the ***differential pressure transducer***.

The differential pressure transducer senses the change in fresh gas flows and in turn regulates the variable resistance near the vaporising chamber to maintain a constant output (which is set by the concentration dial).

Why special vaporiser for Desflurane?

Desflurane is highly volatile and has moderate potency (high MAC value) and these two factors preclude its use with contemporary variable-bypass vaporizers, such as Tec vaporisers:

The vapour pressure of Desflurane is near 1 atm (669 mmHg). Normal flow through a traditional vaporiser would vaporise many more volumes of Desflurane. At greater than 22.8°C at 1 atm, Desflurane boils. The amount of vapour produced would be limited only by the heat energy available from the vaporiser owing to its specific heat. Since Desflurane has a high MAC value, we would need lot more vaporisation than other volatile anaesthetics, this would cool the liquid down and drop its SVP. Looking at the graph below it is evident that even small drop in temperature reduces the SVP for Desflurane much more than that for Isoflurane or Sevoflurane. The temperature compensating devices in the Tec vaporisers will not be able to compensate for this massive drop in the SVP with Desflurane and hence the need for a special vaporiser.



13. **How are vaporiser for Desflurane classified?**

Desflurane vaporisers are not variable bypass flow over vaporisers. These vaporisers are classified as:

- Electrically heated
- Thermostatically controlled to a temperature of 39-40^{O}C
- Pressurised
  - To nearly 2 atmospheric pressure
- Dual circuit
- Electro-mechanically coupled
  - Using differential pressure transducer
- Gas-Vapour blender

14. **What do you understand by the following terms pressurising and pumping effect? How can these effects be minimised?**

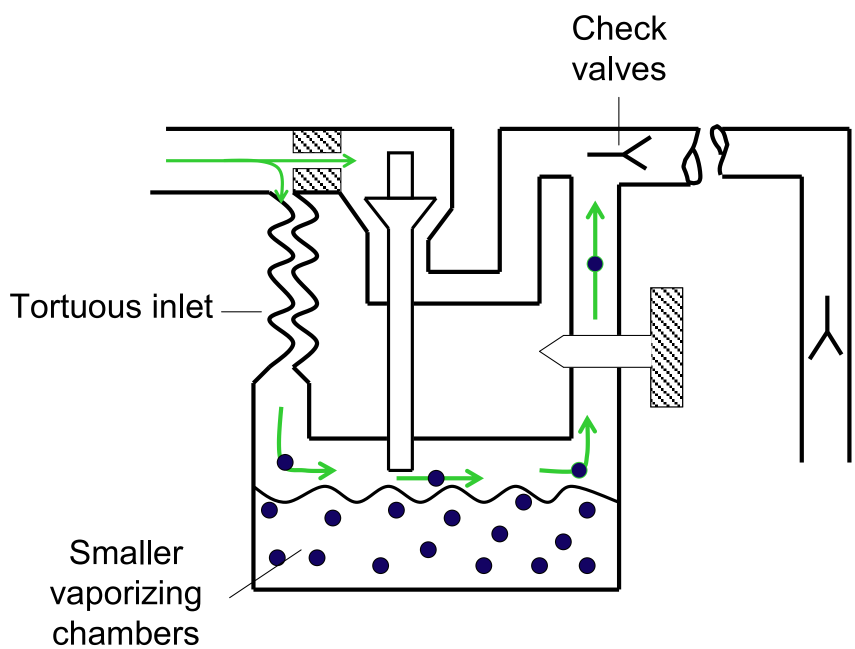
The '**Pressurising effect'** occurs because of back-pressure but the effect of it is a *decreased* vaporiser output. This effect occurs when the total flow coming from the flowmeters is very high.

The **pumping effect** is due to positive pressure ventilation or use of the oxygen flush valve. It can increase vaporizer output.

Modern vaporizers are relatively immune due to,

- Check valves between the vaporizer outlet and the common gas outlet,
- Smaller vaporizing chambers, or

- Tortuous inlet chambers



Any of these design features prevent gas, which has left the vaporisers from re-entering it.

15. What happens to the Tec vaporiser output at high altitude and in a hyperbaric chamber?

The effect of the change in barometric pressure on the output of any vaporiser can be calculated by using the following formula:

$$X` = X (P/P`)$$

X` is the output at the new altitude (P`) and X is the concentration output at the altitude P, where the vaporiser is calibrated (Sea level).

Let us take a vaporiser calibrated at sea level (100kPa) to a place where the P` is 50kPa and set the dial at 1%. The new output X` will be 1% x

100/50 = 2%, but for anaesthesia purposes partial pressure of vapour not the concentration, is important. 1% at sea level is 1kPa and 2% at 50kPa is 2 x 50/100 = 1%, so the partial pressure does not change.

Similarly taking the vaporiser to 200kPa pressure (2 ATA) the output will be 1% x 100/ 200 = 0.5 % but 0.5% at 200kPa is 0.5 x 200/100 = 1%.

16. **How does altitude affect Tec-6 vaporiser?**

Unlike contemporary variable-bypass vaporizers, the Tec 6 vaporizer requires manual adjustments of the concentration control dial at altitudes other than sea level to maintain a constant partial pressure of anaesthetic.

The Tec 6 works at absolute pressures; therefore, altitude makes no difference to the vaporiser's performance. It can accurately deliver the dialled volume percent of Desflurane. However, when this gas is brought to ambient atmospheric pressure at high altitudes, the volume percent represents an absolute decrease in the partial pressure of the anaesthetic, unlike the contemporary variable-bypass vaporizers, which deliver a constant partial pressure of anaesthetic.

To compensate for the reduction of partial pressure of vapour at altitude, the Tec 6 rotary valve must be advanced to maintain the required partial pressure of anaesthetic. The required dial setting may be calculated using the following formula:

Required dial setting =

$$\textbf{Normal dial setting (Volm\%)} \times \frac{\textbf{100kPa or 760mmHg}}{\textbf{Ambient pressure (kPa /mmHg)}}$$

For example, at an altitude where the ambient pressure is 50kPa, the operator must advance the concentration control dial from 6 % to 12 % to maintain the required anaesthetic partial pressure. In hyperbaric settings, the operator must decrease the dial setting to prevent delivery of an overdose.

17. Does the carriers gases have any effect on the output of Desflurane vaporisers and if so, how?

Vaporiser output approximates the dial setting when oxygen is the carrier gas because the Tec 6 vaporiser is calibrated using 100% oxygen.

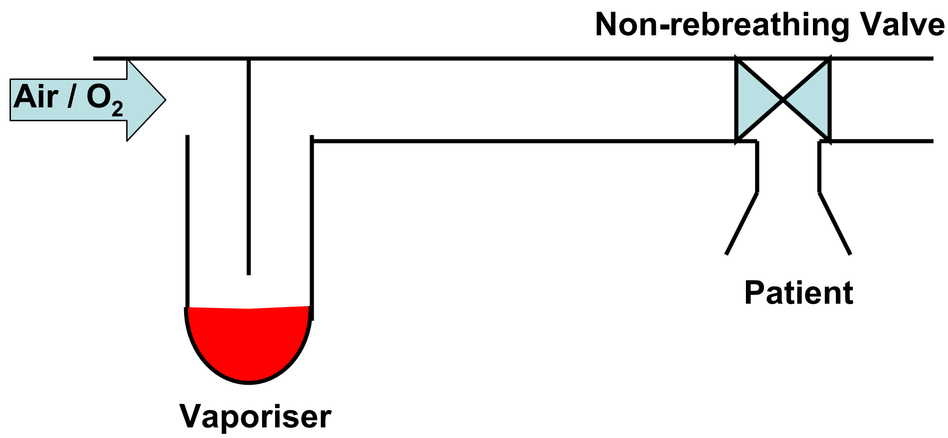
At low flow rates when a carrier gas other than 100% oxygen is used, a clear trend toward reduction in vaporiser output emerges. This reduction parallels the proportional decrease in viscosity of the carrier gas. Nitrous oxide has a lower viscosity than oxygen, and the backpressure generated by resistor R_1 is less when nitrous oxide is the carrier gas, and the working pressure is reduced.

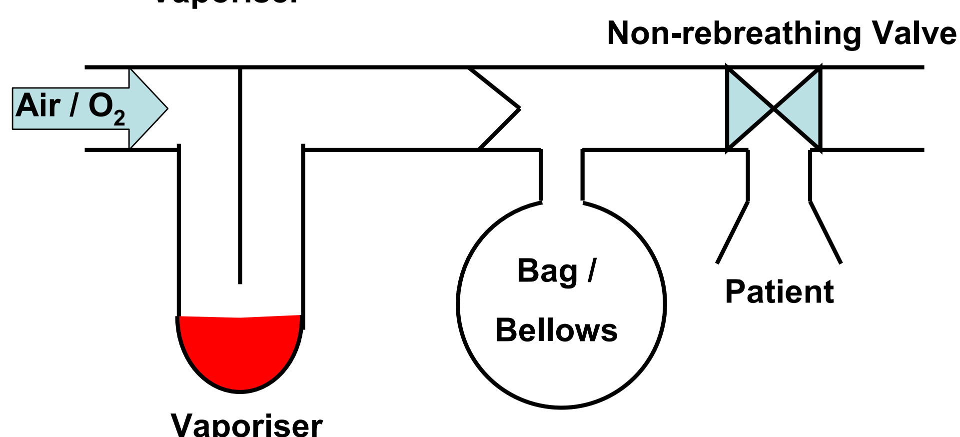
At low flow rates using nitrous oxide as the carrier gas, vaporiser output is approximately 20% less than the dial setting. This suggests that, at clinically useful fresh gas flow rates, the gas flow across resistor R_1 is laminar, and the working pressure is proportional to both the fresh gas flow rate and the viscosity of the carrier gas.

18. What are draw over-vaporisers and what is their place in anaesthesia practice?

The principle of Draw-over is similar to plenum vaporisers. These vaporisers have low resistance to internal flow of gases, so that patient can breathe through them easily.

Patient's inspiratory effort draws room air (with or without added O_2) over a volatile agent with each breath. Because of the low resistance these vaporizers can be used in closed circuits (vaporiser in circle system).





19. A volatile anaesthetic agent has an SVP of 243 mmHg. If the total fresh gas flow is 5 l/min of which 200 ml is directed through the vaporising chamber, the inspired concentration will be approximately?

Consider that $f = P_{vap}/P_{atm}$, and since $P_1/V_1=P_2/V_2$ or $P_1/P_2=V_1/V_2$ at any constant temperature, f is also the ratio of anaesthetic vapour volume to other gases in a given volume, and the vaporizer output ratio is also the same. Thus vapour output (X) is related to:

$$X/(X + Fv) = f$$

$X = f(X + Fv)$

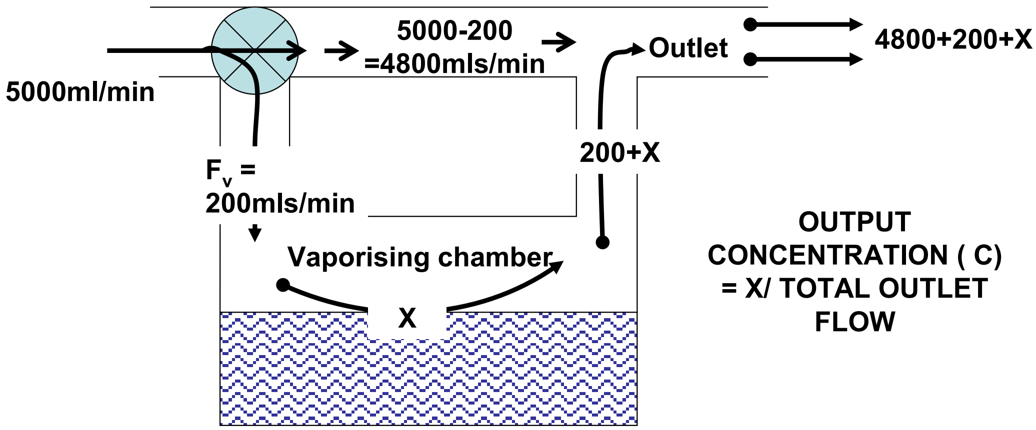
$X\text{-}f(X) = f(Fv)$

$X(1-f)/f = Fv$

thus, $X = Fv(f/(1-f))$

Concentration (C) is best thought of as vapour output divided by total gas flow. Note that vapour output (X) is added onto the vaporizer gas flow (Fv, which is also known as the carrier gas flow).

Plenum vaporisers work on the principle that the part of the flow that goes through the vaporising chamber becomes fully saturated. Since the SVP is 243 mmHg, fresh gas passing through the vaporising chamber will have a vapour concentration approximately one-third of the atmospheric pressure (760 mmHg)i.e $f = 243 / 760 \sim 1/3$. Thus $x = 200(1/3 / 1-1/3) = 200 \times 1/2$ mls i.e 100mls i.e 200ms of fresh gas passing through the vaporising chamber will have approximately 100 ml of vapour added to it. The final volume $Ft = (5000-200) + 200 +100 = 5100$ and therefore the final vapour concentration is 100 ml in 5100 ml which is approximately 2%.



$$X/\ X+F_v = f \text{ i.e } V_1/V_2$$

Since $P_1/P_2 = V_1/V_2$ therefore V_1/V_2 or $f = 243/760 \approx 1/3$

$X/X+200 = 1/3$ i.e $3X = X+200$ or $2X = 200$ and $X = 100$