

Advances in vaporisation: A narrative review

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ABSTRACT

The output of inhalational agents from modern vaporisers are both electronically and pneumatically controlled. They are designed to deliver set agent concentrations accurately with low fresh gas flows and possess enhanced safety features. The purpose of this review article is to give an overview of three modern vaporisers, namely, the Aladin cassette vaporiser, injection vaporisers and AnaConDa™. The Aladin cassette is integrated with Datex Ohmeda S/5 ADU and GE Aisys anaesthesia machines. The electronic vapour control unit is incorporated within the anaesthesia machine. The agent specific cassettes act as a detachable vaporising chamber. The system can work as a variable bypass and measured flow vaporiser but requires a power supply to function. Injection vaporisers can achieve the set end-tidal agent concentration very rapidly with even metabolic flow rates. Hence, anaesthetic depth can be rapidly altered with minimal wastage and theatre pollution. The two types of injection vaporisers, namely, Maquet and DIVA™ are customised to function with Maquet FLOW-i and the Drager Zeus anaesthesia machine, respectively. AnaConDa™ is a combination of vaporiser and humidity and moisture exchange filter which can be fitted in the ventilatory circuit. It is primarily designed for use in intensive care for sedation and out of operating room use.

Key words: Aladin cassette, AnaConDa, anaesthesia machine, injection vaporiser, vaporisers

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INTRODUCTION

Vaporisers are a salient component of modern anaesthesia workstation and are integrated with the anaesthesia workstation to match the accuracy and safety standards. Since the evolution of the anaesthesia machine into a workstation, the vaporisers have evolved too; integrating electronics with pneumatics. These electronic vaporisers have been made very safe for use and have incorporated different priority alarms to warn the end-user whenever there is a malfunction. In addition, with the use of more potent volatile agents and agents with low boiling points, the modern vaporisers have the ability to control the vapour output with extreme accuracy even when the anaesthesia machine fresh gas flows (FGF) are changed to alter the anaesthetic depth rapidly. The high-end anaesthesia workstations have an option to set the target end-tidal anaesthetic concentration (ETAC) and these vaporisers are designed to respond to such demands with precision. Hence, this review aims to describe the components, electronics and pneumatic

integration, operation and safety features incorporated in modern vaporisers to yield to end-user demands.

A thorough literature search was done from inception till March 2019 using databases/search engines (Medline, Embase, Scopus, PubMed and Google Scholar). The articles were manually searched by the authors for cross-referencing. All the articles published in English were searched. We used the following keywords 'anaesthesia machine', 'anaesthesia workstation', 'gas delivery', 'vaporisers', 'Aladin cassette', 'injection vaporiser' and 'AnaConDa'. Amongst 2400 articles (review articles, primary

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manuscripts, case reports, letter to the editors and chapters from books) the relevant information pertinent to the topic were sorted out. The information available is very limited and only 14 references could be included.

ALADIN CASSETTE VAPORISER

Aladin cassette vaporiser electronically controls the gas flow and vapour concentration. This system is used in the Datex Ohmeda S/5 ADU and GE Aisys anaesthesia workstation.^[1] The vaporiser system consists of an electronic vapour control unit internalised within the anaesthesia workstation and coded agent cassettes that contain the anaesthetic liquid that serves as a detachable vaporising chamber. The cassettes are coloured and magnetically coded and are designed to deliver five different inhalational anaesthetics (halothane, isoflurane, enflurane, sevoflurane and desflurane).

The structural and functional components: The Aladin cassette comprises of two parts, namely, the agent-specific vaporiser chamber (cassette) and the central processing unit (CPU) which is integrated into the anaesthesia machine. The cassette is a leakproof metal box which has a smaller front portion which is colour-coded to the specific agent and a larger rear portion that is black in colour. The front portion has an agent-specific filling system, a glass window to display the level of the anaesthetic liquid and a handle with a lever for locking the cassette in the slot provided on the anaesthesia machine. This portion also houses the contact for the electronic temperature sensor and liquid anaesthetic agent level. There are four copper coloured circles that can be seen on the top surface of the front of the cassettes. These are the copper contacts of the electronic bus that power the capacitor plates which sense the level of the liquid agent. Information from the liquid level sensor and vaporiser temperature data is transmitted by this electronic bus to the anaesthesia workstation. There are also five agent identification magnets arranged in a sequence in the front portion of the cassette, but these are not visible externally. These signature magnets allow the anaesthesia machine to identify the agent cassette that is inserted into the machine slot.

There are three types of Aladin 2 cassettes (which are currently used in modern anaesthesia workstations) filler systems. Enflurane and isoflurane use a colour-coded, Easy-Fil mechanism. Sevoflurane

cassettes are available with a colour-coded, Easy-Fil or Quik-Fil mechanism. On the other hand, desflurane cassettes have a filling mechanism that is compatible with Saf-T-Fil desflurane bottles [Figure 1a]. These cassettes can hold up to 250 mL of liquid anaesthetic.

The larger rear section of the cassette is the vaporising chamber containing the liquid anaesthetic at its SVC (saturated vapour concentration). The cassette is a specially designed liquid sump that requires main power supply or battery backup and adequate oxygen and air pressure to work. It is filled with a synthetic material soaked in liquid anaesthetic that is arranged as lamellae with metal plates interspersed between the lamellae. They are so arranged to form a convoluted pathway for the FGF so that the surface area available for vaporisation is maximised. The back panel has an inflow valve and outflow valve which are spring-loaded mechanical ball valves to prevent agent leak during transport [Figure 1b].

Functional Anatomy: The Aladin cassette vaporiser is concentration calibrated, flow over and electronically thermo-compensated that works both as variable bypass and measured flow vaporiser.^[2,3]

Function as a variable bypass: Aladin cassette vaporiser is in many ways similar to the other variable bypass vaporisers such as Tec 4, Tec 5 and Tec 7 vaporisers, however, there are several important differences. The vaporiser consists of (a) a bypass chamber which houses a backpressure regulator that builds pressure at the input to the vaporiser if necessary, to drive gas through the cassette, and this is permanently housed in the anaesthesia machine and (b) a detachable cassette that serves as the vaporising chamber. The two separate parts must come together to form a functioning vaporiser. The liquid anaesthetic is filled in the front section and enters the rear section through a one-way valve. The FGF and the vaporiser output are electronically controlled with the necessary hardware and software built into the anaesthesia machine [Figure 2].

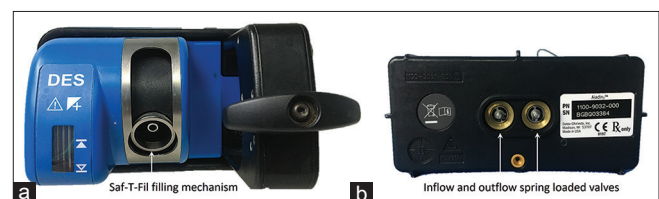


Figure 1: Desflurane Aladin Cassette Vaporiser. (a) Front panel showing the Saf-T-filling mechanism compatible with Desflurane bottles (b) Rear panel with inflow and outflow spring-loaded mechanical valves

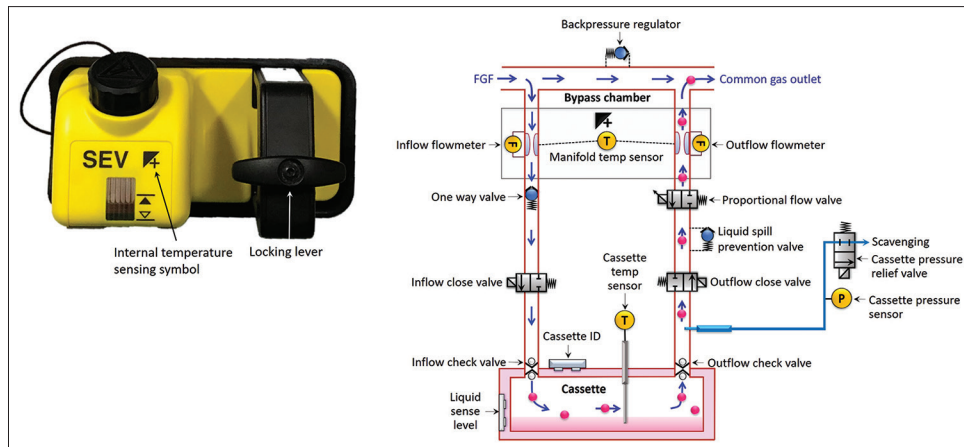


Figure 2: Schematic illustration explaining the components and basic functional aspect of Aladin 2 cassette vaporiser. FGF = Fresh gas flow

Gas flow: The FGF is first split into two portions; the bulk of the FGF passes through the bypass chamber and a smaller portion passes through a mechanical one-way valve and an electronic inflow close valve. It then enters the cassette by passing through the open mechanical ball valve in the rear panel of the cassette. This cassette inflow valve only opens when the cassette is plugged into the slot in the anaesthesia machine. The FGF enters the vaporising chamber to pick up vapour at its saturated vapour pressure (SVP). The gas saturated with anaesthetic vapour exits the cassette/vaporising chamber through the cassette outflow valve and passes sequentially through an electronic outflow close valve, a liquid flow prevention valve and a proportional flow valve. Finally, it passes through the agent flow measurement device and into the outlet of the control unit, gets mixed with the bypass chamber gas and is delivered at the common gas outlet [Figure 2].

Function as a measured flow vaporiser: To deliver the requested concentration of the volatile agent, the outflow from the cassette (the variable control of flow through the cassette) is controlled by a proportional valve. Hence, the control loop of the system depends upon the cassette flow and not the agent concentration (that amount of cassette flow is added to the bypass chamber flow to meet the desired set concentration of the volatile agent) which is delivered to the common gas outlet [Figure 3a].

Delivery of the set agent concentration: Volatile anaesthetic agent is delivered from the cassette-based on the mixer output pressure and the cassette pressure. When the cassette pressure exceeds the mixer output pressure the entire FGF is directed through the bypass chamber and inflow valve closes to prevent any gas

flow to the cassette [Figure 3b]. The excess pressure in the cassette is then brought down by metering out some of the gas containing inhalational agent from the cassette pressure relief valve attached to the scavenging system. Once the cassette pressure falls below the mixer output pressure some of the FGF is again routed through the cassette [Figure 3c]. Hence, the control loop will differ depending upon whether the entire FGF is routed through the bypass chamber or to split between cassette and bypass chamber. When the *entire FGF is through the bypass chamber*, the control loop depends on mixer flow. On the other hand, when *FGF is split between the cassette and the bypass chamber*, the control loop for delivery of the volatile agent depends on the reported mixer flow, cassette flow, cassette pressure and temperature.

The flowmeters: The inflow and outflow flowmeters determine the flow by detecting the pressure drop across a fixed flow restrictor (pressure drop is proportional to gas flow over fixed resistance). A zeroing valve is incorporated into each of the flowmeters that temporarily will short the pressure transducer's ports together for an accurate zero measurement. These zeroing valves also prevent agent condensation as they are energised during standby to heat the flowmeter manifold.

Temperature control and compensation: Vapour concentration of the volatile agent is determined by SVP divided by the total cassette pressure (SVP/Total cassette pressure).^[2] Hence, if the temperature falls the SVP of the volatile agent will fall and therefore the proportional valve will accordingly govern the gas flow output from the cassette. Finally, temperature compensation is achieved by the central processing unit. The microprocessor receives input from multiple

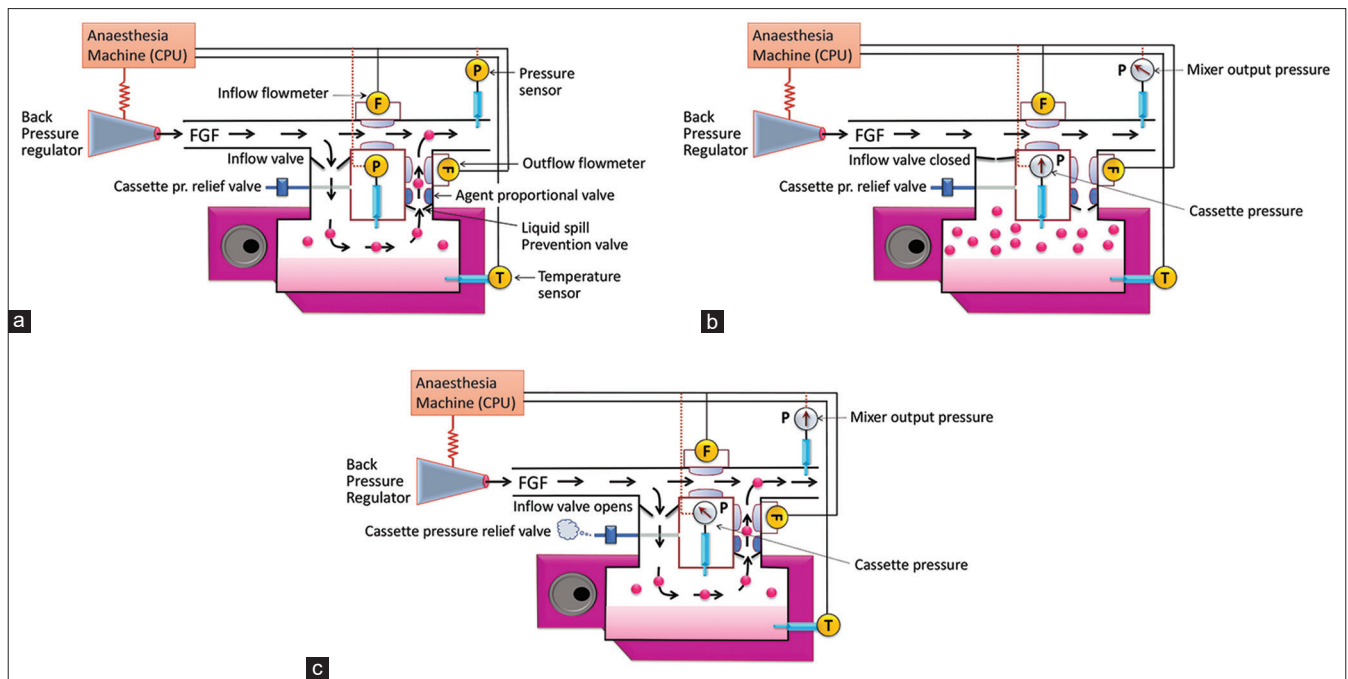


Figure 3: Interplay of the cassette of cassette pressure and mixer output pressure in Aladin cassette function. (a) Cassette pressure and mixer output pressure regulating agent delivery from cassette, (b) Cassette pressure exceeds mixer output pressure and the gas flow to the cassette is stopped (c) Cassette pressure is lowered down as agent is metered out to the scavenging system and cassette pressure falls below mixer output pressure and the gas is routed through the cassette. FGF = Fresh gas flow, F = Flowmeter, P = Pressure sensor, Cassette pr. relief valve = Cassette pressure relief valve

sources every 200 ms including FGF rate, carrier gas composition, set vapour concentration, liquid level and temperature in the vaporising chamber (sump) and controls vapour output electronically. To maintain cassette temperature, there is a fan mounted beneath the Aladin cassette housing operating at cassette temperatures below 17°C. This serves to heat the cassette when large amounts of volatile anaesthetic are being vaporised and heat is lost.

The difference in the delivery of desflurane vapour compared to other agents: The desflurane Aladin cassette works differently compared to that of other agents. When the temperature of desflurane inside the cassette is less than 22.8 °C, it functions as a flow over variable bypass vaporiser just as it is for the other agents. However, when the cassette temperature is above 22.8°C, which is the boiling point of desflurane, the inflow valve closes and no fresh gas enters the cassette. The vaporiser now behaves as an injector and calculated amount of vapour is injected out of the proportional valve to mix with the fresh gas from the bypass.

Aladin 1 and Aladin 2 cassettes: There are some differences between the originally introduced Aladin 1 cassettes [Figure 4] and the currently used Aladin 2 cassettes [Figure 2]. The liquid level display window

is bigger in Aladin 2 and the handle has a locking lever. There is also an additional liquid level sensor which gives input back to the anaesthesia workstation via an electronic bus, which also conveys vaporiser temperature data. Aladin DES and all Aladin 2 cassettes have electronic agent level sensing. Aladin 1 and Aladin 2 both measure temperature. While Aladin 1 had very simple temperature measurement Aladin 2 cassettes are more advanced having internal temperature sensing mechanism. A symbol indicating enhanced temperature sensing is seen on the front of the cassette [Figure 2].

Salient features of Aladin Cassette

The vapour output is not influenced by atmospheric pressure changes since the vapour concentration is determined by the separate environment that is the total cassette pressure. The electronic control in the cassette allows for automatic record keeping and usage calculation. Agent control is monitored by the microprocessor up to 200 ms during operation. Aladin cassette vaporiser is electronically controlled hence, it cannot function in the presence of power failure when the workstation battery gets depleted.

Aladin cassette is featured with specific safety features to ensure safe and constant delivery of vapours to the

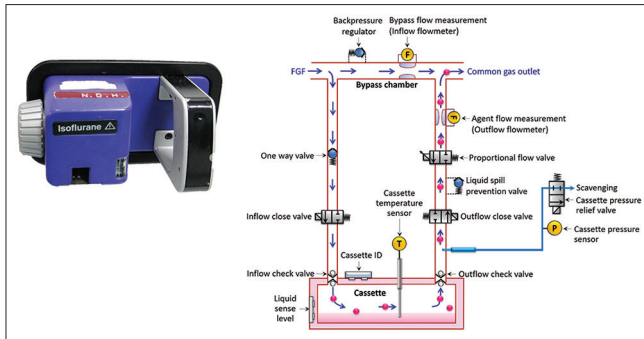


Figure 4: Schematic illustration explaining the components and basic functional aspect of Aladin 1 cassette vaporiser. FGf = Fresh gas flow, Cassette ID = Cassette identification

patients. The cassette features with accurate overflow protection and the level sensing are electronic and more accurate than only visual sensing. There is a liquid spill prevention valve that prevents the anaesthetic liquid in the vaporising chamber from entering the fresh gas line. There is no risk of agent spilling if the cassette is tilted as the inlet valve will close preventing any spillage. The vaporiser undergoes a daily self-check automatically when the anaesthesia workstation is switched on. Aladin cassette also has a pressure relief valve that works as a safety valve that opens whenever the pressure inside the Aladin cassette is greater than 2.5 bar.

Foong *et al.*^[4] reported an accidental over-delivery of desflurane via Aisys Carestation Aladin 2 Cassette™ vaporiser. The inspired fraction of desflurane (FiDes) went up to 17.5% and 19.5% on two occasions during a procedure in end-tidal control delivery mode. Both episodes were managed by temporarily switching off desflurane and washing off desflurane with high FGf (6 l/min). The patient developed hypotension and tachycardia and required pharmacological intervention for restoration of haemodynamic parameters. Changing the cassette did not resolve the issues. However, similar situations could not be simulated later except on one occasion and it was classified as an intermittent error. Hence, vigilance is necessary while using automated drug delivery devices.

INJECTION VAPORISERS

Injection vaporisers^[5,6] inject a known amount of liquid agent or pure vapour into the gas stream to provide desired concentration. The hallmark of injection vaporiser is that it enables rapid titration of anaesthetic depth with highly conservative low gas flows (metabolic flow) in a very short time (as short as 1 min), as a result, they minimise the wastage of the anaesthetic agents and prevent theatre

pollution. Injection vaporisers were introduced with high-end anaesthesia workstations (Maquet FLOW-i and Drager Zeus).

It is worthwhile to know how the injection vaporiser can achieve the set targets of rapidly altering anaesthetic depth in 1 min with exceptionally low FGf. Rapid anaesthetic depth titration with low FGf can be achieved by first calculating the amount of sevoflurane vapour required to achieve 2% ETAC of sevoflurane in approximately 6000 mL capacity reservoir which is 120 mL of vapour ($120/6000 \times 100 = 2\%$) where the reservoir comprises of patient's functional residual capacity of 2000 mL and the anaesthesia circle breathing system capacity of 4000 mL. With a sevoflurane vaporiser set at 2%, the splitting ratio is 12:1. With FGf of 6000 mL/min, 5538 mL/min flows through the bypass chamber and 462 mL/min flows through the vaporising chamber and picks up 120 mL/min of sevoflurane vapour. The total vaporiser output is 6120 mL/min and sevoflurane will represent ~2% of that output.^[7]

Hence, the percentage of sevoflurane vapour that a vaporiser should deliver to achieve 2% ETAC of sevoflurane in 1 min with 180 mL of FGf is equal to sevoflurane vapour/total FGf that is, $120/(180 + 120) = 0.4$ or 40% where 180 mL is the near metabolic FGf (3.5 mL/kg in a 50 kg person ~180 mL) and 120 mL is the sevoflurane vapour added to FGf. Thus, a vaporiser will have to deliver 40% sevoflurane in FGf of 180 mL to achieve the 2% ETAC of sevoflurane in 1 min. None of the vaporisers except the injection vaporisers can achieve this target in such a short time with near metabolic FGf.

Working principle: The anaesthetic agent is dispensed as liquid and that liquid has to be converted into the vapour state. Thus, the working principle involves the calculation of how much vapour will be generated by 1 mL of an anaesthetic agent. For example, the molecular weight of isoflurane is 184.5 and its specific gravity is 1.5 g/mL. Hence, applying Avogadro's hypothesis 184.5 g/moles of isoflurane will occupy 22.4 L at 273 K or 0 and 760 mmHg. Therefore, 1 g/mole at 20 will occupy $22400/184.5 \times 293/273$ and 1 mL will give $22400/184.5 \times 293/273 \times 1.5 = 194$ mL of isoflurane vapour.^[8]

MAQUET INJECTION VAPORISER

The structural and functional components [Figure 5]: This is an electronically controlled injection type of

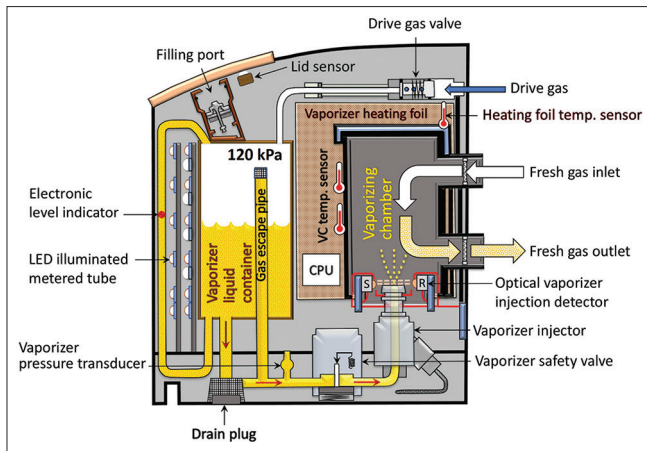


Figure 5: Schematic representation of components and function of Maquet injection vaporiser. VC temp. sensor = Vaporising chamber temperature sensor, Heating foil temp. sensor = Heating foil temperature sensor, S = sensor, R = Receiver

vaporiser that is used exclusively with the Maquet FLOW-i anaesthesia machine. The vaporisers weigh 3.2 kg and are available for isoflurane, sevoflurane and desflurane.

The vaporiser consists of a *liquid fill reservoir (container)* with an agent capacity of 300 mL but at 260 mL it gives an indication of being 100% full. The *electronic level indicator* shows the anaesthetic liquid level with the help of a float in the illuminated metered tube. There are LEDs mounted at 6 different levels corresponding to 5, 10, 25, 50, 75 and 100%. The low and medium priority alarm is triggered at the level of 10 and 5%, respectively. However, the vaporiser does not switch off when it is empty. The vaporiser does not have a concentration control dial. The liquid container can be filled with an anaesthetic agent via filling port that has a *safety fill valve* to handle the pressure inside the liquid container. The safety valve is designed to handle different manufacturer's specifications and filling systems (Isoflurane: Key fill, Sevoflurane: Key fill and Quick Fil™, Desflurane: Saf-T-Fil™). The *vaporiser lid* covers the safety valve and the filling port. Vaporiser lid position is monitored by a lid sensor and it must be closed to activate the vaporiser. The liquid container is also connected to a drive gas inlet to allow entry of a *driving gas* and pressurise the liquid in the reservoir. The liquid container is connected to the vaporising chamber via a vaporiser injector. The liquid container is provided by a *gas escape pipe* which helps to evacuate gas bubbles from the pressurised liquid anaesthetic before it reaches the vaporiser injector. The *vaporiser pressure transducer* measures the pressure of the liquid anaesthetic and a *safety valve* cuts off

the supply of the pressurised liquid to the vaporiser injector device when the vaporiser or the system is off or on standby. The *vaporiser injector* delivers the pressurised liquid anaesthetic in the form of spray into the vaporising chamber. A nozzle plate is placed in front of the injector to convert the liquid into a spray. The injector's opening is pulse controlled to achieve the set concentration of the anaesthetic. This pulsed liquid anaesthetic spray is monitored by the *optical vaporiser injection device (OVID)*. The *vaporising chamber* is heated by the vaporising heating foil for uniform heating and converts the vapour spray into gas. The vaporising chamber has an inlet and an outlet for FGF. The FGF enters the vaporising chamber and gets mixed with the vaporised anaesthetic agent. The mixed FGF exits the vaporiser and is routed through the patient cassette.

Functional Anatomy: Drive gas from the anaesthesia workstation enters the liquid anaesthetic container from the top at 120 kPa and forces the pressurised liquid anaesthetic through a safety valve into the vaporiser injector. The vaporiser injector injects the liquid anaesthetic in a pulsed, intermittent manner into the heated vaporising chamber depending upon the set and the measured concentration. The spray is delivered in short pulses of 0.8 mL of agent per ms and the pulse time varies from 2–10 ms for isoflurane/sevoflurane and 5–10 ms for desflurane. Hence, the volume of agent injected per pulse is 1.6–8 mL for isoflurane/sevoflurane and 4–8 µL for desflurane. The OVID contains 2 PC boards i) vaporiser spray LED and ii) vaporiser spray detector which detects the presence of the spray of the anaesthetic agent into electronically heated vaporising chamber. The temperature of the vaporising chamber is monitored and maintained at 47°C for isoflurane/sevoflurane and 37°C for desflurane. Temperature of the *vaporising chamber* and *heating foil* is measured by separate temperature sensors. 1) The vaporising chamber temperature is monitored by 2 vaporising temperature sensors. The vaporiser gets switched off if the temperature of the vaporising chamber rises above 60°C or when the temperature difference of more than 5°C is detected between the 2 sensors, 2) When the temperature of the heating foil goes beyond 140°C the heating foil is switched off, no alarms are activated and the heating is restarted once the temperature falls. But if the temperature exceeds 170°C the vaporiser is switched off and a technical alarm is activated. The liquid rapidly evaporates in the vaporising chamber and this vapour is carried by the FGF coming in through the inlet valves. The mixed

FGF exits the vaporising chamber through the outlet valves.^[5]

DRAGER DIVA (DIRECT INJECTION OF VAPOUR ANAESTHETIC) VAPORISER

The Drager DIVA vaporiser which is integrated into the Zeus anaesthesia machine allows for *target-controlled anaesthesia* with closed-loop quantitative control of the delivery of oxygen, carrier gas and anaesthetic vapour.

Structural and functional components: The Drager DIVA injection vaporiser can be categorised as measured flow vaporiser. The carrier gas and the anaesthetic agent is uncoupled and both are delivered separately into the system [Figure 6a]. The vaporiser integrated with the anaesthesia machine consists of 2 modules, a detachable vaporising or metering module that is anaesthetic specific and a fixed non-specific gas supply module that is inbuilt in the Zeus anaesthesia machine. The *metering module* [Figure 6b] stores the liquid anaesthetic in a reservoir with a coded filling system, liquid level indicator window and a ventilation outlet. It also houses a dosing chamber that is connected to the reservoir through a liquid gate.

The dosing chamber, whose pressure is monitored, is connected to the heated vaporising chamber through a dosing valve. This dosing valve is controlled by an electronic computer-controlled feedback control unit, which receives information about the FGF rate and set anaesthetic agent concentration (either fresh gas or ETAC). The feedback control unit thus controls the amount of liquid injected through the dosing valve into the heated vaporising chamber. The *gas supply module* [Figure 6c] is part of the anaesthesia machine. It consists of propellant gas (air) inlet, a non-return valve, a pressure buffer and pressure reducer and a supply valve through which gas (air) enters the metering module [Figure 6].^[6]

Functional anatomy: When the vaporising module is placed in its slot it gets integrated with the gas supply module. The propellant gas (air) enters the metering module and propels the liquid anaesthetic through the liquid gate into the dosing chamber. The pressure in the dosing chamber is transmitted to the feedback control unit. Depending on the set agent concentration (that is transmitted electronically from the feedback control unit to the dosing valve) a fixed amount of liquid anaesthetic is injected into the heated vaporising chamber. The liquid anaesthetic is vaporised in the

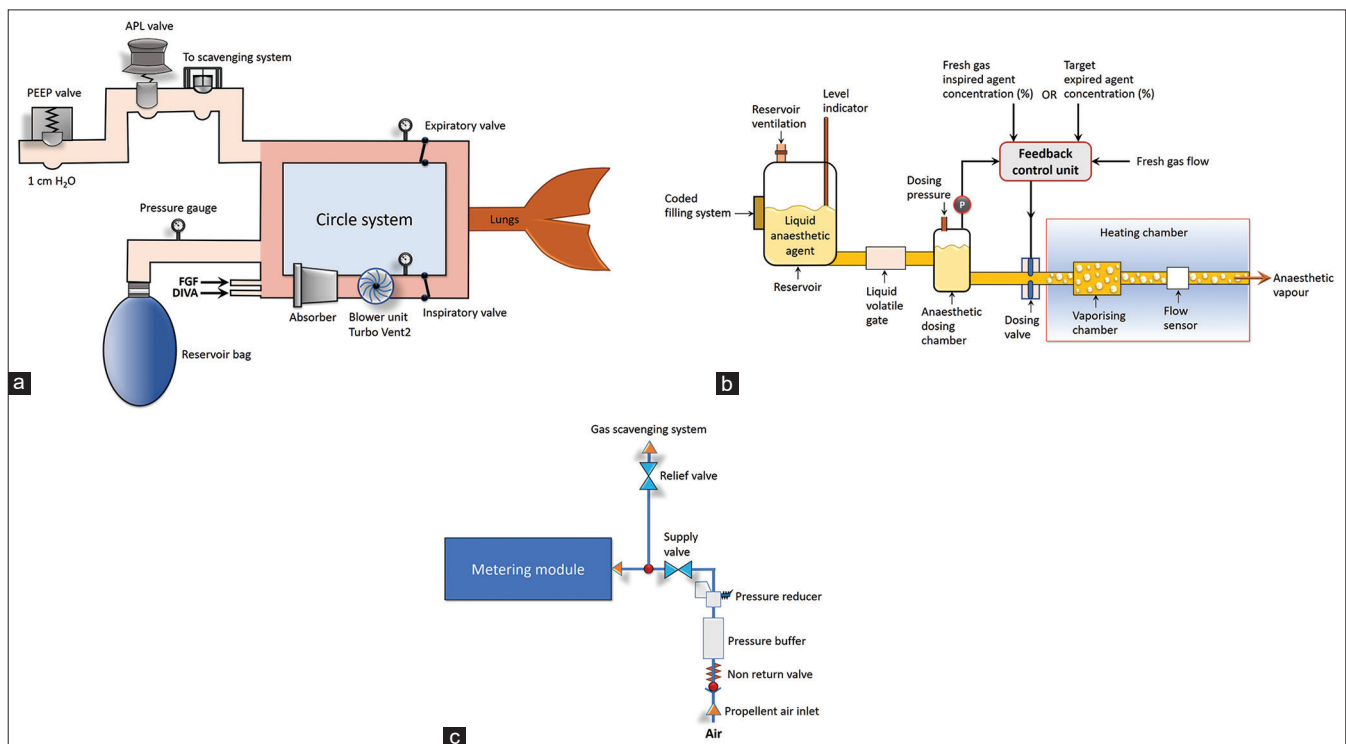


Figure 6: Gas flow schematic illustration of Zeus/Zeus IE rebreathing system. (a) Illustration showing uncoupled carrier gas and direct injection volatile agent (DIVA), both delivered separately into the circle system. (b) Schematic illustration showing the components and function of the *metering module* of DIVA vaporiser. (c) Schematic illustration of the *gas module* within the anaesthesia machine that gets integrated with the metering module of DIVA vaporiser during use. FGF = Fresh gas flow, APL = Adjustable pressure limiting, P = Pressure sensor

heating chamber and passes through a flow sensor out of the metering module [Figure 6b].

The anaesthetic vapours can take one of the two pathways once they exit the metering module, depending on the mode set on the Zeus anaesthesia machine. If it is set at fresh gas control mode, the vapours pass through a fresh gas valve to a mixing chamber, where they mix with the FGF and the mixture is directed to the breathing system. If it is set in auto control mode, the vapours exit through another pathway, pass through the saturated vapour valve directly to the breathing system, where they mix with the FGF. Thus, in auto control mode, anaesthetic vapours and FGF are injected separately into the breathing system while in the fresh gas control mode; the system emulates a classical system with flowmeter and vaporiser. The electronic feedback control unit thus determines the amount of liquid that would be dosed through the dosing valve into the heated vapourisation chamber and controls the vapour output. Hence, quantitative closed-system anaesthesia or target-controlled anaesthesia can be achieved. The blower unit (TurboVent2) is the crucial component that creates the gas flow (inspiration) to the patient.

Salient features of injection vaporisers

Injection vaporisers are electronically and pneumatically operated with safety features that switch off the vaporiser with an audiovisual technical alarm when there is a malfunction of temperature and pressure. The vaporiser is not vulnerable to tipping as it has no wicks to saturate and agent cannot spill into the vaporising chamber. Filling of the vaporiser can be performed while the vaporiser is in use (though agent delivery does not happen during filling).

Struys *et al.*^[9] compared time to reach desired ETAC, initial overshoot and stability at target ETAC and washout time using agents desflurane and sevoflurane between Zeus (Dräger, Lübeck, Germany) apparatus using direct injection of inhaled anaesthetics and Primus apparatus (Dräger, Lübeck, Germany) using a classic out-of-circle vaporiser. The authors observed that electronic control allows instantaneous changes in vapour concentrations to achieve set ETAC values even with very low FGF. In Zeus, the wash-out times were faster, inhaled anaesthetic concentration was the lowest, no overshoot at the target was seen and the time course of sevoflurane and desflurane was minimally influenced by changes in FGF.

AnaConDa VAPORISER

AnaConDa™ or Anaesthetic conserving device was the brainchild of Giebeck AB and introduced in the market by Sedana Medical, Stockholm, Sweden.^[10] It is a miniature anaesthetic vaporiser and HME (humidified moisture exchanger) filter combined together. The device is meant to be used mainly for sedation in the intensive care unit (ICU) and outside operating rooms. It is designed to deliver only isoflurane and sevoflurane [Figure 7].

The structural and functional components: The AnaConDa™ the device has a colour-coded patient side (transparent) and a ventilator side (black) separated by a bilayer filter. It is a unique oval-shaped device where the ventilator inlet and the patient outlet are aligned parallel to the filter medium to facilitate laminar airflow. The device is customised to fit between the Y-piece and endotracheal tube (ETT) like an HME filter. The patient end has an outlet which can be connected directly to the ETT or a connector. The patient's end has a gas sampling port connected with a standard Leur lock through which end-tidal gas monitoring can be performed. AnaConDa™ does not require any additional power supply for its operation [Figure 7]. The vaporiser should be placed at an angle of 45°. Internally in the vaporiser, the first layer of the bilayer filter is an electrostatic polypropylene filter, a protective layer situated towards the patient side, which prevents the ventilator from bacterial and viral contamination. The second layer is a thick 3–4 mm activated carbon felt adsorptive layer which adsorbs and reflects inhalational anaesthetics and moistures in the circuit. However, for proper functioning, the device should be replaced daily [Figure 8a].

AnaConDa™ is available presently in two different internal volumes of 100 and 50 mL to be used in

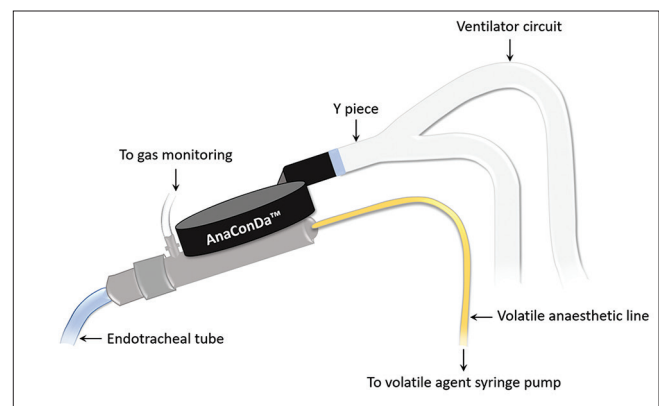


Figure 7: Set up of AnaConDa™ vaporiser for use

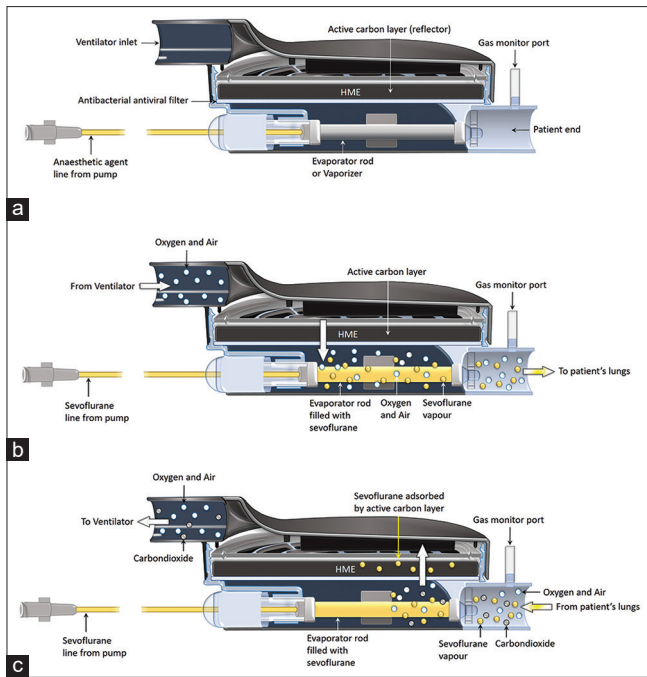


Figure 8: Schematic cross-section of AnaConDa™ vaporiser (a) Schematic cross-section illustrating the inner components of AnaConDa™ vaporiser when switched off. (b) The flow of gases during inspiration through the AnaConDa™ vaporiser. (c) The flow of gases during the expiration phase through the AnaConDa™ vaporiser. HME = Humidity moisture exchanger

patients with high and low tidal volumes, respectively. AnaConDa™ (50 ml) is for the patients with less than 50 kg body weight and a tidal volume of fewer than 350 mL as a dead space of 100 mL will lead to inadequate carbon dioxide washout and thus may give rise to deleterious hypercapnia. The 50 mL device can be used even in patients with a tidal volume as low as 200 mL. While the 100 mL AnaConDa™ is recommended for tidal volumes ranging from 350–1200 mL. The 50 ml device is slightly less efficient (by approximately 2%) than the 100 mL device, therefore, requiring a slightly higher infusion rate for a desired end-tidal vapour concentration.

Functional anatomy: AnaConDa™ delivers constant inhalational agents to the patients despite having no measurement dials.^[11] A porous polypropylene evaporator rod is mounted to the patient's end of the device [Figure 8a]. The rod has an external agent line made of polyethylene connected to a 50 mL specially modified syringe mounted on a syringe pump. The agent line has an adaptor with a small spring valve which only opens when the syringe is fully fitted to the adaptor. This safety feature prevents anaesthetic agents from leaking backwards into the device at the time of syringe disconnection of the syringe for refilling. The device adaptor and the Syringe share

unique thread different in diameter and look from other commonly used medical threads so that they are exclusively keyed to each other. Specially designed polyoxymethylene bottle adaptors are available for filling the syringe attached to the AnaConDa™. During inspiration [Figure 8b], the gas in the inspiratory limb picks up vapour from the evaporator rod and delivers it to the patient. During expiration [Figure 8c], the unabsorbed part of the anaesthetic vapour is absorbed by the thick carbon filter. A major portion (as high as 90%) of this absorbed vaporiser is delivered to the patient again (or 'reflected' back) in the next inspiration. The small amount of vapour which reaches the expiratory limb gets scavenged eventually. The rate of infusion of anaesthetic vapour depends on the type of vapour used (isoflurane and sevoflurane), patients' mass and tidal volume used. Pharmacokinetic models for manually adjusted infusion rates have been tried with some success [Figure 8].^[12]

The AnaConDa™ devices are validated by the manufacturers in bench-top tests as per ISO-9360 standards for HME and HME filters.^[13] The AnaConDa™ has a keyed system in the form of a unique thread that connects the adaptor and the syringe. Neither AnaConDa™ can be connected to any other syringe than the customised one nor the syringe can be attached to any other Luer lock or other intravenous devices. AnaConDa™ by its recycling mechanism (activated carbon) saves anaesthetic vapours as well as prevents environmental pollution. Nishiyama *et al.* demonstrated that AnaConDa™ could save anaesthetic vapour consumption and fasten emergence from general anaesthesia versus conventional TEC vaporisers.^[11] However, the device has certain limitations. AnaConDa™ creates a dead space effect larger than its internal volume due to reflection of carbon dioxide hence, it is used in patients with acute respiratory distress syndrome and other respiratory illness is questionable as it limits giving low tidal volume ventilation as well as increases the physiological dead space.^[14]

Summary: The modern vaporisers have both electronic and pneumatic control and can deliver set or target anaesthetic agent concentration accurately. The FGF rates through the vaporisers may vary as in Aladin or constant as in Flow-I and DIVA to achieve the target agent concentration with minimal wastage and theatre pollution. They are designed to alleviate hazards and ensure safe, constant and effective delivery of inhalational anaesthetics to the patients.

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Conflicts of interest

There are no conflicts of interest.

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