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Understanding the circle system

By the perioperativeCPD team

Introduction

A breathing system is defined as an assembly of components, which delivers gases from the anaesthetic machine to the patient's airways. All breathing systems are composed of similar components but are configured differently and have different characteristics.

Many older Mapleson type circuits required high fresh gas flows of over 10 litres/minute throughout the entire anaesthetic to prevent rebreathing of CO2 and this resulted in over 90% of the fresh gas flow being wasted. Within theatres these have mostly been replaced by circle systems as they allow the use of lower fresh gas flows which reduces the cost of anaesthetic gases and has both economic and environmental benefits. Although the circle system looks relatively simple, it is a deceptively complex arrangement that needs to be fully understood to use safely, especially at low flows.

This module explains the components, setup and both advantages and disadvantages of the circle system.

An ideal breathing system should be

- be simple and portable (which the circle system is not)
- be safe to use in all age groups including paediatrics (yes with paediatric circuit tubing)
- reliably deliver the intended gas mixture (yes but only at high flows or with gas analysers)
- be efficient in both spontaneous and controlled ventilation (yes)
- protect patients from barotrauma (yes)
- permit scavenging of waste gases (yes)
- offer low resistance to gas flow (no, valves, CO2 absorbers etc add to resistance)
- conserve heat and moisture (only if a HME filter is used and/or low flows)

Unfortunately, no system fits all criteria and compromises are made.

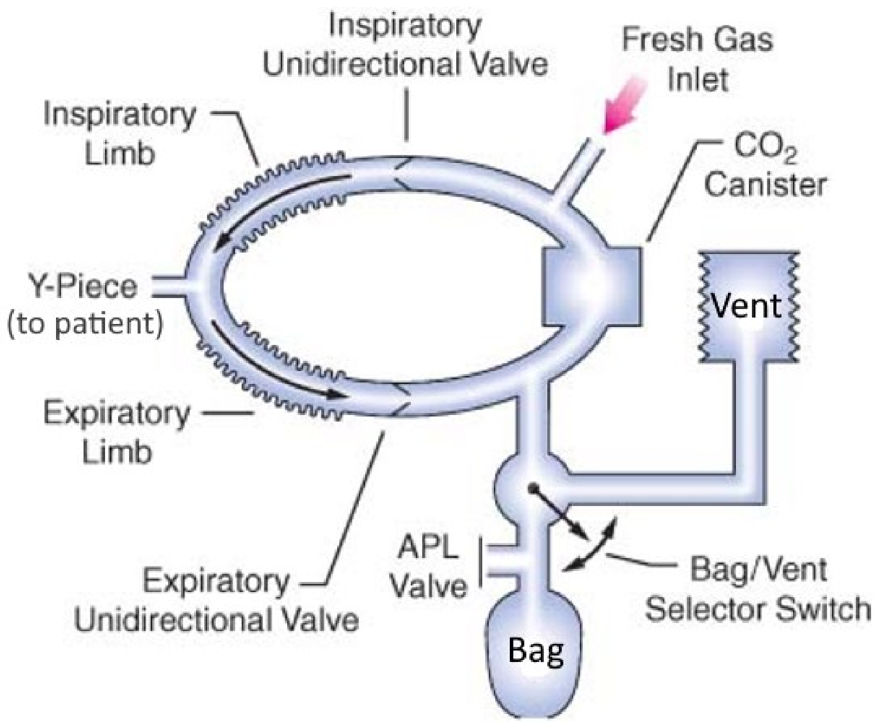
How a circle system works?

A circle system improves the efficiency of anaesthetics by recycling expired oxygen and anaesthetic gases, removing the carbon dioxide, and therefore reducing the fresh gas flow (FGF) requirements. This is possible as only a small percentage of the oxygen (approx. 25mls*) and less than 5% of the volatile agent is consumed by the patient each breath.

Over 90% of the anaesthetic gases can be wasted if a high FGF is used. Typically, lowering the FGF from 3.0 litres/min to 1.0 litre/min results in a saving of about 50% of the total consumption of any volatile anaesthetic agent.

An early anaesthetic circuit using soda lime from 1924

*Oxygen consumption for a normal adult at rest is approximately 250-300mls/minute so 300mls divided by 12 breaths/minute gives 25mls per breath although this is patient variable.



Note: the above diagram is of a typical circle system with a bellows ventilator (GE). Anaesthetic machines with pistons (Draeger) and turbines (Maquet) have a different configuration.

How it works: Spontaneous breathing

Inspiration

During spontaneous inspiration, gas flows from the reservoir bag and through the CO2 absorber, where it joins with the fresh gas and flows to the patient via the inspiratory one-way valve and Y connector.

Exhalation

During exhalation, exhaled gases pass into the reservoir bag until it is full. Then excess gases are vented through the APL valve to the scavenging.

How it works: Mechanical Ventilation

Inspiration

During inspiration, gas is pushed from the ventilator through the CO2 absorber and inspiratory one-way valve to the patient. The gas in the ventilator bellows will consist of exhaled gas from the patient’s previous breath.

Exhalation

During exhalation, exhaled gases will flow into the ventilator bellows. Excess gases are vented through a spill valve in the ventilator and out to the scavenging when the bellows are full.

In GE machines the APL valve and reservoir bag are isolated from the circuit during mechanical ventilation.

But the circle systems appear to be simpler than Mapleson systems.

Although a circle system looks initially like a relatively basic circuit, the visible tubing only makes up a small part of the system. It has many parts and each of these adds resistance and the possibility of malfunction to the system. The typical circle system has over 20 connections between the various components, each with the possibility of leaking.

Also, while a circle system allows efficient low flow anaesthesia, this needs accurate gas monitoring systems to be safe. When flows are reduced to less than 1 Litre/minute, fresh gas flow concentrations do not match inspired gas concentrations. This is explained in more detail later.

What are the advantages of the circle system:

- Economy of anaesthetic gas consumption.
- Warming and humidification of the inspired gases by the soda lime.
- Reduced atmospheric pollution.

A circle system comprises:

- a fresh gas inlet containing the volatile anaesthetic and oxygen/air/nitrous oxide mix.
- a reservoir bag and a ventilator.
- two one-way valves (one in each of the inspiratory and expiratory sides).
- lengths of corrugated (kink-resistant) tubing to connect the components to one other and the patient.
- a Y-piece connector joining the circuit tubing to the airway device (mask, filter, ETT etc.)
- an APL valve.
- a soda lime canister that absorbs carbon dioxide.

Note: there is no vaporiser within a traditional circle system, the volatile anaesthetic is added to the fresh gas flow on the backbar before it enters the circle system.

All of these components have a volume of 3-5 litres with the reservoir bag/bellows and soda lime cannister making up most of it.

Fresh gas Inlet

Although the fresh gas inlet on the circle system is not normally visible as in other circuits, it is still there and performs the same function. It supplies the selected oxygen/air/NO2 and anaesthetic gas mix at the required flow.

Reservoir bag

A reservoir bag is part of all modern breathing circuits as it improves efficiency and allows for manual ventilation. The bag should hold a volume which exceeds patient's inspiratory capacity. They come in 0.5, 1.0 litres sizes for paediatrics and 2.0 litre size for adults. There are also available 4 & 6 litre bags for use in inhalation anaesthetics for adults. Reservoir bags are ellipsoidal in shape to enable easy grip, antistatic and latex free. The bag contains a plastic cage at the opening which prevents the two sides sticking together due to moisture. Without the cage this can result in an occlusion the flow of gas into the bag, particularly during spontaneous expiration.

Reservoir bags have four main functions:

- Accommodates fresh gas flow during expiration ready for next inspiration, therefore working as reservoir.
- During spontaneous breathing, acts as a monitor of the patient's ventilatory pattern.
- Permits manual ventilation.
- Works as a pressure relief if the APL is unintentionally left closed. The bag will increase in size not pressure thus protecting the patient from barotraumas (Laplace's Law). As the size increases the sustained pressure in the circuit should not be greater than 40-50cm H2O.

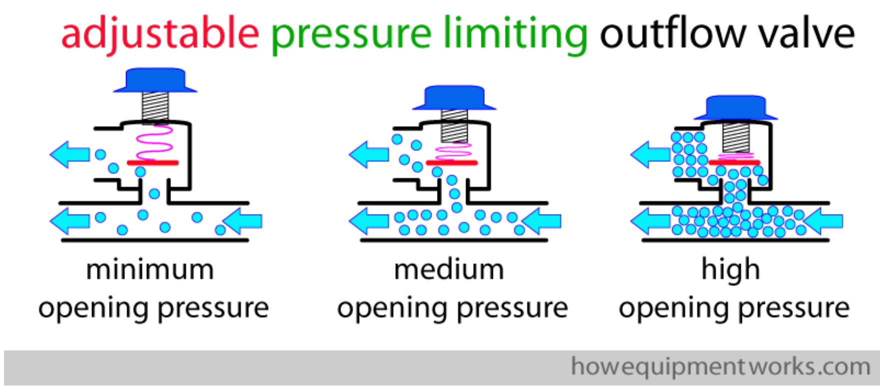
Some machines without bellows, such as the Draeger Primus which has a piston ventilator, use the reservoir bag to store FGF so it moves during mechanical ventilation as well as spontaneous ventilation.

Paediatric and adult reservoir bags

Always open your APL valve

The Adjustable Pressure Limiting (APL) Valve

APL valves are an essential component of most breathing systems including circle systems (except the paediatric Mapleson F). It is a spring-loaded pressure release valve in which the release pressure can be varied to suit the situation. At a pressure above the opening pressure of the valve, a controlled leak of gas is allowed from the system, which enables control of the patient's airway pressure.



The minimum pressure required to open the valve is 1cm H2O. A safety mechanism exists to prevent pressure from exceeding 60-70cm H2O (depends on manufacturer), however, be aware that pressures below this can still lead to barotrauma. The APL feeds the excess gases into the scavenging during spontaneous breathing.

APL valve

One-way valve

Note: Most GE anaesthetic machines with a bellows ventilator in the circle system bypass the reservoir bag and APL valve when using the ventilator.

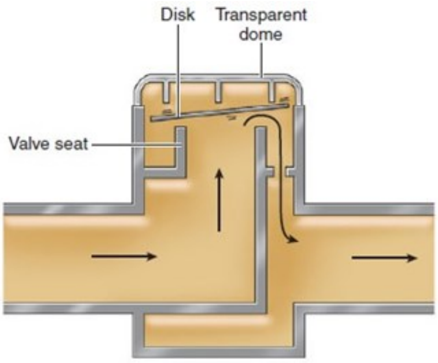
Breathing System Tubing

The tubing may be either co-axial or side-by-side and comes in various lengths. The inspiratory limb allows passage of fresh gas flow to the patient for inspiration. The expiratory limb allows passage of expired gas from the patient.

The normal tubing sizes are 22mm I.D. for adults and 15mm I.D. for paediatrics. For an adult circuit the internal volume of 22mm tubing is 400-500ml/metre. The corrugations prevent kinking and provide increased flexibility.

Unidirectional valves (one-way valves)

The unidirectional inspiratory and expiratory valves in most circle systems are of the turret type, in which the pressure generated by the patient's breathing causes the disc to rise and allows gas to pass in one direction only with minimum resistance. Many have a transparent dome so that the operation of the valve may be observed.



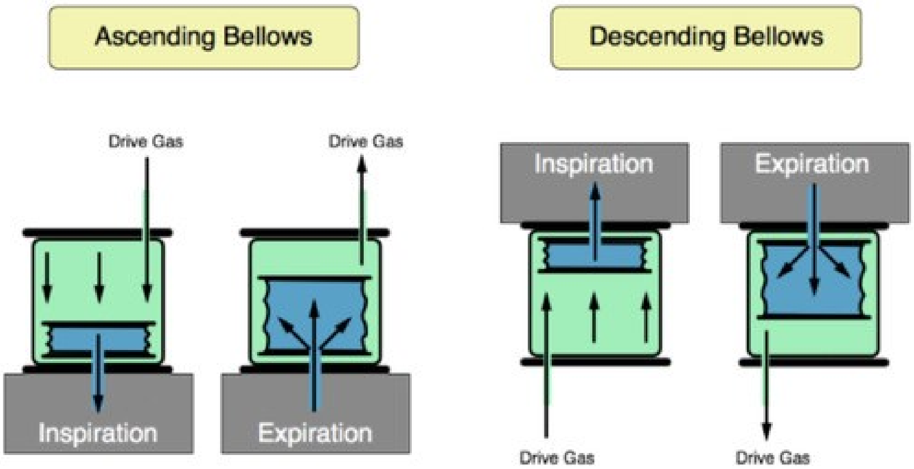
A unidirectional valve

The disc material may be mica, ceramic or plastic. Plastic is less expensive, but tends to warp and allow the valve to become incompetent. Incompetence may also be caused by the valve sticking in the open position, owing to condensation of water vapour. Incompetent inspiratory or expiratory valves will reduce the efficiency of gas circulation and result in rebreathing and consequent CO2 retention.

Bellows/ventilator

The bellows which are the visible part of the ventilator, perform a similar function as the reservoir bag. During expiration the bellows fill up with the patients expired anaesthetic gas (blue). During inspiration the ventilator drive gas (green) pushes the bellows down the required amount (tidal volume) pushing the contents into the patient's lungs.

Most modern anaesthetic machines with bellows use ascending bellows which are safer as the give a clear visual indication of a leak or disconnection.

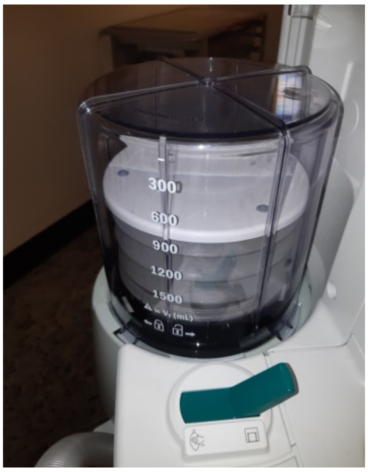


The drive gas that pushes the bellows down is totally separate from the circuit and is wasted gas, during exhalation when the bellow refill it is vented into the scavenging.

Traditionally the driving gas has been oxygen to prevent hypoxia in the case of a leak or tear in the bellows although this is no longer as much of an issue with modern gas monitoring systems. During the Covid outbreak many hospitals changed the driving gas to air to help conserve oxygen.

The bellows have the advantage of providing a very rough indication of a ventilated patients respiratory rate and tidal volume. They also give a visual indication of any leaks in the system.

Some modern machines have replaced the bellows with piston systems (Draeger) similar to ICU ventilators or a fan/turbine (Maquet) where there is no visual confirmation of ventilation.



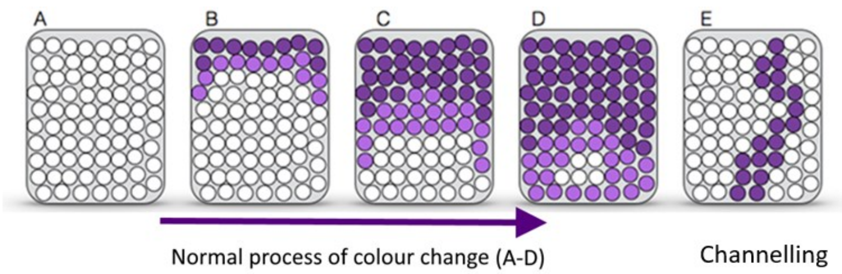
GE Aisys bellows

Soda Lime

The purpose of the soda lime is to remove the exhaled or end tidal CO_2 (4.5-6%) from the circle system. It does this through a chemical reaction which neutralises and traps the CO_2 in a process that produces heat and water as by-products (exothermic reaction). The soda lime may rise in temperature up to 40° centigrade. The additional advantage of using circle systems in that the gases within the circle are warmed and humidified prior to inspiration as a result of flowing through the soda lime (wall oxygen temperature can be below 15^0 Celsius).

There are many different formulas from various manufacturers but they are all commonly referred to as 'soda lime' and the largest ingredient in modern formulations is calcium hydroxide.

Traditional soda lime has a granule size of 4-8 mesh which means that each granule will fit through a mesh that has 4 openings per inch, but not one that has 8. More recent versions have a uniform shape of 3-4mm. When mounted vertically this ensures even airflow through the soda lime with minimal resistance and no channelling (picture E below).



Note: although most modern CO_2 absorption granules are not 'soda lime' but other formulations it is still a common generic term used in operating theatres.

Amsorb 'soda lime'

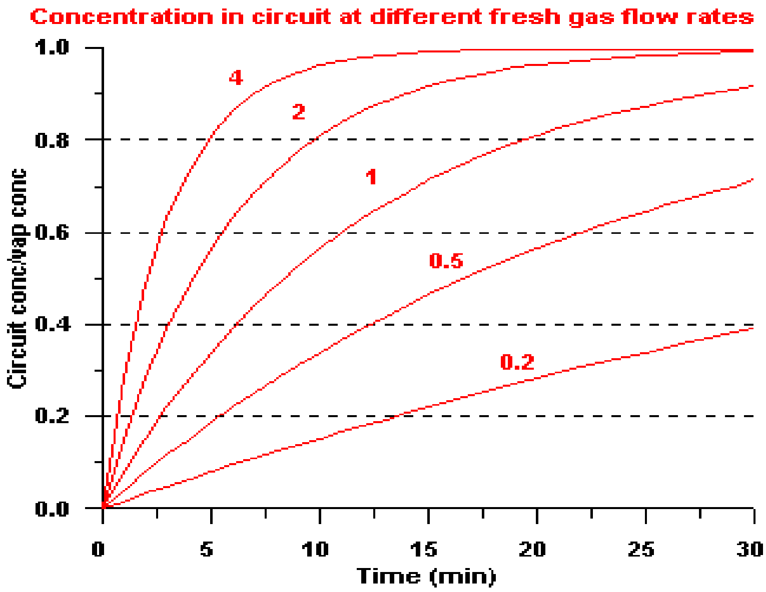
All soda lime will change colour as it gets exhausted. The exact change varies between different formulas so you should know how your specific formula changes. Some are white new, while others change to white when exhausted.

The lower the fresh gas flow, the more of the gas flow is recycled in the circle system and the more CO2 the absorber must remove. Hence, the lower the fresh gas flow, the shorter the duration of time the soda lime lasts, this can be as little as 4-5 hours.

Note: You may hear of Compound A which is produced with the combination of low flows of sevoflurane and soda lime. Previously there were restrictions on minimum flow rates with sevoflurane to prevent this. Modern formulations of soda lime such as Amsorb do not produce compound A. Of the older soda limes that do, it has been proved to have no clinical effect on humans and worldwide counties have removed the restrictions. Also modern soda lime formulations do not produce carbon monoxide when used with dry soda lime and desflurane which was also a historical issue.

Practical Use of Circle Systems

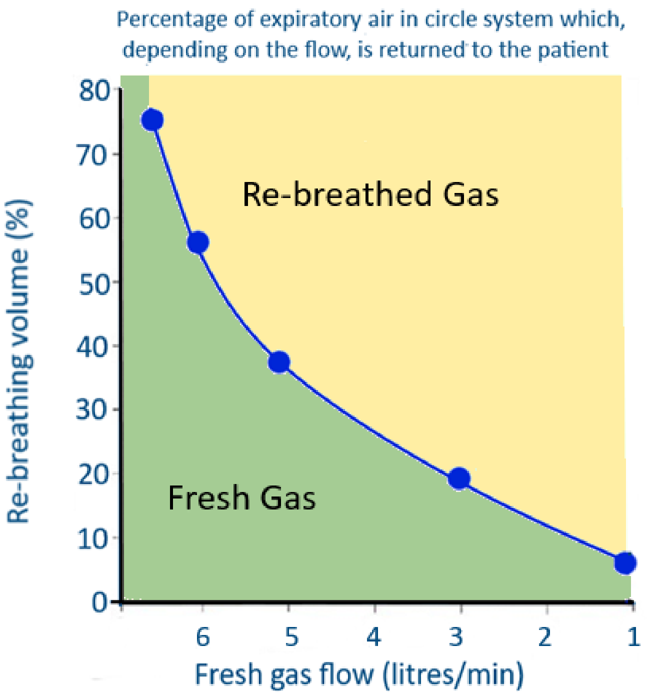
During the first 5-10 minutes of an anaesthetic, large amounts of the volatile agent will be taken up by the patient and distributed through the patient's body, not just to the brain. If low fresh gas flows and a vaporizer setting of 1.0 MAC are used from the start it will take an excessively long time for the patent to be sufficiently anaesthetised to allow surgery. This may be prevented by using higher volatile agent concentration and fresh gas flows of 4-6 litres/min for the first 10-15 minutes of each anaesthetic (wash in).



Reducing flow rates

Once an equilibrium of anaesthetic has been reached after 5-10 minutes, the flow rates can be reduced, this is the maintenance phase. Lower flows reduce costs, waste and help retain heat and moisture but need to be monitored closely.

With flows of greater than 1000mls/min. the inspired concentration of oxygen and volatile agent will be similar to the FGF set. With flows less than 1000mls/min. the oxygen and volatile agent concentration must be monitored as they may drift down and should only be used with accurate gas monitoring. This is because at low fresh gas flow rates only a small amount of fresh gas is added each minute and the majority of the gas breathed in by the patient is that already contained in the circle system (with CO_2 removed). This fresh gas flow may not include enough oxygen to replace that consumed by the patient.



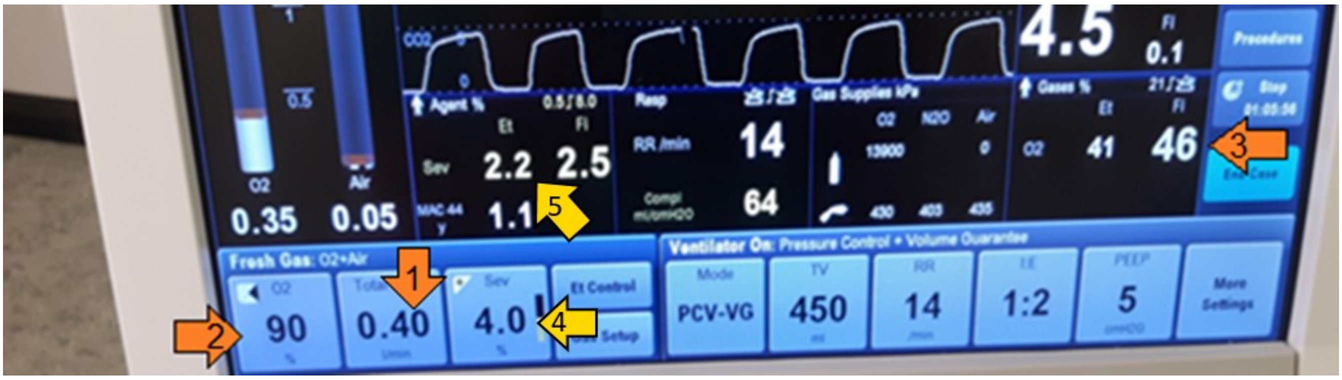
At very low fresh gas flows a higher percentage of O_2 needs to be selected to prevent the oxygen concentration within the circle system falling. Remember the normal oxygen consumption for an resting adult is roughly 250ml/min although this is obviously highly patient variable. *

Fresh Gas Flow (FGF)	Oxygen component of FGF at 40% oxygen.	Minimum oxygen concentration to replace 250mls used by patient (approx. values only)*
5litres/min	2000 ml/min	
1 litre /min	400 ml/min	
500ml/min	200 ml/min	>50%
400ml/min	160 ml/min	>65%
300ml/min	120 ml/min	>85%

*Note: This is without any leaks in the system and losses through the scavenging so a higher figure will be needed in real life. Often a minimum of approx. >300mls/minute 100% O_2 FGF is necessary.

As can be seen with the anaesthetic below, with a fresh gas flow of 400mls/minute (1), the anaesthetist has set the FGF oxygen concentration to 90% (2) to maintain 46% Fi O2 (3) oxygen within the system. It is the 46% Fi O2 that the patient receives.

This also applies to the volatile agent, at very low flows the sevoflurane is set higher (4) to ensure the end tidal percentage is kept at the required level (5).



Newer anaesthetic machines with end-tidal control systems do this automatically where the anaesthetist chooses the oxygen and volatile anaesthetic percentages that they want the patient to receive and the anaesthetic machine automatically adjusts the fresh gas flow mix and vaporizer output to achieve this.

Low flows also have the consequence of slowing down the any changes in oxygen and volatile agent concentrations. This is because most circle systems have a large internal volume of 3-5 litres; the 22mm circuit tubing alone contains over 1.5 litres. If the sevoflurane in the above example is turned off and the flows not increased it will take a long time before the sevoflurane is flushed from the system as you are only replacing a small part of the total volume every minute. That is why to change concentrations quickly. either up or down, the fresh gas flow rate must be increased.

Vaporiser Position.

Normal vaporisers, with high internal resistance, cannot be used within the circle so are placed on the backbar outside the system. Also since the gases are recirculated, if the vaporiser is placed in the circle, gas already containing volatile anaesthetic agent will re-enter the vaporiser and the resulting output will exceed the calibrated vaporiser setting and if agents have been changed, contaminate the new vaporiser with the previous volatile agent.

Finally

"*Anaesthetic staff should ensure that components are unwrapped only when needed, and if the patient breathing circuit is assembled in advance its end should be kept covered to prevent entry of foreign bodies.* "

Dept of Health (2004)

Caps and other small items stuck in circuits and airway devices has led to deaths. You can read about it here

https://www.frca.co.uk/documents/Protecting%20the%20PBC.pdf

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